The Hague
The Netherlands
15-17 November 2023

iCSC international Cycling Safety Conference

11th
International Cycling Safety Conference 2023

15 - 17 November 2023, The Hague, The Netherlands

SWOV

Since 2012, the International Cycling Safety Conference (ICSC) has been a forum for scientists and experts whose scientific and practical activities are aimed at making cycling safer. It has offered the opportunity for exchange and discussion, for getting to meet old friends and new collaborators. Over the years, hundreds of contributions have addressed novel research questions and presented innovative practical solutions dedicated to the improvement of cycling safety.

The 2023 edition of ICSC was held in The Hague, The Netherlands, hosted by SWOV. This book of abstracts contains the extended abstracts of all contributions that were presented at the conference.

SWOV Institute for Road Safety Research
The Hague, November 2023

Contents

Authors Index XI

Bicyclist crashes with cars and SUVs: Injury severity and risk factors 1
S.S. Monfort, B.C. Mueller

Reliability of cooperative ADAS and the importance of the acceleration function for cycling safety 4
M. Junghans, M. Zhang, H. Saul, A. Leich, P. Wagner

Safety of Active Mobility Device Users on Singapore Roads 7
P.P. Koh, Chandrasekar

A Data-driven Approach to the Safety Management of Active Mobility Users 10
M. Ee, P.P. Koh, L.Neo

Why (e-)cyclists don't wear high-visibility vests. Comparison between Doers and Non-Doers 13
A. Uhr, P. Hertach

E-Scooters: Transport or leisure? Findings from naturalistic data collection 16
R.R. Pai, M. Dozza

Experimental investigation on the safety performance of a new class of small wheel micro-mobility devices 19
M. Paudel, F.F. Yap

How do professional and non-professional drivers interact with cyclists at unsignalized intersections? Results from naturalistic data 22
A. Mohammadi, M. Dozza

In-depth analysis of scenarios and injuries in crashes between cyclists and commercial vehicles in Germany 25
R. Schindler, H. Jeppsson

Road safety-relevant factors in accidents between cyclists and truck drivers and the role of advanced driver assistance systems (ADAS) 28
K. Ausserer, J. Rieß, E. Tomasch, H. Hoschopf

Contents

Design of Urban Junctions in Relation to Cycling Safety 31
T.S. Buch, W. Hansen, M.G.L. Jensen, M.W.J. Sørensen

Study on Quantitative Expression of Cycling Workload 34
J. Hu, S. Qu, R. Wang

Overtaking in Stuttgart – Analysis of the lateral distances between motor vehicles and bicycle traffic with reference to traffic volume and cycling infrastructure 38
L. Casey, L. Gaspers, H. Mandel

Introducing Right Turn on Red for Cyclists – A Before-After Study on Behavioural Adaption in Germany 41
B. Schröter, S. Hantschel, M. Niestegge, H. Schüller, R. Gerike

Cognitively distracted cycling – a bike simulator study 44
M. Møller, F.L. Berghoefer, M. Vollrath

Comparison of different cargo transport concepts on bicycles and their influence on cycling stability in open and closed loop 47
C. Groß, J. Vortanz, S. Müller

Autonomous Vehicles and the Future of Bicycle Urbanism: Insights from Contemporary Living Labs 50
A. Gaio

Incomparable Results: Exploring the Challenges of Measuring Lateral Passing Distance 53
Z. Janoška, M. Bíl

Odds of self-reported minor cycle crashes with conventional and electric assisted cycles adjusted for cycling frequency in Dutch and Belgian adults. A prospective study 56
B. de Geus, T. Ampe, J. Van Cauwenberg, P. Schepers

A Matter of Space and Perspective - Cyclists’ and Car Drivers’ Assumptions about Subjective Safety in Shared Traffic Situations 58
R. von Stülpnagel, H. Rintelen

Contents

Towards Understanding the Safety-in-Numbers Effect – A Road-Based Approach 61
R. von Stülpnagel, J. Ehlers, A. Liebscher

Older and Younger Cyclists: Exploring the relationship between neuropsychological task performance and inner-city cycling behaviour 64
F. Westerhuis, D. de Waard

Enhancing Cycling Safety with Advanced Analysis of Accident Data: Techniques for Evaluating the Pre-Crash-Phase 67
A. Schubert, M. Petzold, T. Unger, H. Liers

Required field of view of a sensor for an advanced driving assistance system to prevent heavy-goods-vehicle to bicycle accidents 71
E. Tomasch, H. Hoschopf, K. Ausserer, J. Rieß

Injuries with e-bikes: young cyclists at risk 74
K. Klein Wolt, I. Krul

Bicycle safety experienced by cyclists within city limits in The Netherlands 76
J. van 't Zelfde

Can crowdsourced large-scale near-crash data replace crash data? A comparison of models using both sources 79
K.Y. Chou, A.F. Jensen, K.H. Janstrup, M. Paulsen, O.A. Nielsen, T.K. Rasmussen

Coexisting on the Road: A Study on Drivers' Attitudes Toward Cyclists in Czechia 82
E. Adamovská, Z. Dytrt, J. Kočková, P. Skládaná, M. Šimeček

The safety of group compared to individual cyclists when cars pass on urban roads in Queensland, Australia 85
E.M. Rubie, N. Haworth, N. Yamamoto

On-Site Measurements and Model for Gust Loads on Cyclists induced by Vehicles in Overtaking Manoeuvres 88
C. Gromke, B. Ruck

Contents

Assessing Cycling Infrastructure and Bike-Transit Accessibility Through Shortest Path Routing 91
R. Passmore, K. Watkins, R. Guensler

Bicycle simulator validation study: A methodological approach 94
M. Suing, P. Seiniger, M. Bierbach, A.C. Kiehl, H. Ma, S. Pliquett, F. Surges

Bicycle Exposure Models Using Bayesian Updating 97
R.T. Panik, K.E. Watkins, I. Tien

Acceptance in numbers? – Determinants of cyclists' choices on where to cycle in mixed traffic situations 100
S. Hantschel, B. Schröter, R. Gerike

Kick-plate test for assessing bicycle dynamics and tyre effect 103
G. Dell'Orto, L. Alizadehsaravi, R. Happee, J.K. Moore

Project Cycling Life – a large-scale RCT to evaluate the safety effect of daytime running lights on bicycles 106
H. Lahrmann, T.K.O. Madsen, A.B.Tallaksen, A.V. Olesen

Designing public education campaigns to reduce dehumanisation of cyclists 109
N. Haworth, A. Delbosc, A. Schramm, N. Haslam

Review of the literature on the safety of micromobility 112
V. Petraki, K. Deliali, G. Yannis

Examining the crash risk factors associated with cycling: findings from four Dutch cities 115
T. Uijtdewilligen, M.B. Ulak, G.J. Wijlhuizen, F. Bijleveld, K.T. Geurs, A. Dijkstra

How Smooth is Your Ride? A Comparison of Sensors and Methods for Surface Quality Assessment using IMUs 118
M. Beeking, H. Wies, M. Steinmaßl, K. Rehrl

Contents

Visual attention and riding behaviour of e-scooter and cyclist users in shared paths – system development and in field experiment 121
G. Pappalardo, S. Cafiso, J. Wachnicka, O. Giudice, R. Leotta, S. Battiato

Road safety of delivery riders on pedelecs in the Netherlands – An online survey 124
C. Mons, A. Stelling-Kończak, K.G. Kamphuis

ReCyCLIST – a new powerful tool to register and locate bicycle and e-scooter accidents 126
T. Bjørnskau, K. Karlsen, R. Ingebrigtsen, I. Hesjevoll, K.V. Weyde, O. Mjåland

Hitting the Target: What 75% travel means for cyclists 129
M. Olyslagers, S.T. Lucchesi

Perception of cyclists while being overtaken by motorized vehicles: A semi-naturalistic field study in urban mixed traffic 131
F.H. Strelow, M. Vollrath

How is cycling safety affected by micro-level built environment variables? A case study using a deep learning approach 134
L. Xu, S. Luo, S. O’Hern, A. Delbosc

Comparison of driving characteristics between e-scooters and e-bikes 137
M. Suzuki, K. Endo

Interactions among cyclists riding the wrong way on the bicycle path 140
C. Leschik, I. Irizar da Silva, K. Gimm, M. Junghans

Bicyclists’ attitudes and perceptions towards self-driving cars: A mixed methods approach 143
E. Hollauf, C. Luger-Bazinger, V. Hornung-Prähauser

What turns a bicycle street into a street for cyclists? A multimodal study on subjective safety of infrastructure measures on bicycle streets using an approach in virtual reality 147
M. Schwarzkopf, A. Dettmann, M. Kreußlein, J. Trezl, A.C. Bullinger

Contents

Cyclists’ Gaze Patterns and Driver Detection when Encountering Manual and Driverless Vehicles: A Field Study 150
S.H. Berge, J.C.F. de Winter, D. Dodou, N. Reddy, Y. Dong, N. Raju, A.P. Afghari, E. Papadimitriou, H. Farah

Share the road – International experiences with recommendations and laws on lateral distance to cyclists 153
A. Eriksson, S.U. Jensen

Assessing Micromobility Safety on Horizontal Curves of Bike Lanes: A Video Motion Analysis Methodology 155
M.H. Sabbaghian, D. Llopis-Castelló, A.G. García

Understanding Perception of Cycling Safety through Pairwise Image Comparisons 158
M. Costa, F.W. Siebert, C. Lima Azevedo, M. Marques, F. Moura

Shared E-Scooter Crashes and Probe Data Exposure: A Case Study for Nashville, Tennessee 161
S. Aryal, N.R. Shah, C.R. Cherry

Safe and Risky Behaviours of Group Cyclists 164
O.M. Heeremans, E.M. Rubie, O. Oviedo-Trespalacios

Evaluation of the trial of smart bicycle lights 167
H. Alavi, D. Young, H. Reddan, J. Johnson, N. Haworth

Implicit Communication between Cyclists and Turning Automated Vehicles – A Low-Level Simulator Study 170
A.M. Harkin, A. Mangold, K.A. Harkin, T. Petzoldt

Keep Me Safe – Evaluating the Safety Perception of Different Bicycle Facilities 173
T. Stoll, D. Hagmann, M. Hackenfort

How does an Electrically Propelled Bicycle Trailer influence the driving properties of a Bicycle-Trailer-Combination? – Simulation and Driving Experiments 176
B. Bourauel, P. Seiniger, J. Gail

Contents

Development of a new zone-based cycling safety metric to determine the crash risk associated with work trips 179

M. Asadi, M.B. Ulak, K.T. Geurs, W.A.M. Weijermars

Analysis of High School Students' Safety Behavior Change through Workshops with Exploratory Learning by Using Naturalistic Cycling Data 182

F. Ishigamori, N. Yoshida, Y. Kitamura

Analysis of cyclists' safety on "bicycle streets" in four large Dutch municipalities: A crash risk and conflict study 185

M.J.M. Odijk, M. Nabavi Niaki, M.B. Ulak, K.T. Geurs

Evaluating (Protected) Bike Lanes in a Bicycle Simulator 189

M. Naujoks, M. Vollrath, A.K. Huemer

Evaluating safety risks for micromobility users in protected bike lanes based on vertical element selection 192

A.M. Pérez-Zuriaga, J. Dols, M. Nespereira, A. García

Evaluation and acceptance of an online cycling training for adults to master complex traffic situations 195

M.A.B. van Eggermond, N. Studer, L. Johnson, L. Knecht , D. Schaffner

Road users' attitudes about present and future active mobility in Munich, Germany 198

S. Ruf, S. Aumann

Bicycle crashes involving commuters - a special group of crash victims. Results of a detailed survey of crash victims 201

V. Zuser

Using body sensors for evaluating experiences with smart cycling technology 204

M.R. Boot, M.B. Ulak, K.T. Geurs, P.J.M. Havinga

A Systematic Review on Significant Factors Contributing to the Bikeability 208

L. Yang, Y.J. Kum, C.T. Tan, H.J. Yap

Contents

Public opinion on smart bicycle technologies enhancing cycling safety: A survey study among 1354 cyclists across Europe 210
G. Kapousizis, M.B. Ulak, K. Geurs

How to design road safety campaigns for e-scooter riders – a mixed-method study 213
J. Anke, M. Ringhand, T. Gehlert

E-scooter riding: Prediction of hazards from the perspective of users and non-users 216
T. Jung, M. Ringhand, J. Anke

Comparison of Electromechanical Means of Stabilizing a Bicycle 219
J.K. Moore

Experimental evaluation of Rideability Index as a Handling quality indicator 222
J. Ronné, L. Dubuis, T. Robert

Exploring the Spatiotemporal and Behavioral Patterns of Utilitarian E-Bike Users in North America 225
M. Azad, J. MacArthur, C.R Cherry

Experimentally validated models that predict cyclist falls 229
M.M. Reijne, F.H. van der Meulen, F.C.T. van der Helm, A.L. Schwab

Increasing safety through geofencing based regulations for e-scooter parking: Evaluation of impact and acceptance among e-scooter users in Munich 231
S.-T. Graupner, J.-H. Müller, J. Schade, R. Alfahel

Video-Based Safety Evaluation of Interactions Between Cyclists and Motorized Vehicles 235
S. Albanello, T. Lelke, F. Orsini, W. Fourati, A. Trifunović, B. Friedrich, R. Rossi

Positioning Human Body Models in Cyclists' postures based on experimental data 238
M. Oikonomou, A. Lioras, L. Rorris, J. Iraeus, A. Mihailides

Safe cycling routes: Seven road safety indicators for cycling routes 241
S.E. Gebhard, W.A.M. Weijermars

Contents

Analysis of Selective Conflicts between Multiple Bicycles and Left-Turning Vehicle at Signalized Intersections by using Video Tracking Data **244**
K. Goshona, N. Yoshida

Large cities are "enlargers" of cycling distractions: common technological and non-technological distractions in >300 cities of different sizes **247**
S.A. Useche et al.

"¡Vamos en Bici!": Exploring the Relationship between Spanish Cyclist Characteristics and Crashes **252**
S.A. Useche, F. Alonso, M. Faus, O. Oviedo-Trespalacios

Comparison of emergency response records with police collision reports for improving cyclist safety **256**
N. O'Reilly, B. Caulfield, M. Mulville

Mental workload of cyclists in different urban road layouts : towards a study with a bicycle simulator **259**
K. Li, S. Saudrais, L. Desire, B. Barbedette, C. Morel

Digital Support Systems for Cyclists: Early Hazard Notifications and their Implementation Challenges **262**
T. von Sawitzky, T. Grauschopf, A. Riener

Sickness absence and disability pension among bicyclist after an accident, a nationwide register-based study comparing bicyclist with other road user groups with matched references **265**
L. Kjeldgård, H. Stigson, K. Farrants, E. Friberg

Bicycle crashes with curbs **268**
V. Zuser

Proactive Safety Assessment for Single Bicycle Crashes: A Dynamics-Informed Cyclist Tracking Approach **271**
K. Gildea, A. Laureshyn

Contents

Impact of road safety to enhance cycling culture in Sub-Saharan Africa 274
A.T. Legese , A. Francke , W. Mitullah, G. Feleke, H. Namakula

Investigating the Safety Behaviour of Cyclists in Construction Sites 276
M. Klosterkamp, E. Rothauge, P. Papendieck, A. Francke

Development of a VR bicycle simulator for assessment of a new ADAS in interaction with vehicles and cyclists: departing intention case study 279
M. Imanipour, A. Barbier, S. Saudrais, B. Barbedette

An Investigation into the Road Interactions Experienced by Bicycle Food Delivery Riders with Other Road Users 282
O. Oviedo-Trespalacios, L. Martinez-Buelvas, N. Haworth

Trends in US Bicycle Crash Geometries and Cyclist Age 285
D.H. Good

Near-misses Involving Cyclists – A Neglected Problem? 288
L. Bhaskaran-Kenny, A.P. Morris, L. Brown

Essential safety elements concerning infrastructure of cycle paths; a risk based approach in cycling safety 291
G.J. Wijlhuizen, E. de Kievit

Authors Index

A

Adamovská, E. 82
Afghari, A.P. 150
Alavi, H. 167
Albanello, S. 235
Alfahel, R. 231
Alizadehsaravi, L. 103
Alonso, F. 247, 252
Ampe, T. 56
Anke, J. 213, 216
Aryal, S. 161
Asadi, M. 179
Aumann, S. 198
Ausserer, K. 28, 71
Azad, M. 225
Azevedo, C. Lima 158

B

Barbedette, B. 259, 279
Barbier, A. 279
Battiato, S. 121
Beeking, M. 118
Berge. S.H. 150
Berghoefer, F.L. 44
Bhaskaran-Kenny, L. 288
Bierbach, M. 94
Bijleveld, F. 115
Bíl, M. 53
Bjørnskau, T. 126
Boot, M.R. 204
Bourauel, B. 176
Boyko, A. 247
Brown, L. 288
Buch, T.S. 31
Bullinger, A.C. 147
Buyvol, P. 247

C

Cafiso, S. 121
Casey, L. 38
Castañeda, I. 247
Caulfield, B. 256
Cendales, B. 247
Cervantes, A. 247
Chandrasekar 7
Cherry, C.R. 161, 225
Chou, K.Y. 79
Costa, M. 158

D

De Geus, B. 56
De Kievit, E. 291
Delbosc, A. 109, 134
Deliali, K. 112
Dell'Orto, G. 103
Desire, L. 259
Dettmann, A. 147
De Waard, D. 64
De Winter, J.C.F. 150
Dijkstra, A. 115
Dodou, D. 150
Dols. J. 192
Dong, Y. 150
Dozza, M. 16, 22
Dubuis, L. 222
Dytrt, Z. 82

E

Echiburu, T. 247
Ee, M. 10
Eggermond, M.A.B. van 195
Ehlers, J. 61
Endo, K. 137
Eriksson, A. 153

F

Farah, H. 150
Farrants, K. 265
Faus, M. 247, 252
Feitosa, Z. 247
Feleke, G. 274
Fourati, W. 235
Francke, A. 274, 276
Friberg, E. 265
Friedrich, B. 235

G

Gail, J. 176
Gaio, A. 50
García, A. 192
García, A.G. 155
Gaspers, L. 38
Gebhard, S.E. 241
Gehlert, T. 213
Gene-Morales, J. 247
Gerike, R. 41, 100
Geurs, K.T. 115, 179, 185, 204, 210
Geus, B. de 56
Gildea, K. 271
Gimm, K. 140
Giudice, O. 121
Gnap, J. 247
Good, D.H. 285
Goshona, K. 244
Graupner, S.-T. 231
Grauschopf, T. 262
Gromke, C. 88
Groß, C. 47
Guensler, R. 91

Authors Index

H

Hackenfort, M. 173
Hagmann, D. 173
Hansen, W. 31
Hantschel, S. 41, 100
Happee, R. 103
Harkin, A.M. 170
Harkin, K.A. 170
Haslam, N. 109
Havinga, P.J.M. 204
Haworth, N. 85, 109, 167, 282
Heeremans, O.M. 164
Helm, F.C.T. van der 229
Hertach, P. 13
Hesjevoll, I. 126
Hollauf, E. 143
Hornung-Prähauser, V. 143
Hoschopf, H. 28, 71
Huemer, A.K. 189
Hu, J. 34

I

Ibrahim, M.K. 247
Imanipour, M. 279
Ingebrigtsen, R. 126
Iraeus, J. 238
Irizar da Silva, I. 140
Ishigamori, F. 182

J

Janoška, Z. 53
Janstrup, K.H. 79, 247
Jensen, A.F. 79
Jensen, M.G.L. 31
Jensen, S.U. 153
Jeppsson, H. 25
Johnson, J. 167
Johnson, L. 195
Junghans, M. 4, 140
Jung, T. 216

K

Kamphuis, K.G. 124
Kapousizis, G. 210
Karlsen, K. 126
Kiehl, A.C. 94
Kievit, E. de 291
Kitamura, Y. 182
Kjeldgård, L. 265
Klein Wolt, K. 74
Klosterkamp, M. 276
Knecht, L. 195
Kočková, J. 82
Koh, P.P. 7, 10
Kreusslein, M. 147
Krul, I. 74
Kum, Y.J. 208

L

Lahrmann, H. 106
Laureshyn, A. 271
Legese, A.T. 274
Leich, A. 4
Lelke, T. 235
Leotta, R. 121
Leschik, C. 140
Liebscher, A. 61
Liers, H. 67
Lijarcio, I. 247
Li, K. 259
Lima Azevedo, C. 158
Lioras, A. 238
Llopis-Castelló, D. 155
Lucchesi, S.T. 129
Luger-Bazinger, C. 143
Luo, S. 134

M

MacArthur, J. 225
Madsen, T.K.O. 106
Ma, H. 94
Makarova, I. 247
Mandel, H. 38
Mangold, A. 170
Marques, M. 158
Martinez-Buelvas, L. 282
McIlroy, R. 247
Meulen, F.H. van der 229
Mihailides, A. 238
Mikusova, M. 247
Mitullah, W. 274
Mjåland, O. 126
Mohammadi, A. 22
Møller, M. 44, 247
Monfort, S.S. 1
Mons, C. 124
Moore, J.K. 103, 219
Morel, C. 259
Morris, A.P. 288
Moura, F. 158
Mueller, B.C. 1
Müller. J.-H. 231
Müller, S. 47
Mulville, M. 256

N

Nabavi Niaki, M. 185
Namakula, H. 274
Naujoks, M. 189
Neo, L. 10
Nespereira, N. 192
Ngueuteu-Fouaka, S.G. 247
Niaki, M. Nabavi 185
Nielsen, O.A. 79
Niestegge, M. 41

Authors Index

O

Odijk, M.J.M. 185
O’Hern, S. 134, 247
Oikonomou, M. 238
Olesen, A.V. 106
Olyslagers, M. 129
O’Reilly, N. 256
Orozco-Fontalvo, M. 247
Orsini, F. 235
Oviedo-Trespalacios, O. 164, 252, 282

P

Pai, R.R. 16
Panik, R.T. 97
Papadimitriou, E. 150
Papendieck, P. 276
Pappalardo, G. 121
Passmore, R. 91
Paudel, M. 19
Paulsen, M. 79
Pérez-Zuriaga, A.M. 192
Petraki, V. 112
Petzold, M. 67
Petzoldt, T. 170
Pliquett, S. 94

Q

Qu, S. 34

R

Raju, N. 150
Rasmussen, T.K. 79
Reddan, H. 167
Reddy, N. 150
Rehrl, K. 118
Reijne, M.M. 229
Riener, A. 262
Rieß, J. 28, 71
Ringhand, M. 213, 216
Rintelen, H. 58
Robert, T. 222
Ronné, J. 222
Rorris, L. 238
Rossi, R. 235
Rothauge, E. 276
Rubie, E.M. 85, 164
Ruck, B. 88
Ruf, S. 198

S

Sabbaghian, M.H. 155
Saudrais, S. 259, 279
Saul, H. 4
Sawitzky, T. von 262
Schade, J. 231
Schaffner, D. 195
Schepers, P. 56
Schindler, R. 25
Schramm, A. 109
Schröter, B. 41, 100
Schubert, A. 67
Schüller, H. 41
Schwab, A.L. 229
Schwarzkopf, M. 147
Seiniger, P. 94, 176
Shah, N.R. 161
Shubenkova, K. 247
Siebert, F. 247
Siebert, F.W. 158
Šimeček, M. 82
Skládaná, P. 82
Sørensen, M.W.J. 31
Soto, J. 247
Steinmaßl, M. 118
Stelling-Kończak, A. 124
Stephens, A.N. 247
Stigson, H. 265
Stoll, T. 173
Strelow, F.H. 131
Studer, N. 195
Stülpnagel, R. von 58, 61
Suing, M. 94
Surges, F. 94
Suzuki, M. 137

T

Tallaksen, A.B. 106
Tan, C.T. 208
Tien, I. 97
Tomasch, E. 28, 71
Trezl, J. 147
Trifunović, A. 235

U

Uhr, A. 13
Uijtdewilligen, T. 115
Ulak, M.B. 115, 179, 185, 204, 210
Unger, T. 67
Useche, S.A. 247, 252

V

Van Cauwenberg, J. 56
Van der Helm, F.C.T. 229
Van der Meulen, F.H. 229
Van Eggermond, M.A.B. 195
Van ‘t Zelfde, J. 76
Vollrath, M. 44, 131, 189
Von Sawitzky, T. 262
Von Stülpnagel, R. 58, 61
Vortanz, J. 47

Authors Index

W

Waard, D. de 64
Wachnicka, J. 121
Wagner, P. 4
Wang, R. 34
Wang, Y. 247
Watkins, K. 91
Watkins, K.E. 97
Weijermars, W.A.M. 179, 241
Westerhuis, F. 64
Weyde, K.V. 126
Wies, H. 118
Wijlhuizen, G.J. 115, 291
Willberg, E. 247
Winter, J.C.F. de 150
Wintersberger, P. 247
Wolt, K. Klein 74

X

Xu, L. 134

Y

Yamamoto, N. 85
Yang, L. 208
Yannis, G. 112
Yap, F.F. 19
Yap, H.J. 208
Yoshida, N. 182, 244
Young, D. 167

Z

Zelfde, J. van ‘t 76
Zeuwts, L. 247
Zhang, M. 4
Zulkipli, Z.H. 247
Zuser, V. 201, 268

Bicyclist crashes with cars and SUVs: Injury severity and risk factors

S.S. Monfort*, B.C. Mueller#

*Insurance Institute for Highway Safety
988 Dairy Road, Ruckersville, VA, USA
email: smonfort@iihs.org

#Insurance Institute for Highway Safety
988 Dairy Road, Ruckersville, VA, USA
email: bmueller@iihs.org

Keywords: bicyclist injury severity, SUVs, leading edge, crash kinematics.

1 INTRODUCTION

The popularity of bicycles in the United States has increased dramatically over the past decade [1] alongside a similar increase in injuries and fatal crash numbers—particularly among adult riders [2, 3]. The increasing popularity of cycling together with growing the risk of injury or death for those cyclists presents a pressing need to understand how and why these riders are being injured in crashes with motor vehicles. Although past work is clear that larger, taller vehicles pose an outsized risk to bicyclists, we seek to understand why certain vehicle characteristics are associated with more severe bicyclist injury outcomes.

A large body of research has investigated factors that contribute to bicyclist fatalities from crashes with motor vehicles, including preimpact speeds [4], alcohol intoxication [5], bicyclist age [6], time of day [7], and lack of a bicyclist helmet [5]. Relevant to the current study, larger vehicles—trucks, vans, buses, and so on—have consistently been shown to be more hazardous to bicyclists than smaller passenger vehicles [4, 8].

The overrepresentation of certain vehicles in bicyclist fatalities is likely due to the way that their front-end height interacts with the person they strike. Our earlier research on pedestrian crashes found that that SUVs were more hazardous than shorter, smaller cars at least partially because of their higher leading edges [9]. In addition to more critical body regions being higher on the body, being struck above one's center of gravity tends to throw a person forward, possibly resulting in being run over [10]. Being run over is generally more injurious than rolling onto the hood or being thrown backward over the moving vehicle [9].

Although vehicles designed to meet EuroNCAP pedestrian crash protection requirements have also improved bicyclist crash outcomes [11], research suggests that the differences between pedestrians and bicyclists are large enough to warrant separate consideration [12]. For example, bicyclists seem uniquely at risk for forward projection [10] and ground-contact head injury [13]. The current study was designed to elaborate on the risk posed by taller vehicles by exploring real-world bicyclist crash injuries and kinematics.

2 METHOD

Bicyclist crash data were collected by the Vulnerable Road User Injury Prevention Alliance (VIPA) as a part of the International Center for Automotive Medicine (ICAM) Pedestrian Consortium. These data contained detailed records of Michigan pedestrian and bicyclist crashes where police were called to the scene.

2.1 Data

The current study focused on the 71 completed injury crashes occurring between 2015 and 2021 involving one adult-sized (i.e., aged 16 or older) bicyclist being struck by the front end of a passenger car or SUV.

Injury severity data for each crash were recorded using the Abbreviated Injury Scale (AIS). For each bicyclist, the three highest AIS scores were squared and summed to represent the aggregate level of injury, capped at 75 (i.e., the Injury Severity Score [ISS]). The ISS data were used to provide a single score that could characterize overall injury severity and how it might differ between cars and SUVs.

We also analyzed AIS scores separately by body region: for the head (including injuries to the head, face, and neck); for the torso (including injuries to the thorax, abdomen, and spine); for the lower extremities (including injuries to the hip, leg, and feet); and for the upper extremities (including injuries to the arms and hands).

A subset of crashes (n=18) contained additional detailed information related to injury attribution and crash kinematics. These crashes were used to make more granular injury comparisons between cars and SUVs.

2.2 Analysis

Poisson regression models were used to model overall and body region injury severity outcomes. Covariates included preimpact speed, time of day, curvature of the road, and bicyclist age and gender.

3 RESULTS

Controlling for factors unrelated to vehicle design differences, SUVs inflicted injuries that were 55% more severe (95% CI [33%, 81%]) compared with cars, p<.001. When considering body regions separately, only head injury severity emerged as significantly different by vehicle type. The typical head injury inflicted by SUVs (AIS = 1.43) was substantially more severe than that inflicted by cars (AIS = 0.88), p=.042. The distribution of head injury severity for cars and SUVs can be seen in Figure 1.

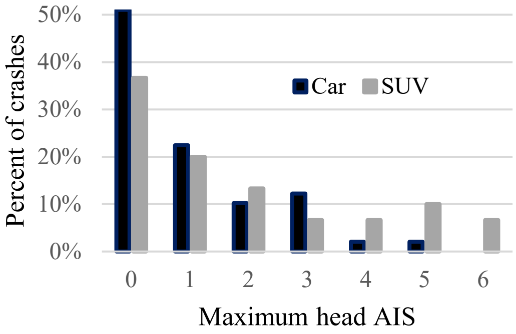


Figure 1. Prevalence and severity of head injuries for cars and SUVs.

To determine whether any regions on the striking vehicles were responsible for a disproportionate amount of injury, we summed the squares of the three most severe AIS scores for each region on the striking vehicle within each crash. We then summed the vehicle regions across crashes. This procedure approximates that used to calculate ISS and conveys at a glance which striking region is responsible for inflicting the largest proportion of net injury severity.

Table 1: Net injury severity by source and vehicle type

	Header/ roof	Hood/ cowl	A pillar/ mirror	Ground	Windshield	Front end	Fender	Wheel/ undercarriage
Car	29% (75)	21% (54)	17% (43)	15% (39)	12% (31)	5% (13)	0% (0)	0% (0)
SUV	0% (0)	0% (0)	19% (65)	25% (84)	1% (3)	4% (15)	14% (46)	37% (125)

A Chi-square goodness-of-fit test suggests that the distribution of ISS across vehicle regions differed by striking vehicle type, $\chi2(7) = 117$, $p < .001$. Compared with cars, SUVs tended to produce injuries concentrated on a smaller subset of components: mostly the wheel, vehicle undercarriage, and ground. This concentration is consistent with the prevalence of run-over crashes among SUV crashes (10% compared to none for cars).

Injurious impacts with the ground seem to be a key differentiator between crashes involving cars and those involving SUVs. Even in cases where bicyclists were not run over, ground-contact injuries were more than twice as common among SUVs compared with cars (40% vs. 19%). Further, among SUV-inflicted head injuries from the subsample coded for injury attribution, 82% resulted from contact with the ground, wheel, or undercarriage. All of the car-inflicted head injuries resulted from contact with the header, roof, or windshield.

4 CONCLUSIONS

We found that bicyclists were injured more severely when struck by SUVs than when struck by cars and that the differences in severity were driven by SUVs' tendency to inflict injury with their wheels, undercarriage, and the ground. We also found that SUVs were disproportionately likely to inflict severe head injuries, and that these injuries were likewise overwhelmingly caused by the ground, or by components near the ground. Even in cases where bicyclists were not subsequently run over, strikes from an SUV were dramatically more likely to cause injurious contact with the ground compared with those from cars.

REFERENCES

[1] NPD Group. NPD Group Market Research; Port Washington, New York: 2021. Bicycle Sales in the U.S.

[2] Ferenchak, N.N. & Marshall, W.E. (2020). Is bicycling getting safer? Bicycle fatality rates (1985–2017) using four exposure metrics. *Transportation Research Interdisciplinary Perspectives*, *8*, 1–12.

[3] Sanford, T. et al. (2015). Bicycle Trauma Injuries and Hospital Admissions in the United States, 1998–2013. Research Letter. *Journal of Automotive Medicine*, 314 (9).

[4] Macioszek, E. & Granà, A. (2021). The analysis of the factors influencing the severity of bicyclist injury in bicyclist-vehicle crashes. *Sustainability*, 14, 215–238.

[5] Kim, J., Kim, S., Ulfarsson, G.F., & Porrello, L.A. (2007). Bicyclist injury severities in bicycle-motor vehicle accidents. *Accident Analysis and Prevention*, *39*, 238–251.

[6] Boufous, S., de Rome, L., Senserrick, T., & Ivers, R. (2012). Risk factors for severe injury in cyclists involved in traffic crashes in Victoria, Australia. *Accident Analysis and Prevention*, *49*, 404–409.

[7] Zahabi, S.A.H., Strauss, J., Manaugh, K., & Miranda-Moreno, L.F. (2011). Estimating potential effect of speed limits, built environment, and other factors on severity of pedestrian and cyclist injuries in crashes. *Journal of the Transportation Research Board*, *2247*, 81–90.

[8] Edwards, M. & Leonard, D. (2022). Effects of large vehicles on pedestrian and pedal-cyclist injury severity. *Journal of Safety Research*, in press.

[9] Monfort, S. S., & Mueller, B. C. (2020). Pedestrian injuries from cars and SUVs: Updated crash outcomes from the vulnerable road user injury prevention alliance (VIPA). *Traffic Injury Prevention*, *21*(sup1), S165-S167.

[10] Crandall, J.R., Bhalla, K.S., & Madeley, N.J. (2002). Designing road vehicles for pedestrian protection. *The BMJ*, *324*(7346), 1145-1148.

[11] Standroth, J. Sternlund, S. Lie, A. Tingvall, C. Rizzi, M. and Kullgren A. (2014). Correlation between Euro NCAP Pedestrian test results and injury severity in injury crashes with pedestrians and bicyclists in Sweden. *Stapp Car Crash Journal*, 58, 213–231.

[12] Maki, T., Kajzer, J., Mizuno, K., & Sekine, Y. (2003). Comparative analysis of vehicle-bicyclist and vehicle-pedestrian accidents in Japan. *Accident Analysis & Prevention*, *35*(6), 927-940.

[13] Badea-Romero, A., & Lenard, J. (2013). Source of head injury for pedestrians and pedal cyclists: Striking vehicle or road? *Accident Analysis & Prevention*, *50*, 1140-1150.

Reliability of cooperative ADAS and the importance of the acceleration function for cycling safety

M. Junghans[*], **M. Zhang**[*], **H. Saul**[*], **A. Leich**[*], **P. Wagner**[*]

[*]German Aerospace Center (DLR)
Institute of Transportation Systems
Rutherfordstraße 2, 12489 Berlin, Germany
email: {marek.junghans,meng.zhang,hagen.saul,andreas.leich,peter.wagner}@dlr.de

Keywords: cycling safety, crash prevention, cooperative ADAS, entropy, traffic conflict analysis.

1 INTRODUCTION

Cycling has become increasingly important on German roads over the past 20 years. However, the number of crashes involving cyclists, which may go along with severe injuries or fatalities, is increasing. Between 2010 and 2018 the number of killed cyclists increased from 381 to 445 (+16.8%) [1]. The interaction of right-turning motorists with passing cyclists is one of the most critical ones, particularly if the cyclist is relatively behind the motorist (i.e., in its blind spot). Advanced driver assistance systems (ADAS) are being developed in order to assist in potential critical situations before they evolve to crashes. Infrastructure-based, cooperative solutions could inform or warn road users before a potential collision via V2X or a roadside entity, such as a dedicated traffic light. The Bike Flash system is an example of such a solution [2]. Its drawback is that it warns if a cyclist is present without considering the possible outcome of the situation (e.g., dangerous or not), which can lead to acceptance problems. Thus, in [3] an algorithm was developed and successfully tested, capable of sending out warnings if a potential crash was predicted. For this purpose, a construction traffic light, called "amber light" (AL), was used to inform the right-turning motorists about potential collisions. This method is based on a decision tree (DT) considering the distances of the interacting cyclists and motorists to their collision/conflict point (CP), their speeds and the predicted post encroachment time (pPET), which continuously quantifies to what extent two interacting partners will miss each other. Interestingly, the acceleration functions of the road users are not part of the DT, although they are—except the change of direction—the only control parameters to realise evasive actions. Further, it is not clear, at what distance to the CP crash warnings are reliable and thus, where such an AL should be installed. We will address these open aspects by analysing the acceleration functions of cyclists and motorists in unaffected, uncritical and critical encounter situations in the time and frequency domains. We will emphasize the importance of acceleration functions distinguishing between critical and uncritical encounters in certain distances before the CP. Furthermore, we will show that critical encounters of cyclists and uncritical encounters of motorists show completely different characteristics, and we will try to measure surprise (or anticipation) by applying the entropy metric on the acceleration functions and conduct inference statistical tests. In terms of reliability and location of such a warning system before the CP we will compute pPET while considering kinematic patterns of the road users. These are examples of some of the essentially important aspects to establish well-accepted cooperative warning systems in the future.

2 THEORY

First, we reduced the whole data set (section 3) by computing and remaining interaction situations with PET<2.5s. The videos of the selected interactions were annotated by experts. For these situations we applied the DT according to [3] and computed the distance-dependent confusion rates sensitivity, specificity, over- and underestimation (Figure 1, top). Second, we computed kinematic patterns of unaffected, uncritical and critical encounters of cyclists and motorists including pPET in dependence on the distance to the CP (Figure 1, bottom left). Third, auto- (ACF) and cross-correlation functions (CCF) of the accelerations (eq. 1) and their auto- and cross-power density spectra (eq. 2) were computed and evaluated ($x(n)$: cyclist's and $y(n)$: motorist's discrete acceleration functions, τ: shift, $\omega = 2\pi f$: angular frequency, j: imaginary unit):

CCF
$$\varphi_{xy}(\tau) = E\{x(n) \cdot y(n-\tau)\} \tag{1}$$

Cross-power spectrum
$$R_{XY}(\omega) = \sum_{\forall\tau} \varphi_{xy}(\tau) \cdot \exp(-\mathrm{j}\varphi\tau) \tag{2}$$

Since the height of the maximum of the ACF reflects the signal energy and thus, allows to estimate the similarity to white noise, we applied this idea on the CCF, too. Based on the results, we computed the entropies on the acceleration functions. The entropy H is a measure of information content, which can be computed with symbols a_i, different binnings, their probabilities p_i and the dual logarithm $\log_2$:

$$H(a) = -\sum_{a_i \in |a|} p_i \log_2 p_i \tag{3}$$

Fourth, we applied inference statistical tests (i.e., Kruskal-Wallis-H, Mann-Whitney-U tests at confidence level α=0.05) to test for significance of the kinematic patterns, pPET, entropies and cross-power density spectra.

3 DATA AND EXPERIMENTS

The trajectory and video data of interacting cyclists and motorists as well as unaffected situations were recorded at 25 fps at the AIM research intersection in Braunschweig, Germany, in the years 2016 and 2018, which were annotated by experts. The trajectory data consist mainly of a GNSS-based time stamps, UTM positions, velocities and accelerations (derived by adequate dynamic motion models and Kalman filtering). 1.169 cyclist and 12.305 motorist trajectories were recorded, while 49 conflict and 273 uncritical encounter pairs resulted by filtering with PET<2.5s and expert annotation. 96 unaffected bicycle and 836 unaffected motorist trajectories were obtained. Due to poor data (e.g., broken trajectories, missing time stamps) not all of the data could be used. For computing pPET we extended those trajectories by 10 data points assuming the road users went on at same speed and direction as before. Then, 40 critical, 237 uncritical and 96 unaffected pairs remained. In case of computing the correlation functions, their spectra and entropies, the acceleration functions were cut at some distance before their CP, the parts from the cut to the CP remained. These limiting values were the result of the potential collision predictability in accordance with the outcomes of pPET, entropies and cross-power density spectra. For statistical evaluation we balanced the remaining data set yielding a 1:2 fraction of 40 critical, 80 uncritical and unaffected pairs, which were chosen randomly.

4 CONCLUSIONS & FUTURE PROSPECTS

Computing speeds and accelerations of road users interacting in critical and uncritical encounters as well and unaffected situations showed significant differences (see also [4]). Computing pPET (Figure 1, bottom left) showed significant differences between critical and uncritical encounters leading to an almost constant difference of approximately 1.3s (conflicts: pPET≈0.9s; encounters: pPET≈2.1s) beginning 12m before to the CP, which manifested the predictability of such situations. The confusion rates showed that sensitivity and specificity values appeared to exceed 50% after 16m (cyclists) and 13m (motorists) before the CP, respectively. The maxima of the cross-power density spectra and the entropies of the acceleration functions of critical, uncritical and unaffected situations (Figure 1, bottom right) turned out to be significant at 11m before the CP, but non-significant at larger distances. The following findings were robust against different binnings of the "acceleration alphabet", although the maximum entropies changed: The entropies of cyclists' critical situations were significantly larger than for all other remaining situations. However, the entropies of motorists' uncritical encounters were significantly larger than the remaining ones, which could reflect anticipation in terms of realising evasive actions. While approximately 70% of the cyclists were relatively behind motorists, cyclists disarmed conflicts by speed adaption while motorists behaved very similarly to unaffected situations. In case of uncritical encounters, motorists reduced their speeds reflecting to be aware of cyclists; anticipation/disarming the conflict was realised by the motorists. Thus, *H* can be a suitable measure to quantifying surprise and anticipation in road user interaction. As shown in [3] the DT worked well to predict conflicts, but was trained on 10 situations assessed by experts only. Further, situations with PET≥2.5s were not included, which might lead to biased data, particularly for uncritical encounters. A detailed investigation of crossing situations with larger PET values is necessary. Next, we will try to gain more insight in the importance of acceleration, particularly in terms of measuring anticipation or surprise in road user interaction. We think that considering solely accelerations might be only one side of the coin leading us to compute a joint entropy with speeds, pPET and distances to the CP.

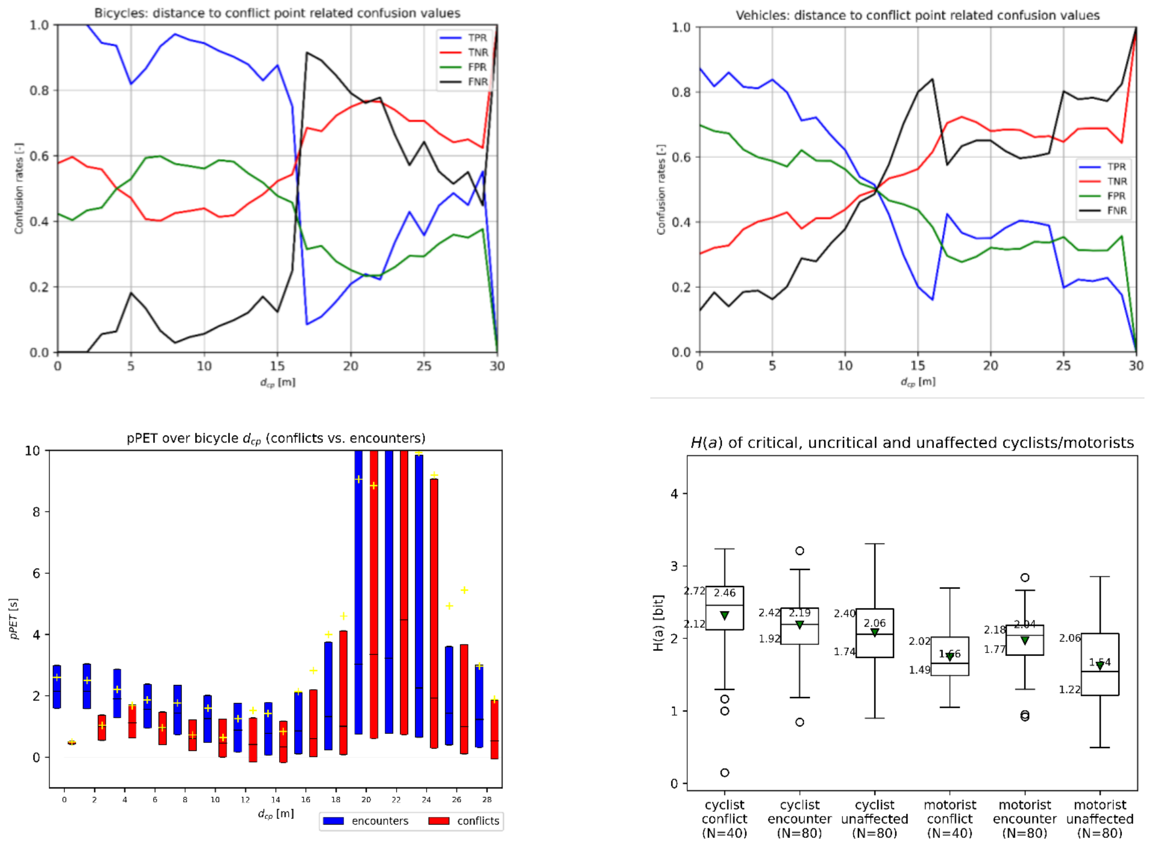


Figure 1. Confusion rates of cyclists (top left) and motorists (top right); pPET values for critical and uncritical encounters over distance to CP d_{cp} (bottom left, outliers and antennas are not shown for reasons of clarity); entropies for critical, uncritical and unaffected acceleration functions of cyclists and motorists (bottom right).

REFERENCES

[1] H. Nier, „Zahl der getöteten Radfahrer steigt wieder“, Statista – Verkehr & Logistik, 12.07.2019, https://de.statista.com/infografik/18675/getoetete-radfahrer-in-deutschland/, visited 03.03.2023.

[2] Bike flash, https://bike-flash.de/, visited 03.03.2023.

[3] H. Saul, M. Junghans, M. Dotzauer, K. Gimm, “Online risk estimation of critical and non-critical interactions between right-turning motorists and crossing cyclists by a decision tree”, in *Accident Analysis and Prevention*, V.163. doi: 10.1016/j.aap.2021.106449. 2021.

[4] M. Zhang, M. Dotzauer, C. Schießl, “Analysis of Implicit Communication of Motorists and Cyclists in Intersection Using Video and Trajectory Data.” Front. Psychol. 13:864488. doi: 10.3389/fpsyg.2022.864488, 2022.

Safety Of Active Mobility Device Users on Singapore Roads

P.P. Koh[*] and Chandrasekar[+]

*Land Transport Authority
No 1 Hampshire Road Blk 11 Level 4
Singapore 219428
email: koh_puay_ping@lta.gov.sg

[+]Land Transport Authority
No 1 Hampshire Road Blk 9 Level 1
Singapore 219428
email: chandrasekar@lta.gov.sg

Keywords: road traffic accidents, active mobility, on-road cycling, countermeasures

1 INTRODUCTION

Globally, active mobility (AM) has been rising as a popular mode of transport over the last few years, especially during the COVID-19 pandemic, when such "domestic travel" made up for the restrictions to international travel. In Singapore, a highly dense city-state, cycling activity has been observed to pick up with on-road cyclists are one particular group that has been observed to increase in number.

With more cyclists on roads, potential conflicts with other road users can arise. The European Commission [1] reported that cyclist accidents are the only type of accidents where there has been no decline in fatalities since 2010 in European countries. This could be a result of the increase in cycling activities, increasing the exposure on the roads. Over the past 2 years, there have been several online posts and comments on cycling, including errant cyclist behaviour, offences and accidents involving cyclists on Singapore roads [2]. With the cycling population getting bigger, it is thus prudent to examine the accidents in details, to put in place measures, so that accidents can be prevented or mitigated.

2 LOCAL CYCLING LANDSCAPE AND SAFETY PERFORMANCE

2.1 Cyclist activity and volume on Singapore roads

Examining Strava data [3] in Singapore, cycling trips had increased in 2020 and 2021, which coincides with heightened restrictions during the COVID-19 pandemic. Once international travel resumed from 1Q2022, cycling trips started to decrease (see *Figure 1*).

Counts were extracted from available CCTV video footages in 2021 to give an overview of the volume of road cyclists along these popular routes. Peak-of-the-peak volumes typically occurred on weekend mornings between 6am-8am, with the highest peak recorded at 755 cyclists per hour along one of the popular on-road cycling routes.

Figure 1: Cycling trips extracted from Strava, 2023

2.2 Overview of AM device accident statistics in Singapore

Accidents involving bicycles have accounted for the majority of AM-related on-road accidents (see *Figure 2*). Since 2017, on-road accidents involving bicycles and power-assisted bicycles (PABs) had been on a downward trend until 2019. Then, the trend reversed, and accidents started to increase again in 2020 and 2021, aligning with the trend of increased cycling trips. This also coincided with the ban on motorized personal mobility device (PMDs) on footpaths starting in 2019, which could have resulted in some users switching to PABs/bicycles as motorized PMDs are also not allowed on roads. In 2022, the total number of on-road AM accidents had decreased compared to 2021. This coincides with the opening of international borders, as well as recent regulatory, education and enforcement initiatives (e.g. new regulations on cycling group size, safety handbook) undertaken to improve road safety.

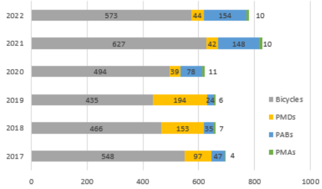


Figure 2: On-road accidents involving different AM devices

A total of 727 road accidents involving bicycles (inclusive of PABs) had occurred in 2022, equivalent to an average of 2 cases a day. As for PMDs, there were still some accidents involving PMDs on roads after 2019, though the numbers had dropped significantly as compared to the years before the footpath ban on PMDs was announced in 2019, and before the decrease in usage of PMDs.

Accidents involving bicycles and PABs between 2017 and 2021 had occurred most frequently at two-way divided roads (32%), intersections (31%), followed by slip roads (19%), one-way roads (11%), then two-way undivided roads (5%). *Figure 3* shows the heatmap of where accidents involving bicycles and PABs had occurred between 2017 and 2021. The locations where accidents had most frequently occurred were along major arterial roads. There was a slightly higher occurrence of AM accidents involving bicycles and PABs on Fridays and Saturdays, from 7AM to 9AM. This coincides with the peak on-road cyclist volumes.

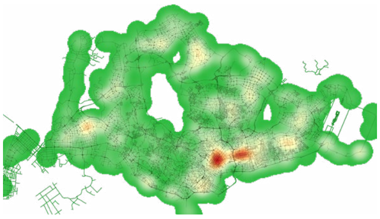


Figure 3: On-road bicycle and PAB accident heatmap (2017-2021)

3 METHODOLOGY

A total of 6 years of road traffic accident database (between 2017 to 2022) from Traffic Police was used to study the case-by-case investigation. Only fatal accident records were used in this study as it is the most complete with a comprehensive reported summary of the accidents.

Overall, fatal on-road accidents involving AM devices made up a minority of all fatal accidents involving other road users. Cyclists and their pillions had accounted for around 10% of total road fatalities (or less than 20 fatalities each year) and PMD fatalities had accounted for less than 5% of all road fatalities. Between 2017 and 2022, there were a total of 76 fatal on-road accidents involving AM device users. For each fatal crash, accident attributes such as vehicle type involved, location type, day/night, collision type movement type were extracted.

3.1 Descriptive analysis

Frequencies and proportions were conducted on all accident attributes, to identify the characteristics of AM device fatal accidents. Almost three-quarters (71%) of the accidents had involved bicycles, and 16% had involved PABs. PMDs and PMAs accidents constituted less than 7% each of fatal on-road accidents, and they had all occurred at road crossings. About 60% of the accidents involved AM device users collided with a larger vehicle (i.e. bus, trailer, lorry) than car.

More than a third (38%) of the fatal on-road accidents involving AM devices occurred at signalised pedestrian crossings at junctions, followed by along arterial roads (21%), then at unsignalised junctions (12%) and zebra crossings (12%). Half of the accidents at signalised pedestrian crossings at junctions involved vehicles hitting AM device users either from the left or right, while 24% had occurred between left-turning vehicles and AM device users. Most of the drivers had claimed that the traffic lights were in their favour during the accident.

3.2 Determining the potential of infrastructure intervention

For each fatal accident, the pre-crash movement was studied and possible engineering intervention (if any), that was believed to have prevented the accident from happening was proposed. This cause and intervention matching allowed one to determine the percentage of the fatal accidents that was preventable. *Table 1* shows that close to 83% of the fatal accidents were avoidable if the interventions were to be implemented. It was assessed that engineering and enforcement intervention could have prevented 47% and 33% of the fatal cases respectively. For 13 cases, longer term softer measures e.g. education, could have been introduced. They include cases where cyclists and vehicles being too close to one another (either rear-end or side-swipe), cyclists hitting stationary parked vehicles, etc.

Table 1: List of interventions that can prevent the fatal accidents

Cause Type	**Intervention Type**	**No.**	**%**
Right angle collision between vehicle approach zebra crossing and AM device user	Traffic calming before slip road zebra crossing	9	12.0
Right angle collision between exiting vehicle from development access with AM device user	Traffic calming at development access	8	10.7
Left-turning traffic hit AM device user at signalised pedestrian crossing	Early ped headstart	5	6.7
Side swipe collision between vehicle and AM device user during starting off at signalised junction	Bike box for cyclist	2	2.7
Tripped over pot hole on the road	Fix pot hole	1	1.3
AM device user hit by vehicle while crossing the road illegally	More designated crossing/buildout kerb	4	5.3
Right-turning vehicle hit AM device user on the signalised pedestrian crossing	Controlled right turn	4	45.3
AM device user lost control on a slope	Traffic calming measure	2	2.7
Traffic calming at the mouth of the unsignalised junction	Traffic calming at the mouth of the unsignalised junction	2	2.7
Non-engineering infrastructure treatment	Enforcement	25	33.3
	Erroneous human behaviour	13	17.3
	Total	76	100.0

4 CONCLUSIONS

This research provided a good appreciation of the on-road AM accident situation in Singapore. It also demonstrated the possible reduction in future fatal accidents, if suitable interventions are introduced. More work has to be done to identify islandwide/mass application of the interventions, where necessary.

REFERENCES

[1] European Commission (2021). *Facts and Figures Cyclists*, European Road Safety Observatory, Brussels, European Commission, Directorate General for Transport.

[2] The Straits Times (2021). “*245 cyclists caught riding on expressways from Jan to Sept as more pick up cycling as hobby*”.

[3] Strava (2023). *Metroview Dashboard*. Cycling activities between 2018 to 2022.

A Data-driven Approach to the Safety Management of Active Mobility Users

Moira Ee[*], Koh Puay Ping[#], Linda Neo[+]

[*]Active Mobility Group
Land Transport Authority
1 Hampshire Road, Block 11,
Level 4, Singapore 219428
email: moira_ee@lta.gov.sg

[#]Road & Traffic Specialists
Land Transport Authority
1Hampshire Road, Block 11, Level
4, Singapore 219428
email: koh_puay_ping@lta.gov.sg

[+]Active Mobility Group
Land Transport Authority
1Hampshire Road, Block 11, Level
4, Singapore 219428
email: linda_neo@lta.gov.sg

Keywords: safety management, accidents, cyclists, active mobility, blackspot

1 INTRODUCTION

With the increasing uptake of active mobility (AM) in Singapore, the probability of pedestrians and AM device users coming into conflict with each other on the paths increases. Taking on board extensive public feedback, the Land Transport Master Plan (LTMP) 2040 was launched in May 2019, with a key goal of encouraging walking, cycling, and riding public transport the way of life for Singaporeans [1]. Aligning with the LTMP targets to provide healthier lives and safer journeys, it is pertinent for Singapore's Land Transport Authority (LTA) to undertake a systematic approach to the investigation, treatment, and monitoring of accident blackspots on the paths. This paper elaborates on the multi-pronged approach taken by the Authority and the possible future enhancements to path safety in Singapore.

2 METHOD

LTA had adopted a multi-pronged approach that systematically manages the safety of AM device users. The approach follows the safe system approach which focuses on infrastructural design and improvements, public engagement, and enforcement. The key initiatives include the planning and implementation of dedicated cycling paths for AM device uses, regulation of AM device usage and the introduction of the blackspot programme. The paper focuses on the implementation of the blackspot programme.

2.1 Introduction of a Paths Blackspot Programme

Blackspots are defined as locations with clustering of accidents that occurred in close proximity. LTA has embarked on the identification and conflict mitigation of such hazardous locations through the introduction of a paths blackspot programme. The paths blackspot programme draws reference from our well established on-road blackspot programme which was introduced in 2005 [2]. The five main steps of this data-driven initiative are the establishment of a good accident database, identification of blackspots, diagnosing the identified locations, implementation and monitoring of the mitigating treatments.

2.1.1 Identification and Diagnostic of Blackspots

Firstly, LTA had established a geographic information system based (GIS) accident database which tracks and monitors accident trends spatially and temporally (Figure 1). To set up the database, LTA geotagged and coded accident reports according to the respective accident contributing attributes. An example of an accident contributing attribute could be the presence of a blind spot. Potential blackspots are identified by overlaying a fixed mesh grid over the island wide AM accidents between a selected time-period and identifying clusters via GIS. LTA would proceed to shortlist and analyze few of the largest clusters in an effort to treat the following blackspots in descending order.

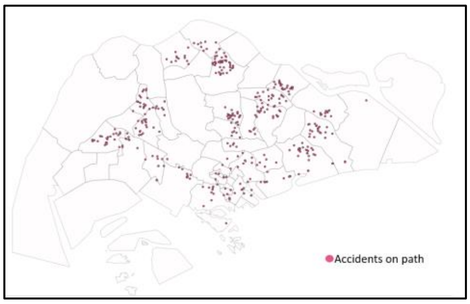


Figure 1: Tracking of AM accidents via GIS (2020-2022)

To illustrate, Figure 2 depicts an example of a potential blackspot with 6 accidents along the road when using a 400m x 400m mesh grid during the blackspot identification process. A 400m-by-400m grid was selected as it is the average block length (distance between two major arterial roads) in Singapore's local residential areas. Further adjustments can also be made to the grids to include surrounding accidents or account for local site constraints within a 400m by 400m mesh width. Taking into account path characteristics, we further cluster the data points along routes of movement for analysis.

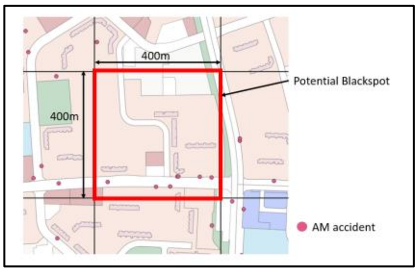


Figure 2: Clustering indicating potential blackspot

During the identification of the blackspot programme, a statistical analysis of its accident contributing factors is also conducted. The analysis will also look potential factors such as the date and time of AM accident, type of AM devices involved and locality of the accident. Accident causation factors analysed and possible mitigating treatments that can reduce the chance of similar accidents from occurring were proposed.

2.1.2 Implementation and Monitoring of Safety Measures at Blackspots

From the blackspot analysis, LTA will implement the appropriate safety engineering measures to tackle each unique blackspot which was locality depended. For example, at locations with a reported trend of AM accidents with collision type-side swipe, LTA could explore safety measures such as the widening of footpaths or implementation of dedicated cycling paths for AM device users to travel on segregated paths (Figure 3). LTA could also explore the creation of a by-pass path behind the bus stop to mitigate conflicting movements between AM device users and commuters aligning and boarding the buses (Figure 4). If there are potential line of sight issues, LTA can explore the trimming of vegetation or relocation of hard structures. After the implementation of safety measures, LTA will continuously monitor the blackspot locations in the subsequent years to see if there is an improvement or drop in the number of AM accidents at the said location and assess if further safety treatment would be required.

Figure 3: Dedicated cycling path with red segment for AM device

Figure 4: Provision of by-pass behind the bus stop

3 CONCLUSION

The blackspot programme should be complemented with other proactive measures that identify potential conflicts and/or accidents prone locations via cycle safety audits or the evaluation of ad hoc feedback. With AM growing as a popular form of commute, LTA has embarked on this multi-pronged approach to systematically manage the safety of AM device users from various angles. This paper has examined the various initiatives taken by LTA with a focus on the blackspot programme. As LTA continuously supports the adoption of AM commute, more studies would need be conducted along with adequate safety enhancements work towards the provision of a safe and more gracious environment that favours AM as a mode of transportation. We would also like to highlight that as we had only recently launched the blackspot programme, we are currently monitoring the effectiveness of the proposed safety measures mentioned above in the local context.

REFERENCES

[1] LTA, *Land Transport Master Plan 2040*, Land Transport Authority, 2019
[2] LTA, *Road Safety*, Land Transport Authority, 2019, Retrieved from link on 11 April 2023

Why (e-)cyclists don't wear high-visibility vests. Comparison between Doers and Non-Doers

Andrea Uhr*, **Patrizia Hertach***

*Swiss Council for Accident Prevention
Hodlerstrasse 5a, CH-3011 Bern, Switzerland
email: a.uhr@bfu.ch; p.hertach@bfu.ch

Keywords: high-visibility vests, cyclists, collisions, Doer/Non-Doer, survey.

1 INTRODUCTION

Collisions involving cyclists and e-cyclists often occur because they are overlooked by car drivers. Personal visibility aids are a promising means to reduce such accidents. A Danish study concluded that overall, yellow bicycle jackets significantly reduce (self-reported) collisions of cyclists with other road users [1]. Various other studies show that fluorescent and reflective materials improve detection and recognition performance in daylight respectively in the darkness [2–4]. It can therefore be assumed that high-visibility (hi-vis) vests also provide a safety benefit. According to a recent observational study, 5% of cyclists and e-cyclists in Switzerland wear a hi-vis vest at dusk or in the dark. The respective percentage in daylight is 3%. There are differences between the types of vehicles: e-cyclists – especially riders of speed-pedelecs – wear hi-vis vests significantly more often than riders of conventional bicycles.

In order to be able to promote the usage of hi-vis vests among (e-)cyclists, it is important to know the reasons for not wearing them. The aim of this study was to identify the relevant barriers that prevent (e-)cyclists from buying/wearing a hi-vis vest.

2 METHOD

An online survey was conducted among 2721 adult bicycle and e-bike riders in the German and French speaking part of Switzerland. The participants were drawn from the panel of a survey institute. People who never wear a hi-vis vest (Non-Doers) and people who do at least occasionally wear a hi-vis vest (Doers) were surveyed. The rate of Doers was increased through targeted recruitment. According to the self-reports, 799 of the participants were categorized as Doers and 1922 as Non-Doers. The questionnaire was developed by incorporating findings from the literature on safety product use, variables from various psychological models, and insights from preliminary qualitative interviews. Descriptive analyses were conducted to identify barriers to hi-vis vest use. In addition, comparisons were made between Doers and Non-Doers with respect to several variables of interest. The Doer/Non-Doer analysis was performed using bivariate procedures (cross-tabulations, chi-square test) as well as multiple logistic regression. The multiple logistic regression was used to identify the most relevant variables for the prediction of hi-vis vest wearing or non-wearing. The dependent variable was the wearing behavior (Doer vs. Non-Doer, independent of daylight). In a first step, all factors potentially linked to the outcome were tested in binary models. Except for age, all other variables were treated as categorial variables. Stepwise, the variables with the highest p-values in the model were then eliminated, until only variables with a p-value of <0.05 (for at least one value) were left in the model.

3 RESULTS

Analyses of the overall sample of respondents showed that (e-)cyclists are probably not sufficiently aware of the problem of being overlooked in daylight. Almost half of the participants believe that being overlooked by motorists in daylight is a (rather) rare cause of collisions between cars and (e-)cyclists. The usefulness of hi-vis vests is seen primarily in twilight/darkness, less so in daylight. In relation to darkness, 62% think that hi-vis vests are very helpful to avoid collisions between cars and (e-)cyclists. In relation to daylight, this share is 31%.

Generally, hi-vis vests are seen as something rather cumbersome (time consuming to put on, cumbersome to take along / store). (Suspected) handling problems emerged as one of the top three barriers to wearing a hi-vis vest. The most important reason for not wearing them is the fact that people have never thought about it before. The second most important reason is that they do not consider hi-vis vests important for themselves personally, e.g. because they already consider themselves sufficiently visible, because they ride carefully or only in places or at times where they find the hi-vis vest unnecessary (e.g. no riding in the dark).

The multiple logistic regression resulted in a model with 17 variables. The variables are listed in Table 1. For reasons of space, the variable values are not reported.

Table 1: Relevant variables identified in logistic regression analysis on the wearing of a hi-vis vest, independent of daylight

Variables
Assessment of effectiveness of hi-vis vests to prevent collisions between cars and bicycles in darkness
Assessment of effectiveness of hi-vis vests to prevent collisions between cars and bicycles in daylight
Agreement with statement: When you ride a bicycle/e-bike with a hi-vis vest, you feel safer.
Agreement with statement: With a hi-vis vest one receives more respect from drivers (e.g. more distance, right of way).
Agreement with statement: With a hi-vis vest you do not need a helmet.
Agreement with statement: Hi-vis vests are uncomfortable.
Agreement with statement: With hi-vis vests one does sweat more when cycling.
Agreement with statement: Hi-vis vests are cumbersome/impractical (e.g. to take along, deposit).
Agreement with statement: Hi-vis vests are something for construction workers/police officers, but not for cyclists.
Bicycle type (only classical bicycle, only e-bike, both)
Frequency cycling in rural areas
Frequency cycling in dense urban traffic
Frequency driving a car (as a driver)
Frequency experiencing critical situations while cycling
Number of collisions experienced while cycling
Age
Region (German or French speaking part of Switzerland)

In the majority of cases, the expected associations emerged. For example, people who believe that hi-vis vests are an effective means of avoiding collisions between cyclists and motorists in darkness as well as in daylight are more likely to wear them. Doers are also more likely to believe that if one wears a hi-vis vest, one gets more respect from motorists (e.g. more distance, right of way). As expected, the type of bicycle ridden and personal experience also play a role: e-cyclists are statistically significantly more likely to wear a hi-vis vest. Those who often experience critical situations or have already experienced several collisions are also more likely to wear them. With increasing age, the odds of wearing a hi-vis vest increase too. Participants from the French speaking part of Switzerland are almost twice as likely to wear a hi-vis vest than participants from the German speaking part of Switzerland. Other variables did not reach a p-value of 0.5 and therefore were not included in the final model, such as gender, or the assessment of one's own collision risk (vulnerability). Contrary to binary analysis, knowledge about the problem of being overlooked in daylight did not reach the level of significance in the multiple logistic regression.

4 CONCLUSIONS

Various barriers and influencing factors for (not) wearing a hi-vis vest could be identified. Important factors are, for example, the knowledge about the effectiveness of hi-vis vests in daylight, the perception that these vests are something cumbersome and simply the fact that one has never thought about the topic. From this, different awareness-raising measures and promotional opportunities to increase the usage of hi-vis vests could be derived. For example, an attempt could be made to increase the knowledge of the effectiveness of these vests during daylight hours. Ideally, opportunities could also be found to make the wearing and carrying along / depositing of hi-vis vests less cumbersome. The fact that the most important reason for not wearing hi-vis vests is that people have never thought about it suggests that any awareness-raising or promotional activity could be a winner.

REFERENCES

[1] Lahrmann H, Madsen TKO, Olesen AV et al. The effect of a yellow bicycle jacket on cyclist accidents. *Saf Sci*. 2018; 108: 209–217. DOI:10.1016/j.ssci.2017.08.001.

[2] Kwan I, Mapstone J. Interventions for increasing pedestrian and cyclist visibility for the prevention of death and injuries (Review). *Cochrane Database Syst Rev*. 2009;(4): 1-53.

[3] Rogé J, Laurent S, Ndiaye D et al. Does a yellow jacket enhance cyclists' sensory conspicuity for car drivers during daylight hours in an urban environment? *Saf Sci*. 2019; 119: 385–391. DOI:10.1016/j.ssci.2018.06.023.

[4] Wood JM, Tyrrell RA, Marszalek R et al. Using reflective clothing to enhance the conspicuity of bicyclists at night. *Accid Anal Prev*. 2012; 45: 726–730. DOI:10.1016/j.aap.2011.09.038.

E-Scooters: Transport or leisure? Findings from naturalistic data collection

Rahul Rajendra Pai[*], **Marco Dozza**[#]

[*]Division of Vehicle Safety
Chalmers University of Technology
Hörselgången 4, 412 96, Göteborg, Sweden
email: rahul.pai@chalmers.se

[#] Division of Vehicle Safety
Chalmers University of Technology
Hörselgången 4, 412 96, Göteborg, Sweden
email: marco.dozza@chalmers.se

Keywords: Naturalistic Data, E-scooters, Data Logging, E-scooter Safety, Vulnerable Road User Safety.

1 INTRODUCTION

Over the past few years, e-scooters have emerged as a popular alternative to motorized vehicles for short journeys ranging from 0.5 to 2 miles [1]. The emergence of shared-scooter providers is the main factor behind this phenomenon. These companies, which debuted on the streets of Santa Monica and San Francisco in 2017 [2], operate in various cities and allow users to ride and pay by the minute. Compared to private modes of transport, one of the significant challenges for public transport is the first-last mile dilemma that the e-scooter-sharing services aim to address. However, the study by Badia and Jenelius [3] indicates that e-scooters are primarily used for leisure activities, with over half the rides accounting for social and recreational activities. This pattern of use indicates that e-scooters are not used just as a mode of transport.

The growing number of e-scooter users has resulted in new kinds of traffic conflicts with bicyclists and pedestrians [4] and other road users, including heavy vehicles. As the number of riders increases, so does the importance of ensuring the safety of e-scooter riders and other road users. The e-scooter phenomenon accompanies a rise in the number of e-scooter rider injuries and hospitalizations [5], with about 38 fatalities documented worldwide until 2019 [6]. Study by Stigson and Klingegård [7] indicates that most e-scooter crashes and injuries in Sweden are single events involving sliding or hitting curbs.

However, the crash causation mechanisms and the rider behavior that precipitated the crash still need to be explored due to the scarcity of this information in crash databases. To prevent crashes or reduce their severity, it is essential to comprehend the events that precede a crash and particularly the e-scooterist's interaction with other road users. Naturalistic data (ND) are a widely acknowledged source for analyzing and modeling the behavior of road users to enhance traffic safety. The gravity of the present situation warrants and necessitates naturalistic data collection using e-scooters. A naturalistic data collection setup has been devised specifically for logging data using the e-scooters in collaboration with Voi. This paper reports the current status of analyzing the mechanisms leading to safety critical events using the Voi naturalistic data.

2 METHODOLOGY

2.1 Data Collection

Besides the customary Internet-of-things (IoT) hub that the Voi's e-scooters come equipped with, a Data Acquisition System (DAS) was developed to gather 22 variables from a range of sensors on the e-scooter. The log consists of the timestamp, 3-axis acceleration, 3-axis angular speed, speed of the wheel, the position of the throttle and the brakes, and the battery state logged at 10 Hz. Complementary to these sensors, the DAS is equipped with a video logger developed as a part of a master thesis [8]. The forward-facing video camera provides visual information about the riding environment. No personal or demographic data were collected, and the camera only captured the road, with no identifiable features of the riders recorded, preserving the anonymity of the data. An encrypted container with restricted access stores the data collected. The established procedures ensure the security and privacy of the data according to Swedish regulations. Sixteen e-scooters are instrumented and are operational in the streets of Gothenburg, Sweden. The dataset compiled so far comprises a total of 3216 rides taken by 2339 riders between July to December 2022.

Figure 1 A fleet of Voi e-scooters equipped with data acquisition system and a frame of the video recorded.

2.2 Data Reduction and Analysis

The pre-processing of the data collected is carried out to synchronize the video and sensor data. The pre-processing also comprised meta-data generation to facilitate video coding. A well-established and comprehensive video annotation protocol based on the bikeSAFE study [9] was adapted to include the updated definitions and new variables specific to e-scooter rides. Based on the video annotation protocols, data reductionists reviewed the video data and coded each of the events. To identify the Safety Critical Events (SCE), the outliers in the longitudinal and lateral accelerations were considered. This study aims to examine how different factors (such as phone usage, intent of the ride, etc.) influence the occurrence of an SCE. Thereby, for each of the SCE, three baseline events were selected, which act as references for evaluating the impact of each of the variables. The baseline events were identified to match the SCE in terms of geographical location, time of the day, speed of the scooter, and weather conditions. These criteria are added to ensure that the baseline events accurately represent the SCE. The video annotation was carried out for the SCE and the baseline events. We use the odds ratio to quantify the risk associated with each variable.

3 RESULTS

Overall, 37 safety critical events have been identified in the dataset. Cars were involved in 15 events, pedestrians in 10, both cars and pedestrians in one. Seven events involved e-scooters or bicycles, and four were single e-scooter crashes. The preliminary odds ratio for the different factors is presented in Table 2.

Table 1: Risk of various factors of the ride. Bold indicates statistical significance

Factor	Odds ratio	95% CI
Intent of the ride: Leisure vs. Commute	**6.55**	[1.147, 37.352]
Object on handlebar	**2.65**	[1.004, 6.862]
Phone	3.29	[0.990, 10.934]
Day of the week: Weekend vs. Weekday	1.43	[0.625, 3.313]
Pack riding	2.03	[0.857, 4.794]
Hands: Single handed vs. both hands-on handlebar	6.17	[0.543, 70.141]

The preliminary analysis conducted on the dataset indicates that when the e-scooters are used for leisure riding, the riders are 6.55 times more likely to be involved in an SCE than when used for transport. The riders having an object (except for a mobile phone) hanging on the handlebar or holding it with their hands are 2.65 times more likely to experience a critical event. Notably, all leisure rides with SCEs have an object on the handlebar. Two types of phone usage when riding an e-scooter are observed, with handheld usage contributing to two crashes. In contrast, the phone mounted on the holder present on the e-scooter contributed to four critical events. The combination of these two usage patterns indicates that phone usage may increase the likeliness of the occurrence of safety critical events by 3.29 times. However, given the limited data, statistical significance could not be achieved here.

4 DISCUSSION

Our study confirms that e-scooters do not only serve as a mode of transport but are also used for leisure activities. Further, our study suggests that, when used for leisure, e-scooters are more dangerous than when used for transport, possibly because of the unsafe behavior of their users. By continuing our analysis of SCE, we will investigate such behaviors more in detail to suggest how to educate users and create policies that will favor the safe use of the e-scooters.

ACKNOWLEDGEMENTS

This work was sponsored by Trafikverket project, SIMT: Safe integration of micro-mobility in the transport system (2022/32014)

This work was supported by the project e-SAFER, funded jointly by Vinnova, the Swedish Energy Agency, the Swedish Transport Administration, and the Swedish vehicle industry through the Strategic Vehicle Research and Innovation (FFI) Program under Grant 2022-01641

REFERENCES

[1] C. S. Smith and J. P. Schwieterman, “E-Scooter Scenarios: Evaluating the Potential Mobility Benefits of Shared Dockless Scooters in Chicago,” Chicago, Dec. 2018.

[2] A. J. Hawkins, “The electric scooter craze is officially one year old — what’s next? - The Verge,” *The Verge*, Sep. 20, 2018. Accessed: Mar. 30, 2023. [Online]. Available: https://www.theverge.com/2018/9/20/17878676/electric-scooter-bird-lime-uber-lyft

[3] H. Badia and E. Jenelius, “Shared e-scooter micromobility: review of use patterns, perceptions and environmental impacts,” *Transp Rev*, pp. 1–27, 2023, doi: 10.1080/01441647.2023.2171500.

[4] J. Todd, D. Krauss, J. Zimmermann, and A. Dunning, “Behavior of Electric Scooter Operators in Naturalistic Environments,” *SAE Technical Papers*, vol. 2019–01, no. 1007, Apr. 2019, doi: 10.4271/2019-01-1007.

[5] N. K. Namiri, H. Lui, T. Tangney, I. E. Allen, A. J. Cohen, and B. N. Breyer, “Electric Scooter Injuries and Hospital Admissions in the United States, 2014-2018,” *JAMA Surg*, vol. 155, no. 4, pp. 357–359, Apr. 2020, doi: 10.1001/JAMASURG.2019.5423.

[6] A. Santacreu, “Safe Micromobility,” Paris, 2020. Accessed: Mar. 30, 2023. [Online]. Available: https://itf-oecd.org/sites/default/files/docs/safe-micromobility_1.pdf

[7] H. Stigson and M. Klingegård, “Kartläggning av olyckor med elsparkcyklar och hur olyckorna kan förhindras,” Stockholm, 2020. Accessed: Mar. 30, 2023. [Online]. Available: https://nyhetsrum.folksam.se/sv/files/2020/08/Folksam-Rapport-Elsparkcyklar-aug-2020-1.pdf

[8] R. R. Pai, “Logging Data From E-Scooters To Improve Traffic Safety,” Chalmers University of Technology, Gothenburg, 2022. Accessed: Mar. 31, 2023. [Online]. Available: https://hdl.handle.net/20.500.12380/305446

[9] J. Werneke, M. Dozza, and M. Karlsson, “Safety–critical events in everyday cycling – Interviews with bicyclists and video annotation of safety–critical events in a naturalistic cycling study,” *Transp Res Part F Traffic Psychol Behav*, vol. 35, pp. 199–212, Nov. 2015, doi: 10.1016/J.TRF.2015.10.004.

Experimental investigation on the safety performance of a new class of small wheel micro-mobility devices

Milan Paudel[*], Yap Fook Fah[#]

[*]Transport Research Centre
Nanyang Technological University, Singapore
50 Nanyang Avenue, 639798, Singapore
Email: milan002@e.ntu.edu.sg

[#]School of Mechanical and Aerospace Engineering
Nanyang Technological University, Singapore
50 Nanyang Avenue, 639798, Singapore
Email: mffyap@ntu.edu.sg

Keywords: Micro-mobility, braking, accelerations, obstacle interaction.

1 INTRODUCTION

Micro-mobility is an emerging term used to describe short-distance transportation using small, compact, lightweight, and usually single-person mobility devices for commuting [1]. Recently motor assisted micro-mobility devices such as E-bikes and e-scooters are becoming increasingly popular as these devices enable riders to cover significantly longer distances with minimum effort. Easy availability due to rental service, light weight, compactness, and environmental friendliness are some of the driving factors for micro-mobility devices [2]. Furthermore, micro-mobility has been considered a prominent and affordable solution for sustainable transportation to bridge the gap between first and last-mile transportation. In fact, many governments and concerned authorities are promoting micro-mobility as a step closer to sustainable green mobility to reduce congestion and pollution and provide seamless connectivity in transportation.

The new class of mobility devices includes electrically assisted vehicles having small wheels(8-16 inches) and a much shorter wheelbase (800-900 mm). These are the most recent additions to modern transportation, and little is known about their safety performances. The lack of proper design guidelines, experimental data, increasing number of accidents involving other road vehicles or pedestrians, and injuries to riders and pedestrians are some challenges micro-mobility faces. Moreover, it is interesting to note that the maximum accidents involving these micro-mobility devices are single-vehicle accidents. Moreover, loss of control, falls from the vehicle, and encountering road obstacles and pedestrians contribute to the major cause of accidents and injuries [3]. Similar outcomes have been reported for E-bikes [4]. One of the important questions is how safe these devices are in terms of their design. Therefore, it is essential to experimentally evaluate the rideability and safety of these small wheel and compact micro-mobility devices. Thus, we conducted experiments to evaluate braking, acceleration, and obstacle-overcoming performance considering the fact that most accidents are single-vehicle in nature. The test devices differ in terms of braking type, riding postures, operating motor power, and battery capacity and most importantly these devices are much shorter than conventional bicycles and E-bikes.

2 METHOD

Figure 1 shows test devices and an illustration of the instrumentations and the experimental and analysis procedure. A 3-axis accelerometer from EnDAQ has been used to collect the data. The sensor is attached to the main frame for the braking and accelerations test and to the handlebars for the obstacle roll-over tendency test. The acceleration data were collected at a sampling rate of 3200 Hz. Furthermore, a Butterworth filter was applied to remove the noise from the data. Braking and acceleration were conducted at 3 speed assist modes roughly close to 15, 20, and 25 km/h. However, the obstacle roll-over test was carried out at 10 km/h. The experiments were repeated 3 times for each speed.

The acceleration test was carried out to find the setting off acceleration of different test devices at different speed assist modes. The aim is to achieve the speed corresponding to the assist mode as quickly as possible either by (i) pressing the throttle (e-scooters) or (ii) activating the hub motor with pedals(e-bikes) or (iii) pedelling as fast as possible (mechanical bike).

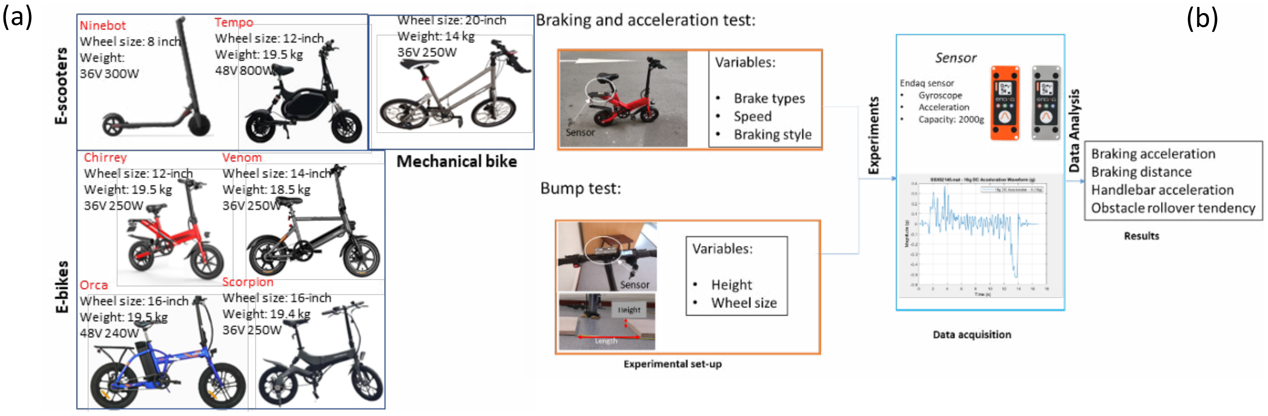


Figure 1: (a) Test devices and (b) instrumentation and data analysis methods

Similarly, the braking experiment is carried out to evaluate the performance of different braking system types, including foot brakes, electronic brakes, and disc brakes. After cruising at a predefined speed for some time, the rider applied hard braking to lock either the rear wheel or both wheels. Finally, an obstacle roll-over experiment is carried out to evaluate the handlebar acceleration or the jolt experiences by the rider, which could potentially cause loss of control while going over obstacles. Multiple plywood were staged together to achieve different obstacle heights ranging from 24 mm to 72 mm.

3 RESULTS AND DISCUSSION

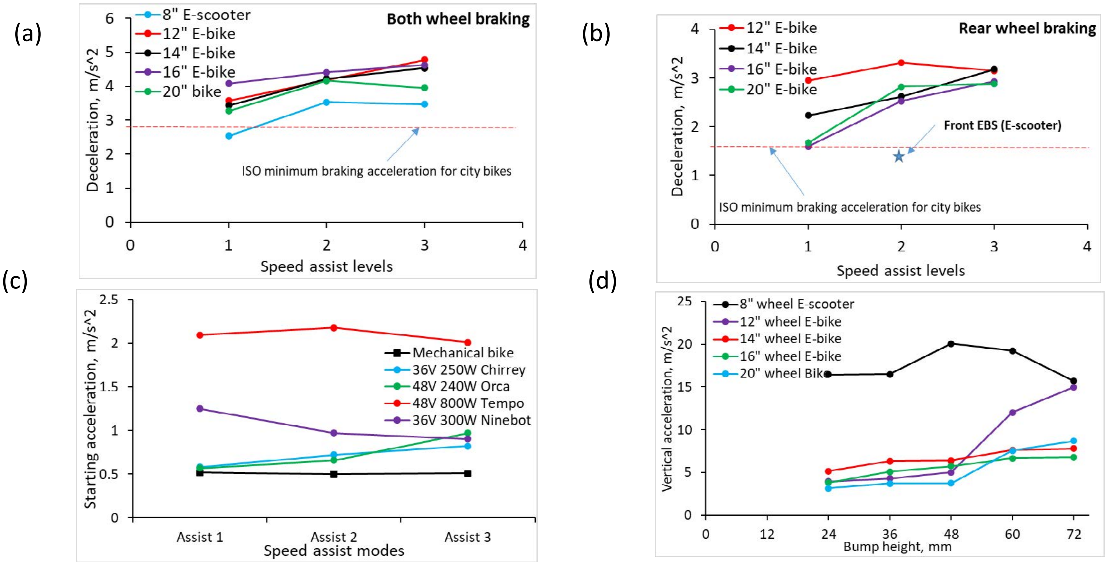


Figure 2: Experimental results (a) both wheel braking (b) rear wheel braking (c) setting off acceleration and, (d) handlebar jolt when front wheel encounters obstacles.

Figure 2 (a) and (b) shows both wheel and rear wheel braking performance of these small wheel devices and compare them with the ISO recommended minimum braking performance. E-bikes generate a braking deceleration greater than ISO recommended minimum value. However, an e-scooter with electronic braking has much lower braking deceleration compared to ISO recommendations and other E-bikes with disc brakes. Moreover, the experiment also revealed that the rear wheel of the small wheel E-bikes has a large tendency to skid while applying the rear wheel brake for speeds close to 20 km/h or more. The results show a safety hazard when these small wheels are braked hard at a speed of more than 20 km/h. The result could also highlight the effect of using 160 mm disc rotors which are designed for big wheel bikes on small wheel sizes.

It becomes evident from Figure 2 (c) that the starting acceleration depends on the motor ratings. E-scooters with higher motor rating shows almost twice the acceleration of 250W-rated e-bikes. Although the acceleration of a mechanical bike depends on the rider, the starting acceleration is generally lower than the electrically assisted devices [5]. Any cargo load at the rear rack of such compact devices significantly alters the weight distribution, and a powerful motor that accelerates rapidly on such compact devices could easily make the front wheel lose contact. Moreover, rapid acceleration is also known to reduce the self-stable speed range, and the vehicle could even become unstable[6, 7]. Therefore, a high starting acceleration could be a potential safety risk to the riders.

Similarly, Figure 2 (d) shows the vertical acceleration, or the jolt experienced by the rider when encountering obstacles/bumps of different heights. The smallest wheel e-scooter yielded a significantly high handlebar jolt and could not roll over the bump when the height was more than 48 mm. Similarly, the 12-inch wheel devices showed a sudden increase in vertical acceleration/jolt when the bump height was more than 48 mm. The results recommend a minimum wheel size of 14 inches, considering the unevenness of the terrain and the road defects that the rider regularly faces on the road. Moreover, suspension at the front could help dampen the handlebar jolt for small wheel devices.

4 CONCLUSIONS

In the experimental investigation, we analyzed the rideability and safety performance of a new class of small-wheel micro-mobility devices that are extremely compact and lightweight compared to traditional bicycles and E-bikes. The results showed that the e-brakes on the e-scooters may not provide effective braking. On the other hand, these small wheel devices have a large tendency to skid when braked at 20km/h and more. In addition, the motor power needs to be regulated for decent acceleration and safety. Finally, a wheel size of 14 inches or more is recommended for better rideability and safety.

REFERENCES

[1] R. L. Abduljabbar, S. Liyanage, and H. Dia, "The role of micro-mobility in shaping sustainable cities: A systematic literature review," *Transportation Research Part D: Transport and Environment,* vol. 92, p. 102734, 2021/03/01/ 2021, doi: https://doi.org/10.1016/j.trd.2021.102734.

[2] Z. Ling, C. R. Cherry, J. H. MacArthur, and J. X. Weinert, "Differences of Cycling Experiences and Perceptions between E-Bike and Bicycle Users in the United States," *Sustainability*, vol. 9, no. 9, doi: 10.3390/su9091662.

[3] H. Kleinertz, D. Ntalos, F. Hennes, J. V. Nüchtern, K. H. Frosch, and D. M. Thiesen, "Accident Mechanisms and Injury Patterns in E-Scooter Users–A Retrospective Analysis and Comparison With Cyclists," (in eng), *Dtsch Arztebl Int,* vol. 118, no. 8, pp. 117-121, Feb 26 2021, doi: 10.3238/arztebl.m2021.0019.

[4] S. Papoutsi, L. Martinolli, C. T. Braun, and A. K. Exadaktylos, "E-bike injuries: experience from an urban emergency department-a retrospective study from Switzerland," (in eng), *Emerg Med Int,* vol. 2014, p. 850236, 2014, doi: 10.1155/2014/850236.

[5] J. Parkin and J. Rotheram, "Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal," *Transport Policy,* vol. 17, no. 5, pp. 335-341, 2010/09/01/ 2010, doi: https://doi.org/10.1016/j.tranpol.2010.03.001.

[6] R. S. Sharp, "On the Stability and Control of the Bicycle," *Applied Mechanics Reviews,* vol. 61, no. 6, 2008, doi: 10.1115/1.2983014.

[7] P. Milan, "An investigation into the design for rideability of small wheel single-track bicycles and e-scooters," Nanyang Technological University, 2019.

How do professional and non-professional drivers interact with cyclists at unsignalized intersections? Results from naturalistic data

Ali Mohammadi, Marco Dozza

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
Chalmersplatsen 4, 41296, Gothenburg, Sweden
email: ali.mohammadi@chalmers.se
email: marco.dozza@chalmers.se

Keywords: cyclists' interaction, vulnerable road users, computational models, automated vehicles.

1 INTRODUCTION

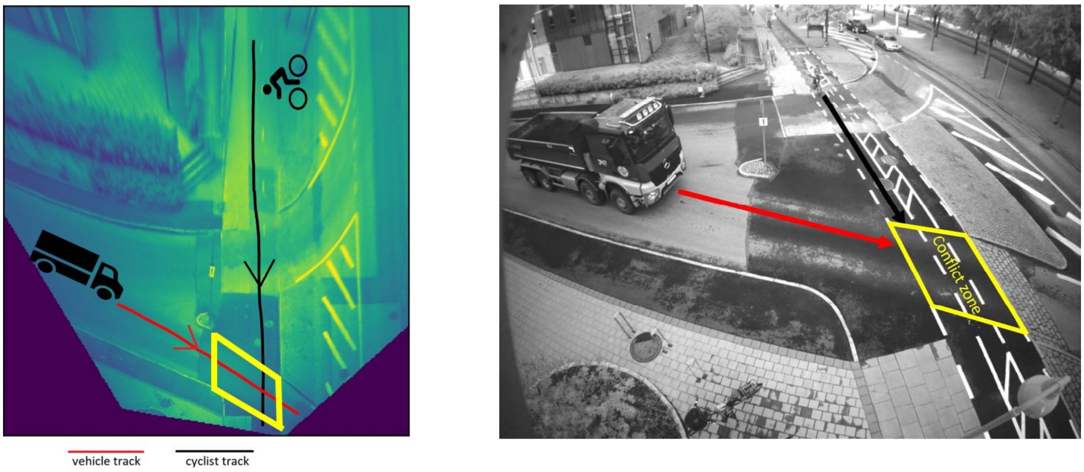
As cycling grows in popularity among European countries, it is increasingly important to understand cyclists' behavior in urban areas. This knowledge will help to develop accurate behavioral models to be used in active safety systems and automated vehicles (AVs). In fact, even as overall traffic fatalities are decreasing, the share of cyclists' fatalities is steady or increasing. Over 70% of cyclists' crashes with motorized vehicles happen at intersections, and in most cases the intersections are unsignalized and the two road users share the path [1]. By law, in Sweden motorized vehicles must give priority to cyclists and allow them to cross first at unsignalized intersections; however, in 42% of car-cyclist interactions the vehicles did not yield [1].

Few studies have quantitatively investigated the interactions between cyclists and motorized vehicles at unsignalized intersections. Of these, Silvano et al. developed a logistic model to predict the cyclists' yielding decision at an unsignalized roundabout [2]. In another study, Velasco et al. showed videos of oncoming vehicles to participants (as cyclists) wearing virtual reality headsets and asked the participants whether they would yield to the vehicle or not [3]. The authors found that two factors, the distance between the car and the bicycle and who has the right of way, most affected their decision to yield. So far, the interaction between cyclists and motorized vehicles has only been investigated for passenger cars, not trucks or taxis (which are driven by professional drivers). Previous literature has found that truck drivers demonstrate riskier behavior compared to passenger cars' drivers in urban areas, especially in interactions with cyclists [4].

In our previous study, we investigated some factors affecting cyclists' yielding decision during interactions with passenger cars. In this work, we compared how passenger cars, taxis, and heavy vehicles interact with cyclists.

2 METHODOLOGY

The data for this study were obtained at an unsignalized intersection in Gothenburg, Sweden (GPS coordinates: 57°42'31.1"N, 11°56'22.9"E). Stereovision and an AI-based sensor from Viscando [5] mounted at the corner of the intersection recorded video of the trajectories of all road users for 14 days in June 2019. Interaction events between bicycles and motorized vehicles were extracted from six days of data (from 6:00 to 18:00). An interaction event is defined as two road users sharing the road, who may try to communicate and determine each other's intent as they each attempt to follow a comfortable, safe path [6]. This definition was used to confirm the interaction events in the trajectory dataset using the videos. Figure 1.a shows an example of the vehicle and bicycle trajectories. We extracted the interaction information for all events comprising one bicycle and one motorized vehicle (with no other road users present). The bicycles' kinematic information was acquired from the trajectory dataset and enriched by adding visual information about the cyclist after watching the video. The visual information included pedaling, hand gesture, and head turn. From the trajectory dataset, we extracted possible interaction events with a DTA (difference in time to arrival at the intersection) of less than seven seconds, and then confirmed them by watching the corresponding videos. The DTA shows which road user arrives sooner at the intersection and by how much. Vehicles were categorized as passenger cars, taxis, or heavy vehicles. For each interaction event, the post-encroachment time (PET) and projected PET were calculated as surrogate measures of the safety of the interactions. Thus, the information for each interaction event consists of bicycle and vehicle kinematics, visual information, and safety indicators. The variables in the model were calculated before the decision point, the point at which cyclists decided whether to cross the intersection first (8m before the intersection points of trajectories).



(a) (b)

Figure 1- Studied intersection: a) layout of the intersection, b) intersection view from the mounted VISCANDO sensor. The yellow box represents the conflict zone

3 RESULTS

In total, 153 interaction events between bicycles and motorized vehicles were selected: 113 with passenger cars, 16 with heavy vehicles, and 24 with taxis. In 60% of cases, cyclists crossed the intersection first; 36% of cyclists were women. Descriptive statistics of the numeric variables are shown in Table 1.

Table 1- Descriptive statistics of numeric variables

Numeric variables	**Bike initial speed (m/s)**	**Vehicle initial speed (m/s)**	**DTA (s)**	**PET (s)**	**Projected PET (s)**
Mean	3.98	3.38	1.83	2.6	4.06
STD	1.06	1.25	2.22	1.04	2.47
Min	0.42	0.26	-2.92	0.89	0.68
Max	7.58	8.52	8.83	6.8	12.5

Interaction events were compared based on vehicle type; the results are depicted in Figure 2. The mean PET value is 2.6 s, 3.47 s, and 2.57 s for passenger cars, heavy vehicles, and taxis, respectively.

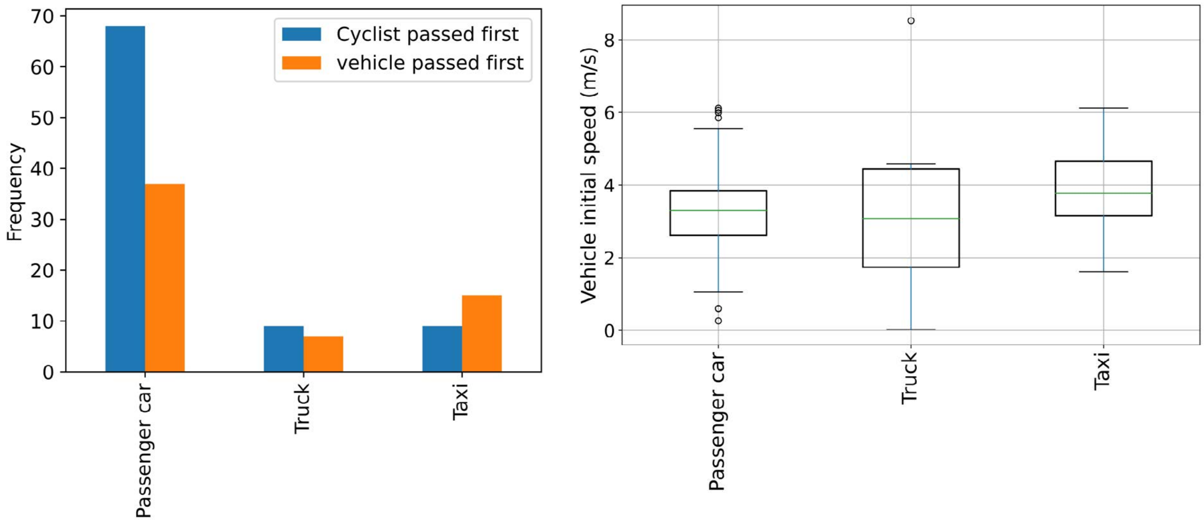


Figure 2- Summary statistics of yielding cases (a), and initial speed (when the two interacting road users see each other) for each vehicle type (b)

4 DISCUSSION

Based on the preliminary analysis of the interaction events, cyclists yielded more often to heavy vehicles and taxis than to passenger cars. This can be attributed to the riskier behavior of professional drivers. Taxi drivers had higher approaching speeds and lower PET values than the other groups. Full results will be presented at the conference and included in our paper. Our models will include: 1) the cyclist's yielding decision based on the significant variables and 2) a comparison of different modeling approaches for predicting the cyclist's decision to yield.

REFERENCES

[1] I. Isaksson-Hellman and J. Werneke, "Detailed description of bicycle and passenger car collisions based on insurance claims," *Saf. Sci.*, vol. 92, pp. 330–337, 2017, doi: 10.1016/j.ssci.2016.02.008.

[2] A. P. Silvano, H. N. Koutsopoulos, and X. Ma, "Analysis of vehicle-bicycle interactions at unsignalized crossings: A probabilistic approach and application," *Accid. Anal. Prev.*, vol. 97, pp. 38–48, 2016, doi: 10.1016/j.aap.2016.08.016.

[3] J. P. N. Velasco, A. de Vries, H. Farah, B. van Arem, and M. P. Hagenzieker, "Cyclists' crossing intentions when interacting with automated vehicles: A virtual reality study," *Inf.*, vol. 12, no. 1, pp. 1–15, 2021, doi: 10.3390/info12010007.

[4] C. Llorca, A. Angel-Domenech, F. Agustin-Gomez, and A. Garcia, "Motor vehicles overtaking cyclists on two-lane rural roads: Analysis on speed and lateral clearance," *Saf. Sci.*, vol. 92, pp. 302–310, 2015, doi: 10.1016/j.ssci.2015.11.005.

[5] "VISCANDO," [Online]. Available: https://viscando.com/.

[6] P. Thalya, J. Kovaceva, A. Knauss, N. Lubbe, and M. Dozza, "Modeling driver behavior in interactions with other road users," *Proc. 8th Transp. Res. Arena TRA 2020, April 27-30, 2020, Helsinki, Finl.*, pp. 1–16, 2020.

In-depth analysis of scenarios and injuries in crashes between cyclists and commercial vehicles in Germany

R. Schindler[*], H. Jeppsson[#]

[*] Autoliv Research,
Wallentinsvägen 22, 447 83 Vårgårda, Sweden
email: ron.schindler@autoliv.com

[#] Autoliv Research,
Wallentinsvägen 22, 447 83 Vårgårda, Sweden
email: hanna.jeppsson@autoliv.com

Keywords: bicycle, bus, heavy goods vehicle, GIDAS.

1 INTRODUCTION

There are many benefits of choosing cycling as a mode of transport. It is good for the environment and the health gains when being physically active are many. Cycling for everyone is promoted through the global agenda by the UN's Sustainable Development Goals and is mentioned in several different targets, for example goal 1, 3 and 11 [1]. However, travelling as a cyclist on the roads is not without danger. Every year, 1.35 million people die related to road traffic, and cyclist fatalities and injuries are frequent [2]. Around 41,000 road traffic fatalities are cyclists [2]. In Europe, there were 2,035 cyclist fatalities in 2019, accounting for 9% of all road fatalities [3]. Cyclists are the only mode of transport where no decline in fatalities can be seen over the last 10 years [3].

Amongst potential crash opponents, commercial vehicles seem to pose a significant threat to cyclists. Buses have been involved in 1.8% of crashes in Germany in 2021, with 0.8% of these being fatal [5]. While buses are one of the safest means of road transport today, at least for the occupants inside the bus that are well protected, it can do a lot of harm to the people outside of the bus, especially pedestrians and cyclists. An Australian study [4] shows that the most common bus-bicycle crashes occur at intersections. Of the non-intersection crashes, crashes involving lateral movement are most common and have also the highest probability of fatalities. Another Australian study [6] interviewed bike riders and bus drivers, with the result showing that only 10% of the bike riders felt comfortable when interacting with buses, and only 8% of the bus drivers felt comfortable interacting with bicycles.

Similarly, heavy goods vehicles (HGVs) are perceived as dangerous as well. While the latest numbers from Germany [5] show that on a national level, around 1% of all crashes are fatal, this percentage increases to 3.4% when an HGV is involved. Furthermore, although HGVs are involved in 2.2% of crashes in Germany, their share in fatal crashes increases to almost 8%. This overrepresentation in fatal crashes has been also identified in previous studies [7-10]. In particular, conflicts at intersections were identified as the most common conflict scenario when cyclists are involved, similarly to what has been identified for buses, especially where the HGV turns right and the cyclist wants to continue going straight [8, 10-12].

2 AIM

As conflicts between cyclists and commercial vehicles pose a serious threat especially to the cyclists, it is important to understand current safety issues related to these vehicles, to facilitate identifying and developing safety interventions that could address them. The aim of this study is to describe the characteristics of and injuries resulting from crashes between cyclists and commercial vehicles (in particular buses and HGVs) recorded in the German In-Depth Accident Study (GIDAS).

3 METHOD AND DATA SOURCE

The data used in this study is based on the latest version of the German In-Depth Accident Study (GIDAS) from January 2023. The database was queried for all fully reconstructed cases that involved either a heavy goods vehicle (HGV) with a gross weight above 3.5 t or a bus. Afterwards, these crashes were filtered for those that involved a cyclist. The resulting dataset was the basis for the following analysis and descriptive statistics provided in the next section.

4 RESULTS

In total, 98 crashes where both a bus and a cyclist were involved, were found. In these crashes, 101 cyclists sustained 309 injuries. For cases where both a HGV and a cyclist were involved, 295 crashes were found with 303 cyclists sustaining 1,397 injuries. For simplicity, only buses and HGVs will be referenced throughout the rest of the paper, but these are still all crashes that involve a cyclist as well.

The crashes with cyclists typically occur within city limits (98% bus, 96% HGV) during daylight conditions (87% bus, 89% HGV) on dry surfaces (90% bus, 86% HGV) and with clear weather (96% bus, 93% HGV). The most common HGV types are articulated HGVs, HGVs with a special body and box trucks, each with a share of around 21%. The most common bus types are city buses (43%), followed by articulated buses (39%).

The cyclists involved in these crashes are mainly male (62% bus, 57% HGV). While people under 18 account for 28% of crashes with buses, their share is only 16% in crashes with HGVs. On the other hand, these percentages are flipped for people above the age of 60 (26% of cases with HGVs, 17% of cases with buses).

The most common crash scenarios for buses are crossing scenarios, followed by turning off a road crashes. For HGVs, these are also the most common crash scenarios, although their order is inversed. Notably, crashes where the bus and cyclist are moving along in the same carriageway have quite a high share, which is not the case for HGVs. When looking at the drivers' actions during the collision sequence, it was coded that there was no action of the driver most of the time. The second most common action for both vehicles is braking, while this is closely followed by accelerating for HGVs.

These different crash patterns and driver actions also result in different speed distributions for both vehicle types. While around 30% of HGV related crashes have an initial speed of 0 km/h (i.e., start from stand still, for example after stopping at a red traffic light), these account only for around 15% of cases for buses. This also results in generally higher initial speeds for buses compared to HGVs. These higher initial speeds for buses then also result in higher collision speeds, compared to HGVs. While the 80% mark for buses is around 35 km/h, it is only slightly above 20 km/h for HGVs.

For buses, in 45% of crashes the cyclist impacted the right vehicle side and in 34% the vehicle front. For HGVs, both categories account for 40% of cases. Along the x-axis of the bus, 80% of impacts are within the first 7 m of the bus, while for HGVs they are within the first 4.5 m.

In bus related crashes, the MAIS3+ injured cyclists account for around 7% of cases, while this share is 15% for HGV related crashes. These AIS3+ injuries are predominantly to the head and lower extremities in bus related crashes, and head and thorax for HGV related crashes. In bus related crashes, these injuries are mostly caused by the road surface and front of the bus (in particular the windscreen and wheels), while run-overs play an important role in HGV related crashes.

5 DISCUSSION

The results show that most of the crashes happen in urban settings, which was to be expected as cyclists are most commonly travelling in urban areas. As a result, most of the buses are city buses, as these most commonly share the same environment. However, it was quite surprising to see such a high number of articulated HGVs as crash opponents, as these are typically heavy long-haul vehicles that should probably not be present in more urban settings. As these vehicles have particularly large blind spots, it can create dangerous conflict situations especially at intersections.

Even though collision speeds in HGV-related crashes are on average only half those of bus-related crashes, the share of severe injuries is two times higher for HGVs. This suggests that injury mechanisms in HGV-related crashes are less speed related, but stem from other sources. Namely, run-over crashes have been identified as a major contributing factor, especially for thorax and lower extremity injuries. In bus-related cases, the road surface has been identified as the main injury causing part for the cyclists, especially for head, lower- and upper extremity injuries. This suggests that the initial impact with the bus is potentially not as severe as the secondary impact to the road surface – which, in addition to the higher collision speeds, then leads to severe injuries.

One notable result was also that the third most common action by the HGV drivers during the conflict was accelerating. While this seems counterintuitive at first, it is in line with the crash scenarios identified. Right turn maneuvers are the most common conflict type, and with the low initial speeds it seems to suggest that these conflicts are likely to happen after the HGV has stopped, with cyclists potentially entering the blind spot without the drivers noticing. The HGV drivers then accelerate and perform the turn maneuver, sometimes not even noticing the collision with the cyclist. Nonetheless, even at these low speeds, these crashes result in serious injuries for the cyclists.

6 CONCLUSIONS

Large vehicles such as buses and HGVs cause severe injuries to cyclists. In bus crashes, collision speeds are typically below 35 km/h and injuries to lower extremities and head dominate, where the injuries are caused by the road surface and front of the bus. In HGV crashes, collision speeds are typically below 20 km/h and injuries to the head and thorax are most common, mainly caused by being run-over. These results provide more detailed and actionable insights for manufacturers and agencies that can help to address safety concerns – to make cycling safer.

REFERENCES

[1] United Nations. (2015). The 2030 Agenda for Sustainable Development. Available at https://sdgs.un.org/goals
[2] World Health Organization. (2020). Cyclist safety: an information resource for decision-makers and practitioners.
[3] European Commission. (2021). Facts and Figures Cyclists. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport.
[4] Ker, I., Yapp, S., & Moore, P. (2005). Bus-Bike Interaction within the Road Network (No. Rept# NS1075).
[5] Destatis. (2022). Verkehrsunfälle 2021
[6] Baumann, C., Brennan, T., & Zeibots, M. E. (2012). Bike rider and bus driver interaction study
[7] Pokorny, P., Drescher, J., Pitera & K., Jonsson, T. (2017). Accidents between freight vehicles and bicycles, with a focus on urban areas. Transportation Research Procedia 25, 999–1007.
[8] T. Richter, J. Sachs. Turning accidents between cars and trucks and cyclists driving straight ahead. Transp. Res. Procedia, 25 (2017), pp. 1946-1954.
[9] Prati, G., Marín Puchades, V., De Angelis, M., Fraboni, F., & Pietrantoni, L. (2018). Factors contributing to bicycle–motorised vehicle collisions: a systematic literature review. Transport reviews, 38(2), 184-208.
[10] Schindler, R., Jänsch, M., Bálint, A., & Johannsen, H. (2022). Exploring European heavy goods vehicle crashes using a three-level analysis of crash data. International Journal of Environmental Research and Public Health, 19(2), 663.
[11] Kircher, K., & Ahlström, C. (2020). Truck drivers' interaction with cyclists in right-turn situations. Accident Analysis & Prevention, 142, 105515.
[12] Pokorny, P., & Pitera, K. (2019). Observations of truck-bicycle encounters: A case study of conflicts and behaviour in Trondheim, Norway.

Road safety-relevant factors in accidents between cyclists and truck drivers and the role of advanced driver assistance systems (ADAS)

K. Ausserer[#], J. Rieß[#], E. Tomasch[*], H. Hoschopf[*]

[#]Factum -apptec ventures GmbH
Mobility . Research . Innovation
Slamastraße 43, 1230 Vienna, Austria
email: jannik.riess@factum.at
karin.ausserer@factum.at

[*]Vehicle Safety Institute
Graz University of Technology
Inffeldgasse 23/1, 8010 Graz, Austria
email: ernst.tomasch@tugraz.at
heinz.hoschopf@tugraz.at

Keywords: Cycling accidents with trucks, Advanced driver assistance systems, Blind spot monitoring

1 INTRODUCTION

The collision of a truck and a cyclist is one of the most dangerous situations in road traffic. In Europe, up to 25% of all fatal cycling accidents are due to collisions between a truck driver and a cyclist. The risk of being killed as a cyclist in an accident with a truck is thirteen times higher compared to accidents with other road users [1]. In particular the blind spot of the truck in turning scenarios is of high risk [1], but truck drivers are also required to be extremely attentive in other situations. Assistance systems, e.g. turning assistants, can help to improve road safety. However, their effectiveness and acceptance have not yet been studied in detail.

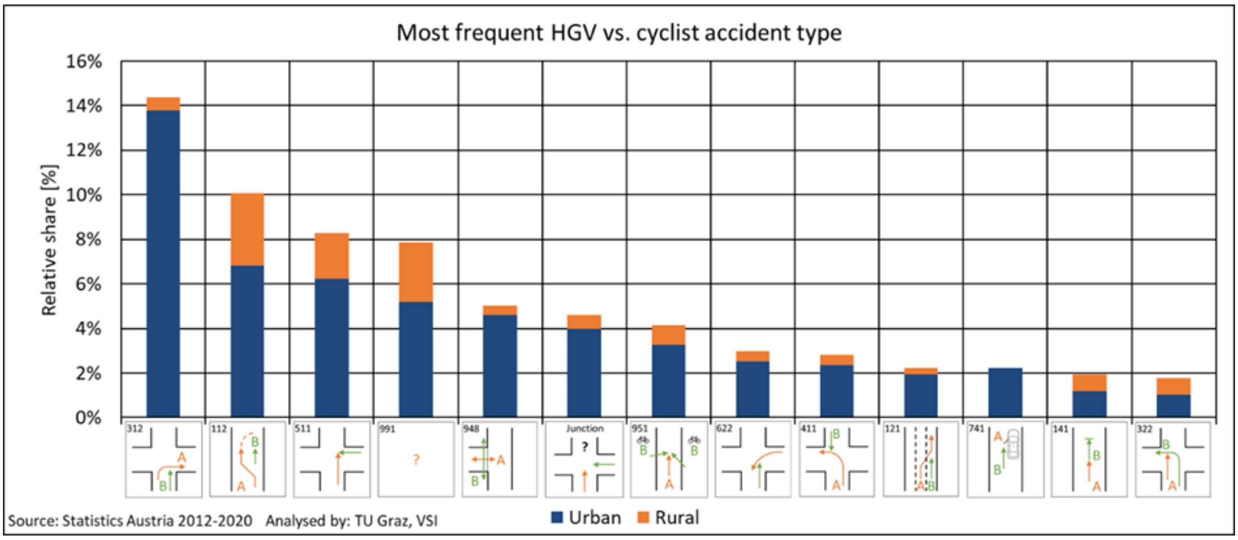
Different methods are used in the project to investigate the research topic. Traffic accidents from the national statistics of Austria were analysed. Accidents from the database CEDATU (Central Database for In-depth Accident Study) were fully reconstructed and reaction behavior of HGV (heavy goods vehicle) drivers and cyclists analysed. The behaviour, perception, and attitudes of truck drivers and cyclists were investigated in qualitative and quantitative surveys.

2 ACCIDENT ANALYSIS

The Austrian accident types are divided into ten main groups, comprising approximately 100 different accident types. The accident types in Figure 1 results in more than two thirds of the accidents between HGV and cyclists. Approximately 80% of bicycle accidents take place in the urban area. Accidents involving electric bicycles, however, are more frequent in the rural area.

The most frequent accident type between a truck and bicyclist takes place when the truck is turning, specifically to right, and the bicyclist is in the blind spot (Type 312). Another critical situation occurs when a truck overtakes with insufficient side distance and changing the lane too early (Type 112). Further high relevance are accidents at intersections and property exits (Type 511 and 948). This is particularly the case when there are sight obstructions from bushes, hedges, fences, etc. A rather high percentage of accidents was not associated with any particular type of accident by the police (Type 991) or could not associated to a specific junction accident type (Type Junction). There are also situations in which cyclists enter the lane of trucks and may not pay enough attention to the traffic (Type 951).

Females are more than twice as often in turning to right accidents compared to males although males are generally more likely to be involved in accidents. Females, however, are more likely to be fatally injured. There is a tendency towards higher injury severity for males on electric bicycles. The average injured cyclist of a conventional bicycle is 51.7 (SD=20.4) years old. The age of a e-bike cyclist, however, is 60.2 (SD=21.4). Females are at average 53.8 (SD=20.5) years old and males are 50.3 (SD=20.5).



Source: Statistics Austria 2012-2020 Analysed by: TU Graz, VSI

Figure 1: Most frequent heavy goods vehicle vs. cyclist accident types

CEDATU's in-depth analysis indicated that both truck drivers and bicyclists were equally at fault for or initiated the accidents. The most frequent accident-causing factor for trucks was identified as the blind spot. The second most causing factor was the lack of safety distance and/or insufficient reaction time response to the danger situation. Furthermore, insufficient attention or distraction is of high relevance, as well as the right of way violations. From the cyclist's perspective, a similar tendency was observed, although there is no blind spot for cyclists. The most frequent causation factors for cyclists were identified as lack of safety distance and/or insufficient reaction time response to the danger situation followed by insufficient attention or distraction and right of way violations. The most frequent environmental contributing factors was identified as sight obstructions and road course.

3 PERCEPTION – BEHAVIOUR - ACCEPTANCE

The views of cyclists and truck drivers were collected qualitatively through focus groups and individual interviews with in total 26 individuals. The aim of the qualitative survey was to identify road safety-relevant behaviour of cyclists and truck drivers, to identify challenges and attitudes regarding assistance systems and to prepare content for the quantitative survey.

In the quantitative online survey, cyclists and truck drivers were asked about their own behaviour in relation to truck/bike encounters, the acceptance of driver assistance systems, as well as other measures to increase road safety. A total of 251 cyclists and 110 truck drivers took part in the survey. Statistical data analysis was carried out to draw conclusions about the characteristics in each and between the two groups.

The results of the surveys showed that,

- Both truck drivers and cyclists are aware of the problem of blind spots, with truck drivers seeing it as a more serious problem and cyclists underestimating the actual range of blind spots.
- Cyclists consider the small lateral safety distance when overtaking as the biggest problem when meeting trucks, while truck drivers don't see it as a problem and stated that they take care to overtake cyclists with a large lateral safety distance.
- The poor or limited communication possibilities between cyclists and truck drivers are reported considerably more frequently by cyclists.
- There is in general a high acceptance of assistance systems amongst truck drivers. The acceptance of driver assistance systems, however, is higher among truck drivers who use assistance systems, while those who do not yet use them are more skeptical.

- Separate cycling infrastructure is seen by both groups as an effective measure to increase cyclists' road safety.
- Awareness campaigns for cooperation in road traffic are considered an important measure.
- Both cyclists and truck drivers assume that driver assistance systems have a potential to increase the road safety of cyclists, but that an overall concept is needed that combines infrastructural and awareness-raising measures with technical solutions.
- Cyclists do not consider assistance systems for bikes as appropriate measure to improve the traffic safety of cyclists.

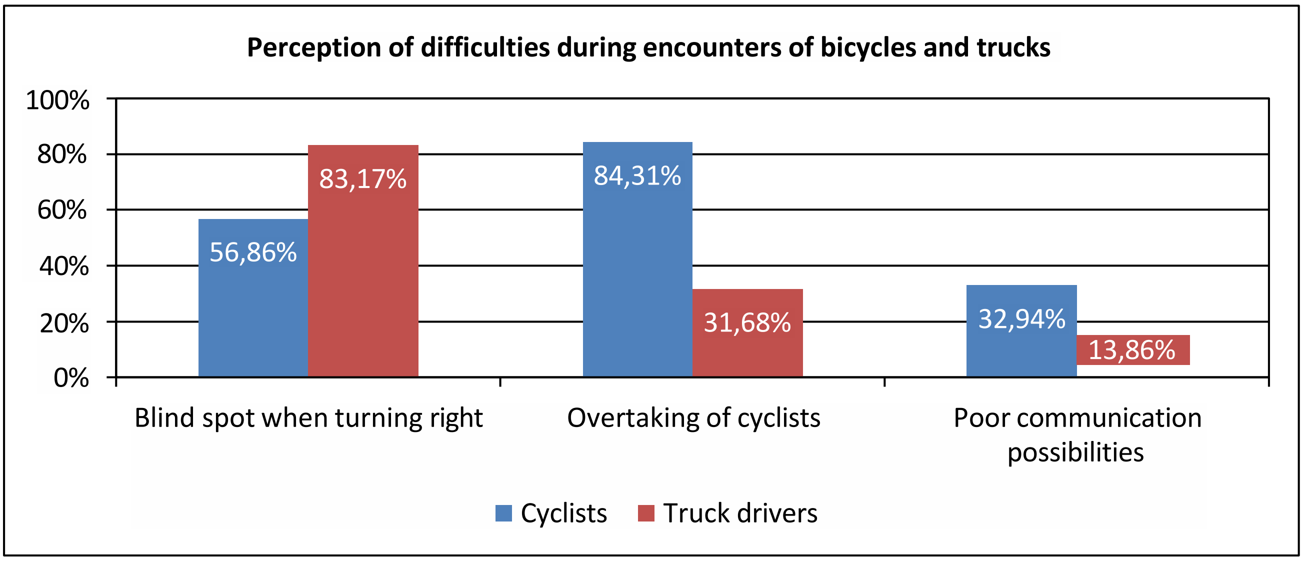


Figure 2: Perception of difficulties cyclists versus truck drivers

4 CONCLUSIONS

The relevance of driver assistance systems is confirmed by this study. Both the accident analysis and the qualitative survey show the potential of such systems to prevent accidents, mainly in two cases:

1. The blind spot when the truck is turning right: Both the accident data and the survey data show the relevance of this case. It is the most common and most fatal type of accident between trucks and bicycles and truck drivers also rate it as the most serious problem.
2. Overtaking manoeuvres: The accident data suggests that truck overtaking cyclists with insufficient space correlates with accidents. This coincides with the experience of cyclists who rate it as the most serious problem.

Both groups show acceptance for driver assistance systems for trucks. However, cyclists are not open for using assistance systems on their bicycles. Other measures that are supported by both cyclists and truck drivers are a separated cycling infrastructure and awareness campaigns for more consideration in traffic.

5 ACKNOWLEDGEMENT

This study was funded by the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) by grants of the Austrian Road Safety Fund (VSF).

6 REFERENCES

[1] Adminaite, D., Allsop, R., Jost, G., 2015. Making Walking and Cycling on Europe's Roads Safer – Pin Flash Report 29, European Transport Safety Council, 2015

Design of Urban Junctions in Relation to Cycling Safety

T. S. Buch*1, W. Hansen*2, M. G. L. Jensen#3, M. W. J. Sørensen#4

*Danish Road Directorate
Carsten Niebuhrs Gade 43, 1577 Copenhagen V, DK
[1]email: tsbu@vd.dk
[2]email: win@vd.dk

#Sweco Danmark A/S
Willemoesgade 13, 8200 Aarhus N, Denmark
[3]email: mortenlind.jensen@sweco.dk
[4]email: michaelwohlkjager.sorensen@sweco.dk

Keywords: bicycle accidents, signal-controlled junction, roundabout, urban area.

1 INTRODUCTION

In urban areas, most accidents between bicycles and motorised traffic happen in junctions. Three recent studies from Denmark [1] have provided new and clarifying knowledge.

Especially right-turn accidents are a great concern when it comes to signal-controlled junctions (countries where traffic keeps to the right). In Denmark, a truncated cycle track (see Figure 1) is a measure. The safety performance of this measure has to some extent been investigated in Denmark but barely not in other countries. Previous studies have not clarified the safety effect, so the first study compares a truncated cycle track with three other typical designs.

Roundabouts benefits the overall traffic safety, especially in rural areas, but there are some safety concerns in relation to cyclists' safety in urban areas. A lot of studies have studied the safety of roundabouts and some of the most important in relation to cyclists' safety are the work by Daniels et al. [2], [3], [4] and Jensen [5], [6]. When it comes to design of roundabouts the previous work shows some differences according to cyclists' safety, but the type of bicycle facility seems important. A weakness is often the lack of good bicycle counts.

In the second study the frequency rates of bicycle accidents in relation to different roundabout design has been calculated. Previous studies show that roundabouts worsen cyclists' safety compared to other types of junctions but while some studies show large negative effects other studies only show minor effects. The third study compares the number of bicycle accidents when converting junctions to roundabouts and vice versa.

2 METHODS

The following only presents the results in relation to accidents with cyclists and small mopeds (maximum speed 30 km/h). Small mopeds are included because they must ride on bicycle facilities or roads like a bicycle.

2.1 Bicycle facility in signal-controlled junctions

A before and after accident evaluation of 159 converted approaches at a total of 113 signal-controlled junctions (see Figure 1). The evaluation is based on police reported right-turn, left-turn and merging accidents resulting in rear-end or side-on collisions. 112 accidents before and 78 accidents after has been observed. Corrections have been made for general accident development and local changes to traffic over time, but also possible regression to the mean. Homogeneity and significance tests have been performed.

2.2 Design of roundabouts

A categorised accident analysis regarding the connection between police reported accidents, roundabout design and car and bicycle traffic in terms of accident frequency rates. Roundabout design considered is e.g. type of roundabout and type of bicycle facility. The analysis is based on 459 urban 1-lane roundabouts and 92 urban mini roundabouts and altogether 1,062 accidents. The amount of bicycle traffic is based on counts in one third of the approaches, assessed volumes by the municipalities based on local knowledge in one third and assessed volumes by the research team in the last third.

2.3 Junction or roundabout

A before and after accident evaluation of 149 urban junctions which have been converted to or from a roundabout. 81 accidents before and 150 accidents after has been observed. Corrections have been made for general accident development, and possible regression to the mean. Homogeneity and significance tests have also been performed. Roundabouts are divided into mini and 1-lane roundabouts with or without bicycle facility in the roundabout and 1-lane roundabouts with setback cycle path outside the roundabout. Junctions are divided into signal-controlled junctions and priority junctions.

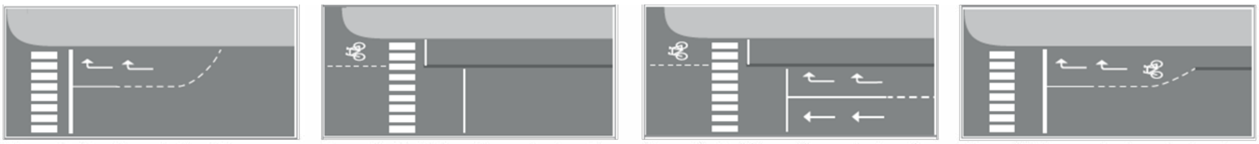
3 RESULTS

3.1 Bicycle facility in signal-controlled junctions

The study of signal-controlled junctions clearly underlines that truncated cycle tracks (Type 4) are the safest design for cyclists of the examined bicycle facility designs (see Table 1). On the other hand, full-length cycle tracks (or lanes) without separate right-turn lane (Type 2) are least safe.

Table 1: Effects of conversion between the four types of approaches in Figure 1.

Type, before	Type, after	No. of junctions	Acc. after, expected	Acc. after, observed	Effect	Homogenic?	Significant?
Type 1	Type 2	25	7.3	17	+131%	Yes	90%-level
Type 4	Type 2	11	2.3	8	+255%	Yes	90%-level
Type 1	Type 3	6	2.5	2	-20%	Yes	No
Type 2	Type 3	32	25.7	11	-57%	No	Yes
Type 4	Type 3	30	7.4	25	+237%	Yes	Yes
Type 1	Type 4	17	4.2	2	-52%	Yes	No
Type 2	Type 4	30	30.5	11	-64%	Yes	Yes
Type 3	Type 4	8	5.9	2	-66%	Yes	No



Type 1: No bicycle facility

Type 2: Full-length cycle track no separate right-turn lane

Type 3: Full-length cycle track separate right-turn lane

Type 4: Truncated cycle track

Figure 1: 4 different types of design in the evaluation of signal-controlled junctions.

3.2 Design of roundabouts

The accident frequency rates depending on type of bicycle facility for mini roundabouts and 1-lane roundabouts are presented in Table 2. It is obvious that the safest roundabout for cyclists is the 1-lane roundabout with setback cycle path where the duty to give way is imposed on the cyclists. The least safe design for cyclists is a coloured bicycle facility but at some roundabouts the coloured markings may have been applied to solve a safety problem already there. The analysis also showed that the number of bicycle and moped accidents per cyclist depends on the car traffic volume in the roundabout. The more vehicular traffic the higher rate. This may explain some of the variations in Table 2, because the choice of both type of roundabout and type of bicycle facility may depend on car traffic volume.

Table 2: Accidents per million cyclists by bicycle facility in mini roundabouts (mini) and 1-lane roundabouts (1-lane).

Type of bicycle facility	No. of sites/acc. (mini)	Rate (mini)	No. of sites/acc. (1-lane)	Rate (1-lane)
None	40/45	0.74	37/29	0.86
Cycle lane, all	45/70	1.84	232/513	2.07
Lane, coloured marking	21/51	2.07	53/148	2.20
Lane, no coloured making	24/19	1.42	179/365	2.02
Cycle track, all	5/8	1.73	130/377	1.60
Track, coloured marking	2/8	3.18	54/256	1.83
Track, no coloured making	3/0	0.00	76/121	1.26
Setback cycle path	2/1	1.74	53/19	0.45
Total	92/124	1.20	459/938	1.65

3.3 Junction or roundabout

Based on these studies it seems that the safest urban junction design for cyclists is a signalised junction rather than a roundabout (see Table 3). Probably due to the great importance of the chosen design in both junction and roundabout (e.g. type of bicycle facility), the two significant results are not homogenic.

Table 3: Effects of conversion of junctions to roundabouts and vice versa. Most rare combinations excluded.

Type, before	Type, After	No. of sites	Acc. after, expected	Acc. after, observed	Effect	Homo-genic?	Signifi-cant?
Priority	Mini, no lane/track	19	3.7	5	+35%	Yes	No
Priority	Mini, lane/track	17	3.4	8	+127%	Yes	No
Priority	1-lane, lane/track	59	20.3	54	+166%	No	Yes
Priority	1-lane, setback path	18	4.8	3	-38%	Yes	No
Signal-controlled	1-lane, lane/track	18	10.9	47	+330%	No	Yes
1-lane, lane/track	Signal-controlled	7	5.9	2	-66%	Yes	No

REFERENCES

[1] Danish Road Directorate, *Safety for Cyclists in Signalised Intersections with Truncated and Full-length Bicycle Paths and in Urban Roundabouts*, Report nr. 617, Danish Road Directorate, 2023.

[2] S. Daniels, E. Nuyts and G. Wets, “The effects of roundabouts on traffic safety for bicyclists: An observational study”, *Accident Analysis & Prevention* 40 (2008), pp. 518-526.

[3] S. Daniels, T. Brijs, E. Nuyts and G. Wets, “Injury crashes with bicyclists at roundabouts: influence of some location characteristics and the design of cycle facilities”, *Journal of Safety Research* 40 (2009), pp. 141-148.

[4] S. Daniels, T. Brijs, E. Nuyts and G. Wets, “Explaining variation in safety performance of roundabouts”, *Accident Analysis & Prevention* 42 (2010), pp. 393-402.

[5] S. Jensen, *Cyklisters sikkerhed i rundkørsler*, Trafitec, 2013.

[6] S. Jensen, *Cyklisters sikkerhed i rundkørsler*, Trafitec, 2013.

Study on Quantitative Expression of Cycling Workload

Jiangbi Hu[*], Shangwen Qu[#], Ronghua Wang[†]

[*]Faculty of Architecture, Civil and Transportation Engineering
Beijing University of Technology
Pingleyuan 100, Chaoyang district, 100124, Beijing, China
email: hujiangbi@bjut.edu.cn

[#]Faculty of Architecture, Civil and Transportation Engineering
Beijing University of Technology
Pingleyuan 100, Chaoyang district, 100124, Beijing, China
email: qu_shangwen@emails.bjut.edu.cn

[†]Faculty of Architecture, Civil and Transportation Engineering
Beijing University of Technology
Pingleyuan 100, Chaoyang district, 100124, Beijing, China

email: wangrh@bjut.edu.cn

Keywords: bikeway, heart rate variability, classifification and regression tree, bikeway characteristics, human factor

1 INTRODUCTION

Improper design of the geometric elements and facilities of bikeway systems could endanger cyclists' safety and comfort, resulting in an increased risk of bicycle accidents; such accidents sometimes have severe consequences, namely casualties. As it is stated in the literature that if the bikeway infrastructure is not properly designed,the bikeway itself will be a cause of accident, even there is no automobile approaching[1].

The method of expression for cyclists' safety and comfort and the question of how the correlation of these factors with bikeway characteristics—such as the design of geometry and facilities—can be quantitatively described are the key problems facing for a reduction in accident risk. However, there has been little quantitative expression research on this cyclists' safe and comfortable feeling, and the qualitative methods like expert evaluation method and survey questionnaire are the mainly used ones[2]. Cycling workload can be employed to assess cyclists' safety and comfort. But there is even no clear definition of cycling workload. Hence, we did this research to address the quantitative expression method of cycling workload, in order to develop guidance for the safe design and operational management of bikeways, which is also essential for controlling conditions that might induce overworking and discomfort among users.

2 CYCLISTS COMFORT AND SAFETY FORMATION MECHANISM

In this paper, the concept of cycling workload is defined based on cyclists' comfort and safety formation mechanisms:

Bicycle operation involves a process of the interaction among a human, a bicycle, and a road environment—a human–bicycle–road environment system—in which the human is the dominant factor. External information from the road environment is the input to the human's brain through their sense organs, such as their eyes, ears, etc. Then, the information is further processed by the central nervous system. Once analyses and judgments are made, the corresponding loco-motor organs (hands and feet) receive instructions and take actions to brake, accelerate, turn, or yield to other road users. Along with any behavior change, a change in cyclists' psycho-physiological status also occurs, which can be reflected in the physiological signal(as shown in Figure 1). The mental workload and physical workload shown in Figure 1 comprise cyclists' workload in dynamic cycling tasks on traditional bikeways in everyday life. Cycling workload therefore can be interpreted as the demands of cycling tasks or the mental and physical stress experienced by cyclists under the road, traffic volume, and environmental conditions when they cycle on a bikeway.

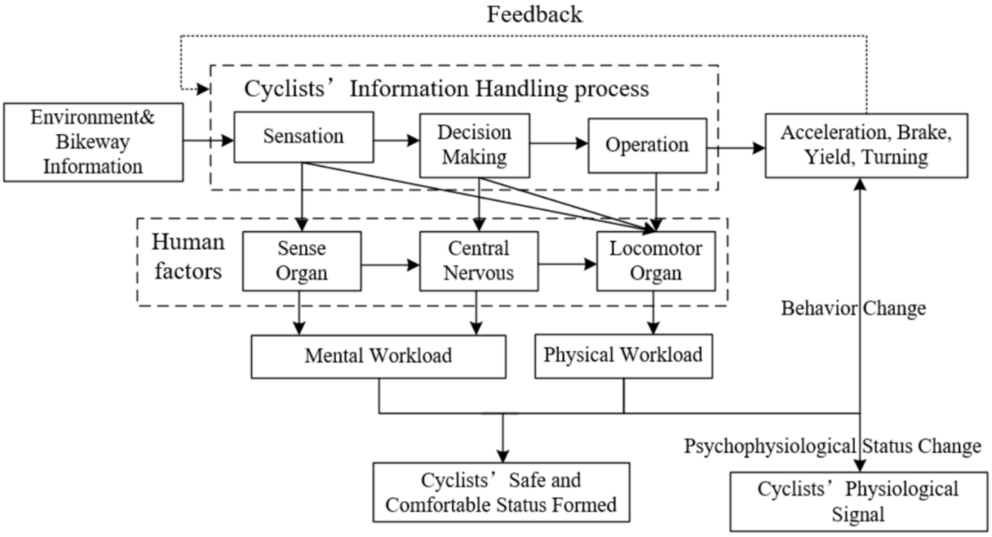


Figure 1: Cycling safety and comfort formation during cycling task

In order to determine a safe and comfortable cycling workload level for cyclists, it is important to choose suitable measurement techniques to measure cyclists' safe and comfortable cycling experiences; these measurement techniques must be sensitive to both the mental and physical workload while aiming to measure the total workload.

3 QUANTITATIVE MEASURE FOR CYCLING WORKLOAD

Through a literature review and a comparative analysis, it is inferred that heart rate variability (HRV) can be used as a quantitative measure and the low-frequency–high-frequency ratio (LF/HF) can be used as a physiological signal to quantify cycling workload.

In addition, given the principle of practical and easy operation, by combining cognitive psychology, information processing, and cycling risks, this study classified cycling status into a three level system with a subjective scale, as shown in Table 1.

Table 1: Subjective scale for the cycling workload level.

Cycling Workload Level	Subjective Scale Description	Cycling Performance
Safe, comfort	In the best condition; feeling energetic, awake, calm, free to ride, and quick to react	Plenty of riding space, the bicycle is safe and easy to handle, and it is easy to stay riding at a certain width
Safe, a little stressful	Sober; can respond; a little more alert; able to deal with emergencies	Riding space is small and the handlebars of the bicycle wobble more but are still controllable
Stressful	Cannot fully adapt to the road conditions; riding control is hectic, nervous, worried	Lack of riding space; large swing of the bicycle; difficult to control handlebars; need to use brake or stop

In order to form various cycling workload states and to obtain the relationship between LF/HF data and various bikeway characteristics, we designed a field cycling experiment to test our hypothesis that, combined with subjective scales for workload level, the LF/HF physiological signal could quantitatively express cycling workload.

4 CYCLING EXPERIMENT DESIGN AND RESULT

4.1 Experiment design

In order to consider how the context of road and environment impact workload condition of cyclists, we designed a field experiment conducted by 24 participants who wore a physiological measuring apparatus under three different bikeway characteristic scenario types including variations in cycling width, direction, and bikeway edges at four cycling speeds in the 10–25 km/h range, the relevant scenarios are as shown in Figure 2~Figure4.

Figure 2: Cycling workload scenarios¬different widths

Figure 3: Cycling workload scenarios¬different road edges

Figure 4: Cycling workload scenarios¬different route scenarios

4.2 Experiment results

Statistical analysis was used to address the collected *LF/HF* values and the subjective scale results, and a quantitative model for assessing cycling workload was established as shown in Equation(1).

$$\Delta HRV = \left(\frac{LF}{HF}\right)_{ij} - \left(\frac{LF}{HF}\right)_{i} \qquad (1)$$

where

$\triangle HRV$: The correction of HRV;

$(\frac{LF}{HF})_{ij}$: The LF to HF ratio of the i-th rider at time j; and

$(\frac{LF}{HF})_{i}$: The median of LF to HF ratio of the i-th cyclist in a calm condition.

By adopting a classification and regression tree (CART) algorithm as a data-mining method, the classification threshold values (*△HRV*) of three cycling workload levels were obtained: 19 indicated a level between comfortable and a little stressful; and 79 indicated a level between a little stressful and stressful.

5 CONCLUSIONS

A high cycling workload caused by an inappropriate design of the geometric elements and facilities of bikeways contributes to the rates and severities of bicycle accidents. Without a quantitative expression method and safe threshold values to determine cycling workload, it is hard to control the workload on cyclists effectively. Based on the concept proposed here for cycling workload, and as per the quantitative measure obtained by analysis, the cycling workload was categorized into three levels–comfortable, a little stressful, and stressful, and the threshold was figured out among the different levels. The research can contribute to the design of safe and comfortable bikeways and their operational management to reduce the risk of bicycle accidents and provide theoretical and practical support for determining the reasonable technical parameters for bikeway characteristics.

Due to the limited space, please refer to [3] for the detailed research content.

REFERENCES

[1] J. Ploeger, *Traffic Safety and Cycling: Some Lessons from History.*Paper presented at Cycling Research Board, Eindhoven, Netherlands, 2020.

[2] J. Calvey, J. Shackleton, M. Taylor, and R. Llewellyn, “Engineering condition assessment of cycling infrastructure: Cyclists’ perceptions of satisfaction and comfort”. *Transportation Research Part A: Policy and Practice* (2015), 78, 134-143.

[3] S. Qu, R. Wang, J. Hu and L. Yang, “Study on Quantitative Expression of Cycling Workload”, *Applied Sciences* (2022), 10209.

Overtaking in Stuttgart – Analysis of the lateral distances between motor vehicles and bicycle traffic with reference to traffic volume and cycling infrastructure

L. Casey[*], L. Gaspers[#], H. Mandel[†]

[*]Leo Casey M. Eng.
Hochschule für Technik Stuttgart
Schellingstraße 24, 70174 Stuttgart, Germany
email: leo.casey@hft-stuttgart.de

[#]Prof. Dr.-Ing. Lutz Gaspers
Hochschule für Technik Stuttgart
Schellingstraße 24, 70174 Stuttgart, Germany
email: lutz.gaspers@hft-stuttgart.de

[†]Prof. Dr.-Ing. Harald Mandel
Duale Hochschule Baden-Württemberg Stuttgart
Rotebühlstraße 133, 70197 Stuttgart, Germany
email: harald.mandel@dhbw-stuttgart.de

Keywords: overtaking, cycling infrastructure, bike lanes, traffic volume.

1 INTRODUCTION

In 2022, the German transport sector failed to meet its greenhouse gas reduction targets under the Federal Climate Change Act for the second year in a row. It is the only sector in Germany that was unable to reduce its emissions by 2019 compared to 1990 [1]. In this context, measures to promote a mobility transition are indispensable.

One component of a strategy to create a sustainable transport system can be the promotion of cycling. The bicycle is considered a climate-friendly and accessible means of transport. Nonetheless it is comparatively little used in Germany. Around 11 % of all journeys in Germany are made by bicycle. In Stuttgart, this figure is only 7 % [2]. This raises the question how cycling can be promoted. 37 % of all people perceive cycling as not at all or rather not safe. A low sense of safety is one of the most common reasons for people to not cycle. Improving cycling safety is therefore not only important to reduce accidents and injuries, but also to shape a sustainable transport sector [3,4,5].

The most stressful situation for cyclists is to be overtaken by motor vehicles [6]. German road traffic regulations prescribe a minimum lateral distance of 1.50 m for motor vehicles while overtaking cyclists in built-up areas. Research to date has shown that this value is often not adhered to. Various studies have found that between 43 % and 75 % of overtaking manoeuvres between motor vehicles and cyclists are carried out too closely [7,8]. The aim of this study is to investigate which factors affect the lateral distance between overtaking motor vehicles and overtaken cyclists. Focus is set on the type of cycling infrastructure and on traffic volume. Recommendations for action can be derived from the findings, through which safety of cyclists can be improved.

2 METHODOLOGY

In order to investigate the research question, scientific measurements were carried out within the city of Stuttgart, Germany. 13 inner-city measurement routes were systematically selected. On all selected routes, cycling is either carried out in mixed traffic or on cycle lanes. In mixed traffic cyclists and motor vehicles share the same lane. Cycle lanes are special lanes for cyclists on the roadway, that are marked by solid or broken white lines. Measurements were carried out by one single subject on a Pedelec. The lateral distances of overtaking processes were recorded by an ultra-sound sensor. The sensor used was the OpenBikeSensor, developed by the Stuttgart-based association of the same name. Measurements on each route were carried out over three set time periods (07:00 a.m. to 10:00 a.m., 12:00 a.m. to 02:00 p.m., 03:00 p.m. to 06:00 p.m.).

The times are based on German guidelines for traffic counts [9]. During the measurement periods, each measurement route was travelled continuously and alternately in both directions. The total gross driving time for each route was eight hours. The subject used the same equipment on each trip. This was a yellow bicycle helmet, a yellow high-visibility waistcoat and street clothes.

3 FINDINGS

A total of 790 km were covered during the project and 4,081 overtaking manoeuvres were recorded. 42.2 % of the recorded overtaking manoeuvres were carried out with a lateral distance of less than 1.50 m. Within this group most overtaking manoeuvres show lateral distances between 1.00 m and 1.49 m. Overtaking manoeuvres with lateral distances lower than 1.00 m occur more rarely. The mean value of all overtaking manoeuvres is 1.59 m.

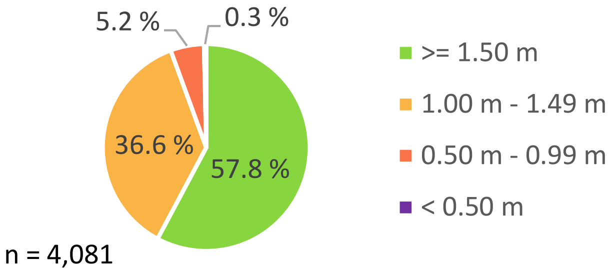


Figure 1: Lateral distances of all recorded overtaking manoeuvres

Based on the data collected, three hypotheses were tested. Hypothesis 1 states that lateral distances on routes with cycle lanes are lower than on routes with mixed traffic. This hypothesis was confirmed by the data collected. In mixed traffic 36.2 % of overtaking manoeuvres were below 1.50 m. On cycle lanes this figure is 44.1 %. The effect was proven by an analysis of variance ($F(1, 4079) = 26.856$, $p < 0.0001$). The effect size can be classified as medium ($\eta^2 = 0,06$). Therefore, the type of guidance is not expected to be the decisive influencing factor on the lateral distances of overtaking manoeuvres.

Hypothesis 2 states that low motor vehicle traffic volumes lead to high lateral distances. In Germany, when planning cycling infrastructure, roads are divided into one of four categories based on the maximum permitted speed and the motor vehicle traffic volume. Each category is assigned a possible selection of guidance forms for cycling. The motor vehicle traffic volume of a road is therefore to be considered a central element of planning [10]. However, hypothesis 2 could not be confirmed with the available data. A linear regression analysis with the motor vehicle traffic volume of each route as independent variable and the respective mean value of lateral distances proved no significant effect ($R^2 = 0.108$, $F(1,23) = 2.971$, $p = 0.108$).

Hypothesis 3 states that during peak traffic times, lower lateral distances occur than during off-peak times. This hypothesis could not be confirmed. An analysis of variance proved no difference between the mean values of lateral distances between the three measurement periods ($F(2, 3153) = 0.973$, $p = 0.378$). In total, the same average lateral distances are to be expected at all times of day.

German cycling infrastructure guidelines specify which kind of guidance forms are suitable dependent on lane width [10]. While not part of the initial evaluation, findings show that lane width seems to be a significant influencing factor on lateral distances. If vehicles are permanently parked at the edge of the lane the effective usable lane width of a road is reduced. Within the group of routes with mixed traffic, five of the six routes with the lowest mean values of lateral distances seem to be affected by this effect. The actual lane width of said routes is within the margins specified by the guidelines. Nonetheless the effective usable lane width is smaller. This effect incites narrow overtaking manoeuvres. For routes with bike lanes no such effect was detected. Further research is necessary to investigate the influence of lane width on lateral distances.

4 CONCLUSIONS

The promotion of cycling can only succeed if cycling is perceived as safe. The collected data shows an urgent need for action to improve the safety of cycling. Bike lanes are perceived as safer by cyclists than mixed traffic. Therefore, bike lanes lead to more bicycle traffic. In consideration of overtaking situations, bike lanes are less safe than mixed traffic. Even on roads with low vehicle traffic volumes, cyclists are exposed to close overtaking situations. These findings must be taken into account in planning practice. The positive effects of bike lanes on bicycle traffic must be weighed against the negative effects on lateral distances. Further research is necessary to investigate the key factors on how to design cycling infrastructure that is accepted by people and offers a high level of safety.

REFERENCES

[1] Agora Energiewende (2023), Die Energiewende in Deutschland: Stand der Dinge 2022. Rückblick auf die wesentlichen Entwicklungen sowie Ausblick auf 2023. https://www.agora-energiewende.de/veroeffentlichungen/die-energiewende-in-deutschland-stand-der-dinge-2022/

[2] C. Nobis (2019), Mobilität in Deutschland – MiD Analysen zum Radverkehr und Fußverkehr. Studie von infas, DLR, IVT und infas 360 im Auftrag des Bundesministeriums für Verkehr und digitale Infrastruktur (FE-Nr. 70.904/15). Bonn, Berlin. https://www.mobilitaet-in-deutschland.de/archive/pdf/MiD2017_Analyse_zum_Rad_und_Fussverkehr.pdf

[3] Sinus Markt- und Sozialforschung GmbH (2021), Fahrrad-Monitor Deutschland 2021. Ergebnisse einer repräsentativen Online-Befragung. https://bmdv.bund.de/SharedDocs/DE/Anlage/StV/fahrrad-monitor-2021.pdf?__blob=publicationFile

[4] J. Mahne-Bieder; M. Popp; H. Rau (2019), Barriers to cycling: A typology of non-cyclists in Germany. DOI: 10.13140/RG.2.2.29733.45283

[5] R. Geller (2009), Four Types of Cyclists. https://www.portland.gov/sites/default/files/2022/Four%20Types%20of%20Cyclists%20updated%202009.pdf.

[6] J. Merk; J. Eckart; P. Zeile (2021), Subjektiven Verkehrsstress objektiv messen – ein EmoCycling-Mixed-Methods-Ansatz. In: *CITIES 20.50 – Creating Habitats for the 3rd Millennium: Smart – Sustainable – Climate Neutral. Proceedings of REAL CORP 2021, 26th International Conference on Urban Development, Regional Planning and Information Society*, pp. 767–778.

[7] A. Koppers, S. Ruf, J. Gerlach., T. Leven, C. Hagemeister (2021), Radfahren bei beengten Verhältnissen – Wirkung von Piktogrammen und Hinweisschildern auf Fahrverhalten und Verkehrssicherheit. Abschlussbericht. https://www.svpt.uni-wuppertal.de/fileadmin/bauing/svpt/Forschung/Projekte/Forschungsbericht_Piktogramme__3_.pdf

[8] R. Langer (2016), Seitlicher Überholabstand von Radfahrern durch den motorisierten Verkehr – Empirische Analyse mit Hilfe von Kameradaten. In: *Verkehrsökologische Schriftenreihe, Heft 6/2016*.

[9] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV) (2012), Empfehlungen für Verkehrserhebungen. Ausgabe 2012. FGSV Verlag, Köln.

[10] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV) (2010), Empfehlungen für Radverkehrsanlagen. Ausgabe 2010. FGSV Verlag, Köln.

Introducing Right Turn on Red for Cyclists – A Before-After Study on Behavioural Adaption in Germany

B. Schröter[*], S. Hantschel[°], M. Niestegge[+], H. Schüller[#], R. Gerike[~]

[*] Chair of Integrated Transport Planning and Traffic Engineering
Technische Universität Dresden
01062 Dresden, Germany
email: bettina.schroeter@tu-dresden.de

[°] Chair of Integrated Transport Planning and Traffic Engineering
Technische Universität Dresden
01062 Dresden, Germany
email: sebastian.hantschel@tu-dresden.de

[+] PTV Transport Consult GmbH
Traffic Management and Traffic Safety
Schwabstraße 18, 70197 Stuttgart, Germany
email: m.niestegge@directbox.com

[#] PTV Transport Consult GmbH
Traffic Management and Traffic Safety
Schwabstraße 18, 70197 Stuttgart, Germany
email: hagen.schueller@ptvgroup.com

[~] Chair of Integrated Transport Planning and Traffic Engineering
Technische Universität Dresden
01062 Dresden, Germany
email: regine.gerike@tu-dresden.de

Keywords: traffic regulation, pilot project, behaviour, conflict study.

1 INTRODUCTION

Right Turn On Red at traffic lights for cyclists (RTOR) is a low-cost and easy-to-implement improvement in cycling provision which has been introduced in the Netherlands in the 1990th and is applied today in many European cities (e.g. Basel, Brussels, Copenhagen) [1–3]. Existing studies do not find strongly negative effects of RTOR but they show that interactions between cyclists and pedestrians are likely to increase. For example, the evaluation of RTOR in Basel (Switzerland) found that cyclists do not always follow RTOR regulation: 22 % of cyclists arriving on red light still waited until the traffic light turned green. Most conflicts (27 conflicts in 552 hours of video recording) due to RTOR were observed with pedestrians, but no accidents occurred [1]. Other evaluation studies also find only minor changes in behaviour after introduction of RTOR [2, 3].

This study is based on a before-after study in nine German cities funded by the Federal Ministry for Digital and Transport under direction of the Federal Highway Research Institute [4]. It aims to determine the behavioural adaption of cyclists and related changes in conflicts after the introduction of RTOR and to develop, on this basis, recommendations for the application of RTOR in the German context.

2 METHOD

Before and after data from video observations was collected at 43 intersection approaches in nine German cities, for 1,414 right turning cyclists (before) and 1,765 right running cyclist (after). Study sites were selected according to their cycling infrastructure and suitability to apply the RTOR. The before-video observations took place in September and October 2018. The RTOR traffic sign was mounted subsequently at the sites in early 2019 based on a special legal approval for these pilots including the obligation for cyclists to stop at the stop line as this is generally requested in the German Highway Code. The after-video observation took place from May to August 2019 so that a period of familiarization with the new RTOR regulation of at least three months was guaranteed at all sites. Video data was recorded similarly for the before and after period for one work day out of which a period of three hours in the afternoon was analysed (including PM Peak Hour).

Video data was analysed manually by instructed surveyors with the same methodology for before and after observations. For all right turning cyclists, it was coded on whether they arrive at the traffic light at green or red light and (if they arrive on red) whether they turn on red without stopping, on red with stopping or on green. This data was used to analyse the acceptance of traffic regulation and compliance with traffic rules.

Conflicts of cyclists with other users were determined for six pre-defined conflict types (① - ⑥) as shown in Figure 1a. For each of these conflict types, the severity of conflicts was classified using four qualitative conflict levels which were determined based on the decision tree as shown in Figure 1b. Conflicts of level 0 describe the interaction of two users whose routes cross each other, but whose compliance with traffic regulations constitutes a clear traffic situation. Conflicts of level 1 and level 2 require a reaction, and, thanks to this reaction do not lead to a collision. The reaction is missing or insufficient in conflicts of level 3 resulting in a collision. The Post-Encroachment-Time (PET) was recorded for conflicts of level 1 and level 2 to measure their severity. Conflict rates were used to evaluate the number and intensity of these conflicts. Trajectories were recorded in addition for each right turning cyclist.

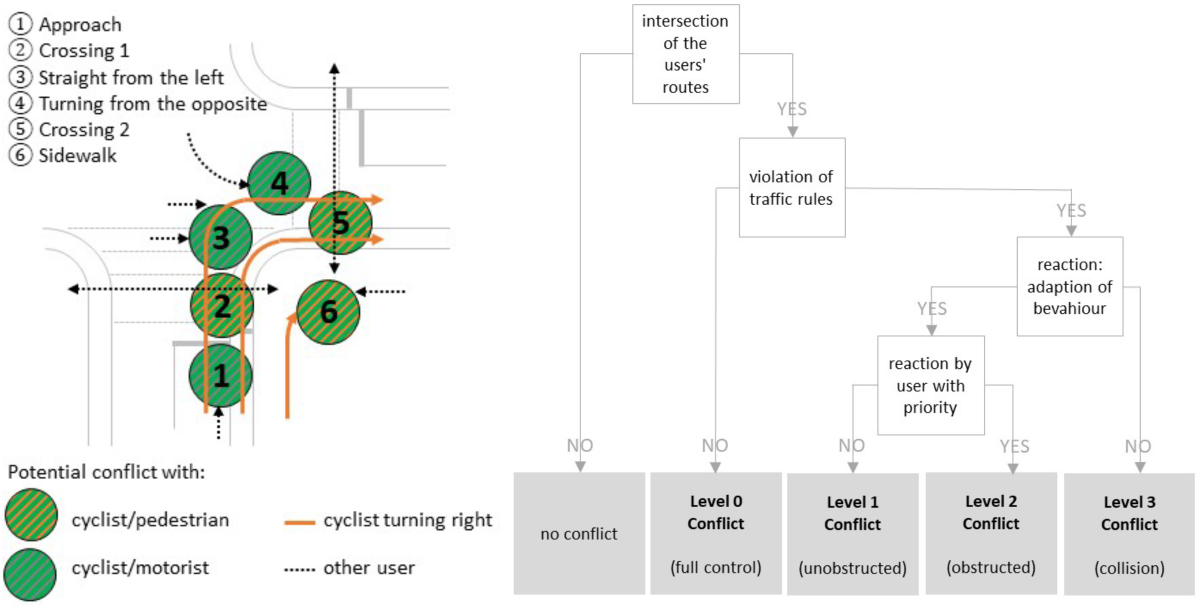


Figure 1: a) pre-defined conflict points; b) decision tree for the qualitative conflict indicator

3 RESULTS

The changes in the behaviour of road users in general and of cyclists turning right were generally minimal with the introduction of RTOR. The acceptance of traffic regulation for cyclists turning right was low before and remained low after the introduction of RTOR – the share of cyclists turning on red increased from 80 % to 93 % with RTOR. On average only 6 % of cyclists using RTOR complied with the obligation to stop. A positive effect was found for the trajectories and for the acceptance of cycling infrastructure: before the introduction of RTOR, 40 % of cyclists decided to leave their cycling facility and change onto the sidewalk to avoid a real red-light violation, afterwards only 30 % of cyclists did so.

The overall number of observed conflicts was low but a tendency can be seen that conflict rates increased slightly with the RTOR. For 543 cyclists turning on red before introduction of RTOR, 411 conflicts were recorded. For 884 cyclists turning on red with RTOR, 816 conflicts were identified. This is on average less than one conflict per cyclist and (at 43 study sites) less than 20 conflicts per site. The share of conflict levels was

- level 0 conflict: 20 % before; 23 % after
- level 1 conflict: 71 % before; 70 % after
- level 2 conflict: 9 % before; 7 % after.

This means that there was only a minor share of level 2 conflicts when road users who did not violate traffic rules needed to react to users with traffic rule violations and, in addition, this share did not increase with introduction of RTOR. Collisions (level 3 conflicts) were neither observed in the before nor after observation.

In terms of conflict types, more interactions were recorded in the approach (① in Figure 1a) and with users from left (③in Figure 1a) after introduction of RTOR. The majority of conflicts in the approach (①) occurred with other cyclists which means that cyclists before RTOR introduction might have only turned on red if there was the possibility to do this without interacting with other cyclists. With RTOR they seem to wriggle through other users to use the newly introduced regulation and to minimize their waiting times. Conflicts with users from the left (③) were observed mainly with other cyclists. Those conflicts are characterised by the lowest PET values compared to other conflict types. PET values were low before and after the introduction of RTOR.

Conflicts on the crossings (② and ⑤ in Figure 1a) occurred equally often between cyclists and pedestrians and cyclists and cyclists. They did not change significantly in number and severity after the introduction of RTOR. Conflicts on the sidewalk (⑥in Figure 1a) occurred less frequently after introduction of RTOR because less cyclists rode on the sidewalk. Conflicts with participants turning left from the opposite (④ in Figure 1a) were too low in numbers to allow for a quantitative evaluation.

A general finding for behavioural adaption with the introduction of RTOR is that overall, the critical time gaps (PET < 2s) across all conflict types decreased on average.

4 CONCLUSIONS

The introduction of RTOR showed positive and negative effects on conflict indicators but overall, no major changes in behaviour were identified, mainly because RTOR was already practiced by cyclists before its introduction. In terms of acceptance of traffic rules, the obligation to stop was hardly ever followed. We do not know to what extent this can be attributed to a lack of knowledge among cyclists or to a deliberate disregard of the rules even though cyclists knew them. The results show that this does not have any negative impacts on other users.

Less cycling on the sidewalk and a lower share of critical time gaps (PET) belong to the positive effects of RTOR whereas more conflicts in the approach are a negative effect. RTOR should consequently only be implemented where sufficient space for overtaking other cyclists is given. One critical point in all observations are good sight visibility conditions because PET values of cyclists turning right versus cyclists from the left are particularly low. It is therefore of highest relevance that users can see the approaching traffic not only from a stop position but also when they approach the intersection.

Based on these results, the approval of RTOR was recommended for Germany. RTOR has now been introduced for cyclists in the amendment of the German Highway Code and many cities have implemented this new traffic regulation at several intersections. A long-term accident analysis could help to better understand the effect of RTOR on safety.

REFERENCES

1. M. Störr, C. Huber, and D. Pöllendorfer, *Final report on the pilot project for cycle-friendly traffic lights* (2017) [de].
2. Belgisch Instituut voor de Verkeersveiligheid, *Pilot project in the Brussels Capital Region allowing cyclists to turn right through a red light (B22) or to drive straight through a red light (B23)* (2012) [nl].
3. M. C. Møller-Lange and N. L. Knudsen, *The effects of allowing right turns on red for cyclists* [da].
4. M. Niestegge, H. Schüller, S. Hantschel, B. Schröter, and R. Gerike, *Berichte der Bundesanstalt für Straßenwesen, Reihe V: Verkehrstechnik - 355*: *Pilot test of the turning right of cyclists on red* (Fachverlag NW in der Carl Ed. Schünemann KG, Bremen, 2022) [de].

Cognitively distracted cycling – a bike simulator study

M. Møller*, **F.L. Berghoefer#**, **M. Vollrath#**

*Division of Transport
Technical University of Denmark
Bygningstorvet 116b, 2800 Kgs. Lyngby, Denmark
email: mette@dtu.dk

#Department of Traffic and Engineering Psychology
Technische Universität Braunschweig
Gaußstraße 23, 38106 Braunschweig, Germany
email: f.berghoefer@tu-braunschweig.de
email: mark.vollrath@tu-braunschweig.de

Keywords: cycling, safety, cognitive distraction, secondary tasks, bike simulator.

1 INTRODUCTION

Studies using a survey or field observational approach show that secondary task engagement has a negative impact on cyclists' performance [1, 2]. Prohibiting handheld phone use, while allowing hands-free use via headphones, is applied to reduce safety critical impact of secondary task engagement [3], and headphone use is now the most prevalent type of secondary task engagement among cyclists [4]. Hands-free secondary task engagement limits visual-motor distraction but increases cognitive distraction. Therefore, effects of cognitive distraction on cycling performance should be examined.

While some evidence of detrimental effects of visual-motor distraction on cycling performance exist [2, 5], no study focused specifically on the effects of cognitive distraction. For drivers, results are mixed showing different effects in different situations and even reduced crash risk in non-demanding situations in which simple behavioral reactions such as braking are required [6]. In accordance with Wickens´ multiple resources theory [7] the results indicate that detrimental effects of the secondary task engagement mirror the overlap in resource need in both tasks. It should be examined if this also applies to cognitive distraction among cyclists.

Based on the above, this study investigates the behavioral effects of engagement in secondary cognitive tasks while cycling with a particular focus on overtaking behavior and behavioral response in potentially critical situations. The study follows a controlled experimental approach using the bicycle simulator at the Department of Traffic and Engineering Psychology at the Technische Universität Braunschweig.

2 METHOD

2.1 Participants and procedure

The study is planned for May 2023. We recruit 60 participants through online platforms of the Technische Universität Braunschweig, the department's mailing list, and among previous participants who agreed to be invited to future studies. Participants are assigned to one of three distraction groups (none vs. Acoustic speech (AS) task vs. Podcast task). We inform participants about the study, how to handle the bicycle, and ask them to sign informed consent. Participants familiarize themselves with the bicycle and virtual environment in a practice scenario before the experimental ride. The duration of the experimental ride is 30 minutes. After the experimental ride, AS task participants receive feedback about the number of correct replies, and the podcast task participants are asked to answer questions regarding the content of the podcast. Finally, all participants complete a questionnaire with questions on demography, cycling habits, phone-use while cycling, and perception of the experimental ride such as safety, distraction, and own performance.

2.2 Material

The bicycle simulator runs with the software SILAB 7.0 [8] and consists of a woman's bicycle standing on a platform which allows slight vertical tilts to the sides (left/right). Twelve monitors assembled with hexagon provide the cyclist with a 360° view. Noise cancelling over-ear headphones provide surrounding noises such as motor vehicles, and additional in-ear headphones provide the participants with acoustic input relevant for the secondary tasks. The test ride includes 12 road segments matching a typical German urban environment. The participants cycle on a cycle lane with a width of 2m, a footpath with pedestrians and houses to the right, and a two-way street with car traffic to the left of the cyclist. The demarcation between the cycle lane and the road differs (Figure 1) and is presented in randomized order. In nine segments a second bicyclist cycles in front of the participant at a slow speed to make the participant overtake. After the overtaking, participants turn right into a side street and at a T-junction thereby entering the next experimental road segment. In three of the 12 segments, the second bicyclist is replaced by one of three potentially critical situations: a traffic light, a construction zone, and a crossing pedestrian (Figure 2). The single line demarcation is used in these three events.

Figure 1 Screenshots illustrating the three different demarcations included

Figure 2 Screenshots illustrating the three potentially critical events

2.3 Experimental design

We apply a 3-level two-factor between-subjects design with secondary task engagement as the independent variable (none, Acoustic speech task (AS), Podcast). The AS task was used in previous studies [9] and involves acoustic input giving spatial information, visual representation and speech output. In the podcast condition participants listen to a podcast of own choice (three different available). To ensure active engagement with the tasks, participants in the AS task receive feedback regarding the number of correct replies, while participants in the podcast task are asked to answer questions about the content of the podcast after the ride. With regard to the behavior before and while overtaking (lateral position before overtaking, standard deviation of lateral position (SDLP), mean speed, overtaking yes or no, distance to other cyclist being overtaken, speed while overtaking), the demarcation is analyzed as a second factor (single line, large separation, separation with bollard). As each participant experiences every demarcation three times, a mean value is computed over these three repetitions. The potentially critical events include a pedestrian that suddenly crosses the cycle lane, a traffic light turning red, and a construction zone on the cycle lane (Figure 2). The three events differ with regards to their degree of predictability. In each of these events, reaction times are computed (brake reaction for the pedestrian, stopping at the red light and starting again at the green light, braking or slowing done or steering to avoid the construction zone). Additionally, we register the number of correct answers for the AS and Podcast tasks.

3 RESULTS AND DISCUSSION

We expect engagement in the secondary tasks to affect cycling behaviour. More specifically, we expect participants in both secondary task conditions to cycle closer to the middle of the cycle lane and to choose a slower riding speed compared to participants not engaging in secondary tasks. Further, we expect reaction time (RT) to be longer for participants in the secondary task conditions compared to participants who do not engage in secondary tasks. Finally, we expect larger effects of secondary task engagement in the AS condition compared to the Podcast condition, due to a higher cognitive demand for active participation in the AS condition and also the visual representation of this secondary task in working memory.

The results will provide insights into the impact of hands-free engagement in secondary tasks while cycling. Hands-free engagement in secondary tasks is legal in many countries, but knowledge on behavioural effects is limited. Additional insight into behavioural effects of hands-free secondary task engagement is therefore relevant in order to support safe cycling in the future. The study will contribute to fill this knowledge gap.

REFERENCES

[1] M.D. Angelis, F. Fraboni, V.M. Puchades, G. Prati, and L. Pietrantoni. Use of smartphone and crash risk among cyclists. *Journal of Transportation Safety and Security, 12,* (2020), 178-193. https://doi.org/10.1080/19439962.2019.1591559

[2] K. Jiang, Z. Yang, Z. Feng, N. N. Sze, Z. Yu, Z. Huang, and J. Cheng. Effect of using mobile phones while cycling: A study from the perspectives of manipulation and visual strategies. *Transportation Research Part F*, 83, (2021), 291-303. https://doi.org/10.1016/j.trf.2021.10.010

[3] R. K. Brandt, S. Haustein, and M. Møller. Exploring the effects of introducing a ban on handheld phone use for cyclists. *Travel Behaviour and Society*, 30, (2023), 212-219. https://doi.org/10.1016/j.tbs.2022.10.001

[4] A. K. Huemer, S. Gercek, and M. Vollrath. Secondary task engagement in German cyclists – An observational study. Safety Science, 120, (2019), 290-298. https://doi.org/10.1016/j.ssci.2019.07.016

[5] D. de Waard, P. Schepers, W. Ormel, and K. Brookhuis. Mobile phone use while cycling: Incidence and effect on behaviour and safety. *Ergonomics*, 53, (2010) 30-42. https://doi.org/10.1080/00140130903381180

[6] M. Vollrath, C. Clifford, A. K. Huemer. Even experienced phone users drive worse while texting – A driving simulator study. *Transportation Research Part F, 78,* (2021), 218-225. https://doi.org/10.1016/j.trf.2021.02.007

[7] C. D. Wickens. Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3* (2002), 159–177. https://doi.org/10.1080/146392202101

[8] Würzburg Institute for Traffic Sciences GmbH (WIVW), *simulatorsoftware, SILAB 7.0,* 2021, Veitschöchheim, Germany.

[9] M. Vollrath, and I. Totzke. Secondary tasks while driving. Effects and countermeasures. Advances in *Transportation Studies an international Journal* Section B 7, (2005), 67-80.

Comparison of different cargo transport concepts on bicycles and their influence on cycling stability in open and closed loop

Clemens Groß[*], Jakob Vortanz[#], Steffen Müller[†]

[*]Chair of Automotive Engineering
Technische Universität Berlin
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
email: gross.1@tu-berlin.de

[#] Chair of Automotive Engineering
Technische Universität Berlin
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
email: jakob.vortanz@campus.tu-berlin.de

[†] Chair of Automotive Engineering
Technische Universität Berlin
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
email: steffen.mueller@tu-berlin.de

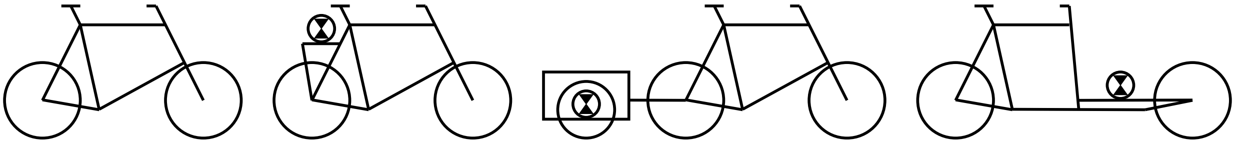
Keywords: cargo bicycle, bicycle trailer, bicycle rack, stability, control.

1 INTRODUCTION

Cargo transport on bicycles has gained a lot of attention, as more and more cargo bicycles join traffic in our cities. Not only cargo bicycles can be used for the transport of goods though: The classic bicycle is often equipped with a bicycle rack and trailers can be used. We study the question which concept is preferable in terms of open and closed loop stability by assessing different bicycle concepts through simulation.

2 BICYCLE MODELS, STABILITY AND CONTROL

Three different cargo transport concepts are considered in this work as shown in Figure 1. A conventional bicycle with a loaded bicycle rack (b), a conventional bicycle with a trailer (c), as well as a single-track cargo bicycle with the load in front of the rider (d). For reference we include an unloaded conventional bicycle (a).



a) *b)* *c)* *d)*

Figure 1: Sketch of the Different Bicycle Concepts.

2.1 Modelling and Parametrization

A linearized Whipple model [1] is implemented in Matlab and parametrized, as well as validated, with the values found ibidem. The complete formulation of the linearized Whipple model can be found at the same place. The equation of motion for the heading angle of the bicycle is shown in Equation (1), which yields (2) when the trailer is added and considered to be coupled friction free:

$$m_T x_t \ddot{y}_p + I_{Txz}\ddot{\varphi} + I_{Tzz}\ddot{\psi} + I_{A\lambda z}\ddot{\delta} - vS_T\dot{\varphi} - vS_F \sin\lambda\,\dot{\delta} = wF_{vy}, \tag{1}$$

$$(m_T x_t + m_{SA} x_{SA})\ddot{y}_p + I_{Txz}\ddot{\varphi} + (I_{Tzz} + I_{Azz} + m_{SA} x_{SA}^2)\ddot{\psi} + I_{A\lambda z}\ddot{\delta} - vS_T\dot{\varphi} - vS_F \sin\lambda\,\dot{\delta} = wF_{vy}. \tag{2}$$

Here, m_T and x_T are mass and the longitudinal position of the centre of gravity (COG) for the bicycle, m_{SA} and x_{SA} are the same for the trailer, I_{Txz} and I_{Tzz} are moments of inertia of the bicycle, I_{Azz} of the trailer and $I_{F\lambda z}$ of handlebar and fork. S_T and S_F are gyrostatic constants of both wheels respectively the front wheel, and F_{vy} is a force acting on the front wheel. Furthermore, y_p is the location of the rear tire contact patch, φ is the lean, ψ the heading, and δ the steering angle, λ the head tube angle and w the wheelbase. Subsequently, we parametrize the model for our reference bicycle, which is then complemented with a load on the rack. This load causes a change in mass parameters. For the addition of the trailer, we make use of the same Whipple model for the baseline bicycle. As shown in [3], the position of the trailer only depends on the heading angle of the towing vehicle. The influence of the trailer on the dynamic behaviour is thus expressed in the equation of motion of the rear tire contact point of the Whipple model as shown in Eq. (2). The Whipple model is parametrized according to [2] for the cargo bicycle and equipped with the load.

2.2 Open Loop Stability and Control

The bicycle is inherently unstable, even the ideal model of it tips over when the smallest disturbance is applied. This is shown in Figure 2 a) – c) in terms of the speed dependent real part of the Eigenvalues. Negative values for the real parts of the Eigenvalues characterize a stable system, while even a single positive value of a real part results in instability. In order to stabilize the bicycle models and have them perform defined driving manoeuvres, a linear-quadratic regulator is used and parametrized equally for all concepts.

2.3 Closed Loop Test Manoeuvre and Performance Index

In order to assess the stability of the different bicycle concepts, we simulate the bicycles driving straight ahead when a disturbance of 1 Nm is applied to the steering. This corresponds to e.g. hitting a pothole. Assessment is done by the help of a stability index from [4] which is adjusted to incorporate steering work. It includes the work performed by the rider for lean and steer as shown in Equation (3)

$$S_{Wst} = \frac{1}{\int_0^t |\varphi|\, dt \cdot \left(\int_0^t \left|T_\varphi \dot{\varphi}\right| dt + \int_0^t \left|T_\delta \dot{\delta}\right| dt\right)}, \tag{3}$$

where T_δ is the torque applied for steering and T_φ for leaning. Thus, S_{Wst} incorporates the steering angle over time and the work done in order to stabilize the bicycle. It incorporates the reference response as well as the disturbance response of the controlled bicycles while penalizing lean angles over time.

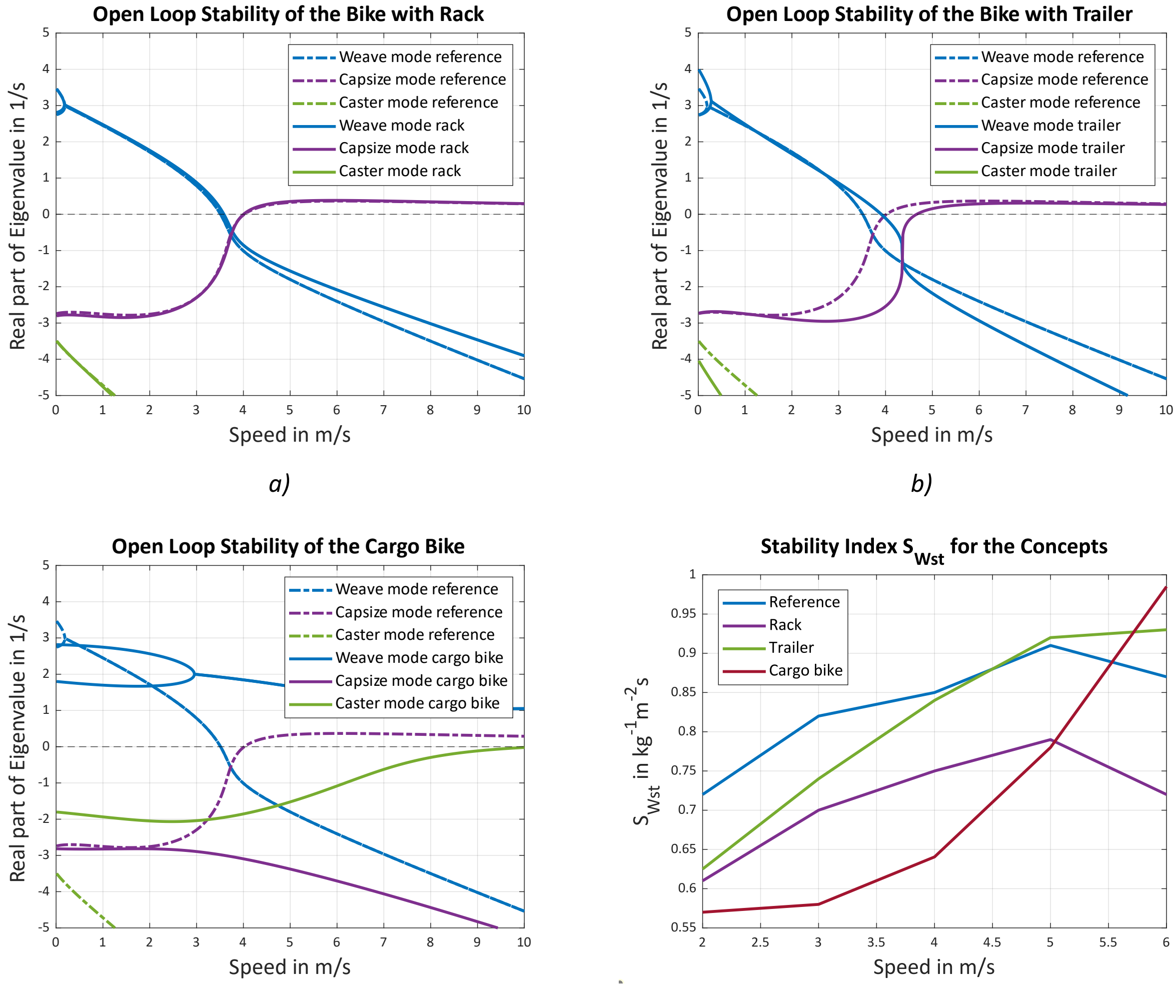
3 RESULTS

We simulate the closed loop test manoeuvre for speeds of 2 to 6 m/s and assess open loop stability for speeds up to 10 m/s. Fig. 2 a) – c) shows open loop stability of the concepts and Fig. 2 d) shows the stability index for the respective bicycle concepts. For the bicycle with rack, open loop stability is increased and the stable speed range of 3.59 to 4 m/s is even slightly larger than for the reference. This can be explained by the fact that the overall COG is lower than for the reference. Adding the trailer enlarges the stable speed range and shifts it to higher speeds (3.91 to 4.66 m/s). Note that the modelled cargo bicycle does not have a stable speed range.

For high speeds, the bicycle with rack shows the lowest value of controllability in terms of S_{Wst} as shown in Fig. 2 d). The bicycle with trailer is worse at low speeds than reference. For low speeds, the cargo bicycle shows better controllability in terms of S_{Wst}. This could potentially be traced back to the comparatively low wheel load of the front wheel of the cargo bike, given that the load in our simulation is far smaller than the body weight of the rider. Furthermore, the cargo bike has the longest wheelbase by far. This results in a smaller influence of the disturbance acting on the front wheel.

4 CONCLUSION

In the regarded driving situation and with the given parameters, the cargo bicycle performs best by the means of our chosen stability index for low speeds. Since abstraction of driving behaviour is a very active research field though, other stability indices can be applied to our models as well. When assessing the different bicycle transport concepts by the help of this work, one should consider that the simulated load is very low for the cargo bicycle and high for a bicycle with a rack. Future works can therefore focus on the behaviour of cargo bicycles with higher loads or different geometry. More sophisticated models, e.g. including a shift of the entire COG due to the rider's movements or other assumptions for coupling the trailer, can be studied too.



a) b)

c) d)

Figure 2: Real Parts of Eigenvalues and Stability Index of the Respective Bicycle Concepts in Relation to Forward Speed.

REFERENCES

[1] J. Meijaard, J. Papadopoulos, A. Ruina and A. Schwab, "Linearized dynamics equations for the balance and steer of a bicycle: A benchmark and review", *Proceedings of The Royal Society A: Mathematical, Physical and Engineering Science* 463 (2007), pp. 1955-1982.

[2] T. A. Williams, *Influence of Frame Stiffness and Rider Position on Bicycle Dynamics: An Analytical Study*, University of Wisconsin, Milwaukee, 2015.

[3] Z. Leng and M. A. Minor, "A simple tractor-trailer backing control law for path following with side-slope compensation," 2011 IEEE International Conference on Robotics and Automation, Shanghai, China, 2011, pp. 2386-2391, doi: 10.1109/ICRA.2011.5979918.

[4] P. Igenlath, *Multibody Simulation Based Bicycle Design*, Rheinisch-Westfälische Technische Hochschule Aachen, 2019.

Autonomous Vehicles and the Future of Bicycle Urbanism: Insights from Contemporary Living Labs

A. Gaio[*]

[*]Department of Geography, School of Natural Sciences
Trinity College Dublin, The University of Dublin
Museum Building Trinity College Dublin, Dublin 2, Ireland
email: gaioa@tcd.ie

Keywords: living labs, transportation, cycling, autonomous vehicles.

1 INTRODUCTION

Living labs are places where novel technology and experimental urbanism are deployed on a small scale with human subjects in their everyday lives. Some scholars describe them as real-world places that foster user ‘co-creation’ [1]. To this end, these labs are a useful tool for co-creating the future of urban cycling and vulnerable road users with novel transport technologies. One area of living lab experimentation to date has been with autonomous vehicles (AVs). Given the current rapidly accelerating deployment of AVs as fixed-route shuttles, and more recently as free-floating ‘taxi’/transportation network company (TNC) services in the United States there is a need to understand how this novel technology implicates bicycle use. Combined with the future anticipated uptake of AV technologies over the coming decades [2], it is important to understand their impacts on behaviour and attitude of both bicycle users and potential bicycle users as non-occupants. Scholars describe non-occupants are those who are present around AVs while they are operating [3, 4]. For example, an area of particular importance is understanding the impact of AVs on sustainable urbanism objectives through active transportation and bicycle mode share targets. Sustainable mobility targets remain largely oblivious to how AVs will affect non-occupant travel behaviour. The purpose of my presentation is to outline implications for bicycle urbanism by employing a proposed ‘coexistence’ model.

2 BACKGROUND & METHODS

I will share findings from an in-depth empirical study titled ‘Ride the Autonomous City’. The study employed surveys, focus groups, and interviews with everyday stakeholders of living labs where AVs are operating in North America and Scandinavia. The findings are intended to inform policymakers, elected officials, and transportation planners to make iterative, responsive, and practical bicycle infrastructure solutions for all ages and abilities in the age of Autonomous Vehicles. The study’s findings have implications for fostering safe interaction between cyclists and connected/automated vehicles. Results from the study include behavioural, observational, and attitudinal data from five living labs. Data from ‘Ride the Autonomous City’ describe how bicycle user confidence, lived-experience, and infrastructure design impact the bicycle user experience in a variety of different bicycle infrastructure configurations.

The data were collected using a mixed-methods approach that combined surveys, focus groups, and interviews. Surveys are the primary source for data included in statistical analysis below and were delivered online to stakeholders in the living labs who can experience AVs in their everyday life. A targeted engagement approach where study invitations were distributed to residents' homes within a 300m radius of the AV test routes in question. Survey respondents were also recruited for focus groups and semi-structured interviews as their availability permitted.

3 RESULTS

3.1 Preliminary Analysis

Statistical analysis of the likert-scale survey data (n= 415) was undertaken using Spearman's rho correlation to understand the linkages between AV exposure in daily life and respondents' tendencies to cycle under different cycling infrastructure configurations (namely separate or shared with AVs).

Table 1: Spearman's correlation check (highlighted cells $\alpha \leq 0.05$)

		cyclist-class	class-bike-regularity	trust-pre	av-shared-cyclemore	av-separate-cyclemore
cyclist-class	Correlation Coefficient	1.000	-.311**	-0.008	.108*	0.004
	Sig. (2-tailed)		0.000	0.888	0.028	0.940
	N	415	415	351	415	415
class-bike-regularity	Correlation Coefficient	-.311**	1.000	0.028	-.209**	0.089
	Sig. (2-tailed)	0.000		0.600	0.000	0.071
	N	415	415	351	415	415
trust-pre	Correlation Coefficient	-0.008	0.028	1.000	.206**	.190**
	Sig. (2-tailed)	0.888	0.600		0.000	0.000
	N	351	351	351	351	351
av-shared-cyclemore	Correlation Coefficient	.108*	-.209**	.206**	1.000	-0.091
	Sig. (2-tailed)	0.028	0.000	0.000		0.064
	N	415	415	351	415	415
av-separate-cyclemore	Correlation Coefficient	0.004	0.089	.190**	-0.091	1.000
	Sig. (2-tailed)	0.940	0.071	0.000	0.064	
	N	415	415	351	415	415

Note: inverse correlation shown in this table is a result of inverted ordinal scales

A selection of variables gathered, and their respective correlations, are shown above in Table 1 that highlight:

- Bicycle user classification (cyclist-class) (see ref [5, 6])
- Bicycle use frequency (class-bike-regularity)
- Participants' trust in AVs before interaction – recalled (trust-pre)
- Participants' tendency to cycle in shared bicycle/AV infrastructure (av-shared-cyclemore)
- Participants' tendency to cycle in separated bicycle/AV infrastructure (av-separate-cyclemore)

Figure 1: Survey visual aid depicting shared AV/bicycle configuration

3.2 Discussion

Only the tendency to cycle in an environment with shared AV/bicycle facilities (Figure 1) has statistically significant modest correlation at the 95% level with bicycle user classification, bicycle use frequency, and AV trustworthiness pre-interaction. This may suggest that those who currently feel safe cycling in mixed traffic, ride a bike regularly, and currently consider AVs trustworthy will continue to feel safe and those who do not feel safe will not automatically feel safe when more vehicles are driven by autonomous technology. Consequently, population-level cycling benefits will only materialise if safe, separated, all ages and abilities cycling facilities continue to be a priority in the age of AVs.

4 CONCLUSION

My presentation will conclude with sharing a proposed ‘coexistence’ model and learnings that could influence amicable coexistence of AVs and active transportation as well as key extracts and broad themes raised in focus groups and interviews highlighting concerns and lived experiences from individuals who have been participants in the living labs that this study has observed. The findings will be useful for researchers to build upon and engage with as well as for policymakers, transport engineers/planners who work with bicycle infrastructure design and traffic policy in the cities of tomorrow and want to understand how AI-enabled mobility will impact their work.

REFERENCES

[1] Burbridge, M. (2017). If living labs are the answer–what's the question? A review of the literature. *Procedia engineering*, *180*, 1725-1732.

[2] Cugurullo, F., Acheampong, R. A., Gueriau, M., & Dusparic, I. (2021). The transition to autonomous cars, the redesign of cities and the future of urban sustainability. *Urban Geography*, *42*(6), 833-859.

[3] Borenstein, J., Herkert, J., & Miller, K. (2020). Autonomous vehicles and the ethical tension between occupant and non-occupant safety. *The Journal of Sociotechnical Critique*, *1*(1), 6.

[4] Gaio, A., & Cugurullo, F. (2022). Cyclists and autonomous vehicles at odds: Can the Transport Oppression Cycle be Broken in the Era of Artificial Intelligence?. *AI & society*, 1-15.

[5] Dill, J., & McNeil, N. (2013). Four types of cyclists? Examination of typology for better understanding of bicycling behavior and potential. *Transportation Research Record*, *2387*(1), 129-138.

[6] Geller R. (2009). *Four Types of Cyclists.* Portland Bureau of Transportation, Portland, Ore. http://www.portlandoregon.gov/transportation/article/264746. Accessed April 17, 2023.

Incomparable Results: Exploring the Challenges of Measuring Lateral Passing Distance

Z. Janoška, M. Bíl

Transport Research Centre (CDV)
Líšeňská 33a, 636 00, Brno, Czechia
email: zbynek.janoska@cdv.cz

Transport Research Centre (CDV)
Líšeňská 33a, 636 00, Brno, Czechia
email: michal.bil@cdv.cz

Keywords: instrumented bicycle, sensors, bicycle safety, urban mobility

1 INTRODUCTION

Lateral passing distance (LPD) between cyclists and vehicles has been researched as of the 1970s [1], but has only recently gained prominence as a safety issue. This was partly influenced by technical developments and the availability of affordable sensors and measurement methods. Instrumented bikes, equipped with a variety of sensors, have been used in a number of studies [see Gadsby and Watkins, 2].

Rubie et al. [3] listed 12 different ways in which lateral passing distance was previously defined, ranging from *"bicycle tire to outside edge of motor vehicle tire"* to *"outermost part of the cyclist to the outermost part of the motor vehicle or something sticking out of the motor vehicle, i.e. side mirror".* The difference in distance between those two extreme definitions can be more than 50 cm.

Another methodological issue arises from the technological advancement of instrumented bikes. Modern sensors with high frequency of data recording produce a number of measurements for each passing event. The minimal distance recorded by sensors can often differ from the distance measured at any point during a passing event – a method extensively used in the past [1][4].

In this paper, we aim to explore if different definitions of LPD produce comparable results and if LPD measured as a single measurement during a passing event is representative compared to continuous measurement by sensors with a high frequency of data capture.

2 METHODS

2.1 Lateral passing distance definitions

Traffic camera footage was collected in the town of Brandýs nad Labem, Czechia, in March 2019. 59 passing events were extracted from a video recording. For each passing event, a lateral passing distance was measured using three definitions: (a) tire to tire, (b) edge of bicycle handlebar to body of car, (c) from outermost point of cyclist to outermost point of car. The proportion of passes under 100 cm and 150 cm was calculated for each definition of LPD. A logit model for the probability of the close pass depending on the distance of the cyclist from the edge of the road was calculated for each definition of LPD.

2.2 Measurement frequency

We used an instrumented bicycle equipped with two TFmini-S LiDAR sensors with a frame rate 50 FPS to measure passing events in real traffic in the city of Olomouc, Czechia in March 2023. An instrumented bicycle was also equipped with a button for manual recording of the passing event. 34 passing events were recorded (excluding overtaking maneuvers by buses). The minimal distance during the passing event measured by both sensors and the distance measured at the moment of manual recording were compared.

3 RESULTS

3.1 Lateral passing distance definitions

The proportion of passes under 100 cm and 150 cm differs significantly for each definition of lateral passing distance. The proportion of passes under 150 cm ranges from 15 % to 86 % for extreme definitions of LPD.

Table 1: Percentage of close passes depending on definition of LPD.

Definition of LPD	% of passes < 100 cm	% of passes < 150 cm
Tire to tire	0 %	15 %
Edge of handlebar to body of car	7 %	69 %
Outermost points of cyclist and car	12 %	86 %

Previous studies show that the closer the cyclist rides to the kerb, the larger the LPD [4][5]. We used a logit model to describe the probability of a close pass under 150 cm, depending on the distance from the kerb, for all three definitions of LPD. The distance from the kerb is evaluated as significant predictor ($p < 0.05$ for definitions (a) and (b), $p < 0.1$ for definition (c)), the shape of the logit function, however, differs (see Figure 1).

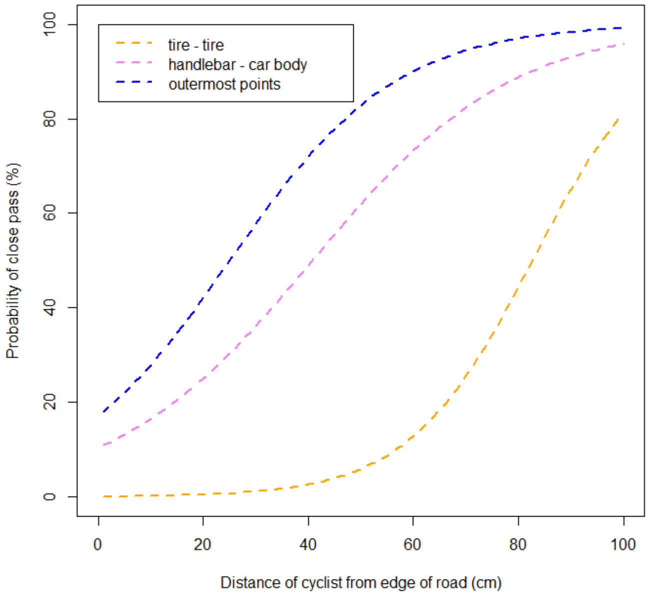
3.2 Measurement frequency

In more than 90 % of cases, the distance measured at the moment of manual recording of the passing event was lower than the minimal distance measured by sensors during the passing event. The median difference was 5 cm, with the difference being greater than 31 cm in 25 % of cases.

4 CONCLUSIONS

The definition of the lateral passing distance influences the measured distance during the passing event. The difference in distances between the various definitions can be more than 50 cm, which makes the results of various studies of LPD incomparable. A very common result of studies of overtaking manoeuvres is the proportion of close passes (with various distances used as the cut-off point for a close pass). We have shown that the definition of distance not only influences the proportion of close passes (from 15 to 86 % dependent on definition) but also the shape of models which aim to explain it.

Another incomparability issue stems from technological advancements. Modern sensors are capable of capturing up to tens of measurements for a single passing event. When the distance is measured at only one point during a passing event, the measured distance is often (> 90 %) greater than the minimal distance measured by sensors during the passing event.



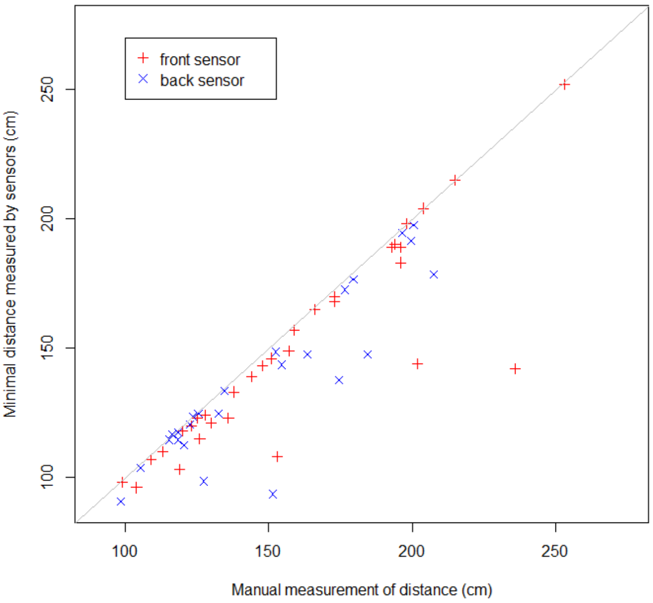


Figure 1: Shape of relation between probability of close pass (< 150 cm) and distance from kerb differs for each definition of LPD.

Figure 2: Distance measured at moment of manual recording differs from minimal distance measured by sensors during passing event.

REFERENCES

[1] G. R. Watts, *Bicycle safety devices-effects on vehicle passing distances*, No. HS-028 717, 1979.

[2] A. Gadsby and K. Watkins, "Instrumented bikes and their use in studies on transportation behaviour, safety, and maintenance", *Transport Reviews*, 40-6 (2020), pp. 774-795.

[3] E. Rubie, N. Haworth, D. Twisk, and N. Yamamoto, "Influences on lateral passing distance when motor vehicles overtake bicycles: A systematic literature review", *Transport reviews*, 40-6 (2020), pp. 754-773.

[4] I. Walker, "Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender", *Accident Analysis and Prevention*, 39-2 (2007), pp. 417-425.

[5] Jansen, R., Lotan, T., Winkelbauer, M., Bärgman, J., Kovaceva, J., Donabauer, M.,…Van Nes, N. (2017). Interactions with vulnerable road users. UDRIVE Deliverable 44.1. EU FP7 Project UDRIVE Consortium. https://doi.org/10.26323/UDRIVE_D44.1

Odds of self-reported minor cycle crashes with conventional and electric assisted cycles adjusted for cycling frequency in Dutch and Belgian adults.

A prospective study

B. de Geus[a,*], T. Ampe[b], J. Van Cauwenberg[c,d], P. Schepers[e,f]

[a,*] IACCHOS, Université catholique de Louvain,
Place Pierre de Courbertin, 1348 Louvain-la-Neuve,
Belgium
bas.de.geus@uclouvain.be

[b] Human Physiology and Sport Physiotherapy
Research Group, Vrije Universiteit Brussel, Pleinlaan 2,
B-1050 Brussels, Belgium
toon.ampe@vub.be

[c] Health Promotion Unit, Department of Public
Health and Primary Care, Faculty of Medicine and
Health Sciences, Ghent University, Ghent, Belgium
Jelle.VanCauwenberg@UGent.be

[d] Fund for Scientific Research Flanders (FWO),
Brussels, Belgium

[e] Department of Human Geography and Spatial
Planning, Faculty of Geosciences, Utrecht
University, the Netherlands
paul.schepers@rws.nl

[f] Ministry of Infrastructure and Water Management,
Rijkswaterstaat, the Netherlands

Keywords: Minor cycle crashes, Cycling frequency, Electric assisted cycle, Conventional cycle, +40-year Prospective

1 INTRODUCTION

Cycling for transportation and recreation is gaining in popularity, especially in the older age groups. The rise in electric assisted cycles (EAC) certainly has a role to play. With an increase in the number of cyclists comes an increase in prevalence of crashes. There is a lack of data on cycle crashes in older age groups, cycle crashes with an EAC and crash studies including exposure data.

Our research team conducted a Retrospective study in Belgium and the Netherlands published in Accident Analyses and Prevention in 2023 [1]. Retrospective studies have the advantage that larger study populations can be reached, and that data can be collected in a relatively short time period. On the other hand, retrospective studies face their own limitations, e.g. recall bias [2]. To circumvent these limitations a prospective study design was used to collect cycle crash data.

2 STUDY AIM

The aim is to study the probability of reporting a cycle crash, with a conventional (CC) or EAC, while controlling for individual characteristics and cycling frequency during a study with a Prospective research design.

3 METHODS

Following the retrospective cross-sectional survey-based study (AAP, 2023) participants were invited to continue their participation by filling out a short questionnaire containing questions relating to their socio-demographic and health characteristics and transport behaviour every 3 months during a one-year period (Prospective research design). If a cycle crash occurred during the 3-month period, a longer questionnaire about the crash characteristics had to be filled out. The study includes male and female cyclists aged 40+ years and is conducted in Belgium and the Netherlands. Binary logistic regression modelling will be used to calculate the odds of reporting a cycle crash with a conventional or electric assisted cycle. Main and interaction effects will be studied.

4 RESULTS

Participants filled out a total of 2621 questionnaires. 149 crashes were reported during the 1-year prospective study period. Results from the regression modelling are being analysed in April and May 2023 and will be available for the ICSC conference in November 2023.

REFERENCES

[1] de Geus B, Ampe T, Van Cauwenberg J, Schepers P, Meeusen R
Odds of self-reported minor cycle crashes with conventional and electric assisted cycles adjusted for cycling frequency in Dutch and Belgian adults a retrospective study
Accident Analysis and Prevention, 179, 2023, 106893

[2] Vanparijs J, Van Cauwenberg J, Int Panis L, Vanhecke E, Gillis D, Sudharta G, Meeusen R, de Geus B.
Cycling exposure and infrastructural correlates in a Flemish adolescent population
Journal of Transport & Health, 16, 2020, 100812

A Matter of Space and Perspective - Cyclists' and Car Drivers' Assumptions about Subjective Safety in Shared Traffic Situations

R. von Stülpnagel [*], H. Rintelen [#]

[*]Abteilung für Kognitionswissenschaft
University of Freiburg
Hebelstr. 10, 79104 Freiburg, Germany
email: rul.von.stuelpnagel@cognition.uni-freiburg.de

[#] FixMyCity GmbH
Karlsgartenstraße 12, 12049 Berlin, Germany
email: heiko@fixmycity.de

Keywords: subjective safety, risk perception, vulnerable road users, urban cycling guidelines.

1 INTRODUCTION

A successful promotion of cycling as a mode of transportation depends on assuring the safety of cyclists. Next to the analysis of crash risks and how to reduce them, cyclists' subjective safety has attracted a lot of research in the last couple of years. Subjective safety has been found to differ depending on, for example, gender [1] or age [2]. Other studies assessed which streets and traffic situations are perceived as more dangerous or safer across individual cyclists (e.g. [3], [4]). In these studies, higher speed limits decreased subjective safety. Furthermore, bike lanes separated by a large buffer or bike boulevards were perceived as safer than cycling on the road, but significantly less safe than any form of protected bike tracks. However, subjective safety is not only determined by the traffic infrastructure itself, but by the behavior of and the interaction with other road users. Only of a very limited number of studies has been concerned with risk perception and subjective safety of the same traffic situations from the perspective of different road users. These studies were primarily concerned with educational issues and did not include systematic comparisons between different perspectives (e.g. [5]). The crucial question is whether a given street design conveys the same subjective safety to different user groups, and what happens if it does not. This is highly relevant because risk perception has been found to affect the likelihood of risky behavior (e.g. [2], [6]). Thus, we argue that it is important to consider (subjective) safety not only from cyclists' perspective, but contrast it to that of drivers as well. If one group of road users experiences a traffic situation as safe, they may adjust their behavior in a way that leads to further impairments of the subjective safety of the more vulnerable road user group.

2 METHOD

We investigated the large-scale survey developed and conducted by 'FixMyCity GmbH', where participants rated the safety level of a wide range of traffic situations illustrated via computer-generated images. The survey was published in the winter 2019/2020 on the website of 'Der Tagesspiegel', a newspaper based in Berlin City, Germany. Participants were first asked to answer demographic and cycling-related questions. Next, they were presented a block of ten randomly selected images showing the perspective of a cyclist (i.e. with a handlebar visible on the bottom of the screen). They were asked to rate how safe they would feel when imagining to cycle at each of the presented locations on a four-point scale (0 = 'unsafe'; 1 = 'rather unsafe'; 2 = 'rather safe'; 3 = 'safe'). Participants could opt to rate additional blocks consisting of ten new images each. In the additional blocks, they could also choose the perspective of a pedestrian (not considered in this research) or of a car driver (with a steering wheel, a dashboard, and a central rear mirror visible at the edges of the screen). Within three months, about 21.500 people participated in the survey and rated about 460.000 images. For further details concerning the survey, see https://radwege-check.de/report. In this research, we focus on two specific cases. The first case concerns cyclists and cars sharing minor streets. The central variable concerns the designation of the street as a cycling boulevard. In the second case, we look at the design of unprotected paint-on cycling lanes at main streets. A detailed description of all factors included or excluded from our analysis is beyond the scope of this summary and will be described in [7].

3 RESULTS

For both cases, we computed a generalized linear model, with the safety rating as an ordinal dependent variable, and various demographic and road design variables as independent variables. Due to space constraints, we refrain from providing statistical details, but summarize the most central effects and findings.

3.1 Case 1: Effects of designating minor streets as cycling boulevards

The central variable of Case 1 was whether the road was designated as a cycling boulevard with a prominent, blue indication or rather unobtrusively with a small, white indication. These instances were contrasted to a standard road. The distribution of the corresponding safety ratings from cyclists' and drivers' perspective, respectively, is shown in Figure 1. In general, mixed traffic in minor streets is perceived as rather unsafe or unsafe by the majority of both cyclists and drivers. We also found a strong interaction between road designation and perspective. In particular, a prominently indicated cycling boulevard increased the safety ratings of cyclists more than that of drivers. This was the only situation we identified where cyclists rated a traffic situation as safer than the car drivers did. In other words, prominently designated cycling boulevards do apparently impress the intended priority of cyclists over cars.

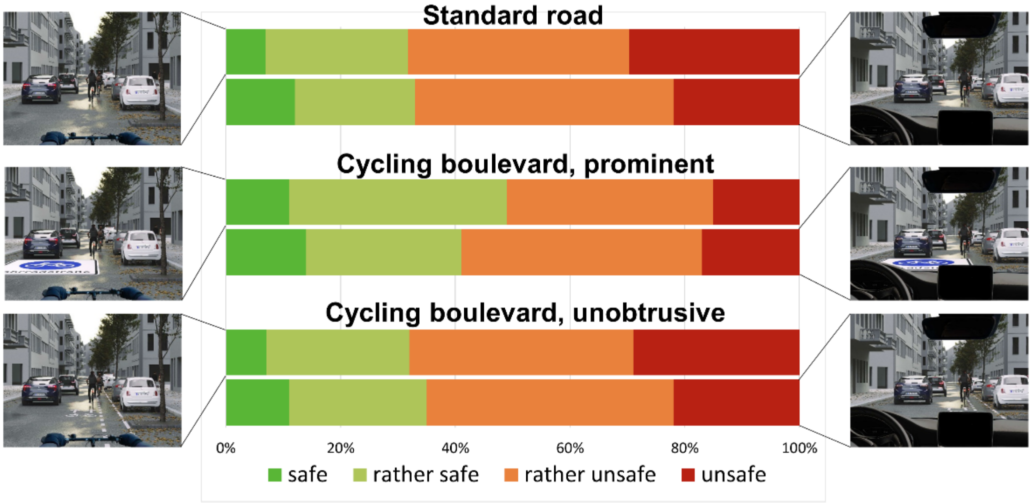


Figure 1. Distribution of safety ratings in Case 1, separately for perspective and road designations.

3.2 Case 2: Effects of cycling lanes on main streets

An initial inspection confirmed that both cyclists and drivers greatly disliked travelling on main roads in mixed traffic featuring no dedicated cycling infrastructure. In contrast, physical separations resulted in a very high safety score for both user groups. However, the discrepancy between cyclists' and car drivers' safety ratings across all types of cycling lanes was quite pronounced and deserved further investigation.

The central effect of Case 2 was a three-way-interaction between perspective, cycling lane width, and right buffer. Figure 2 shows that cyclists rated wide cycling lanes next to parked cars only slightly less safe than drivers did, and almost equally safe in the absence of parked cars. On narrow cycling lanes, there is little change in drivers' safety ratings of, but a severe drop in cyclists' safety ratings. This drop is particularly pronounced when cyclists travel along parked cars. Without parked cars, cyclists' safety ratings approach that of drivers' again. In other words, drivers do apparently not account for the effect of parked cars in their evaluation of the safety of a traffic situation, although this is a major source of discomfort for cyclists.

4 CONCLUSIONS

This research represents one of the first systematic comparisons of the subjective safety different road user groups associate with specific road designs. Our findings imply that discrepancies between the perception of different road user groups are an as of yet under-researched topic with the potential to shed light on mechanisms underlying subjective and objective traffic risks. Taken together, sharing a road without physical separation or clear prioritization feels unsafe for cyclists and drivers alike. The assignment of sufficient space is crucial for subjective safety, especially in the presence of parked cars. A narrow cycling lane improves drivers' subjective safety at the expense of cyclists' subjective safety, thus counteracting its original intention.

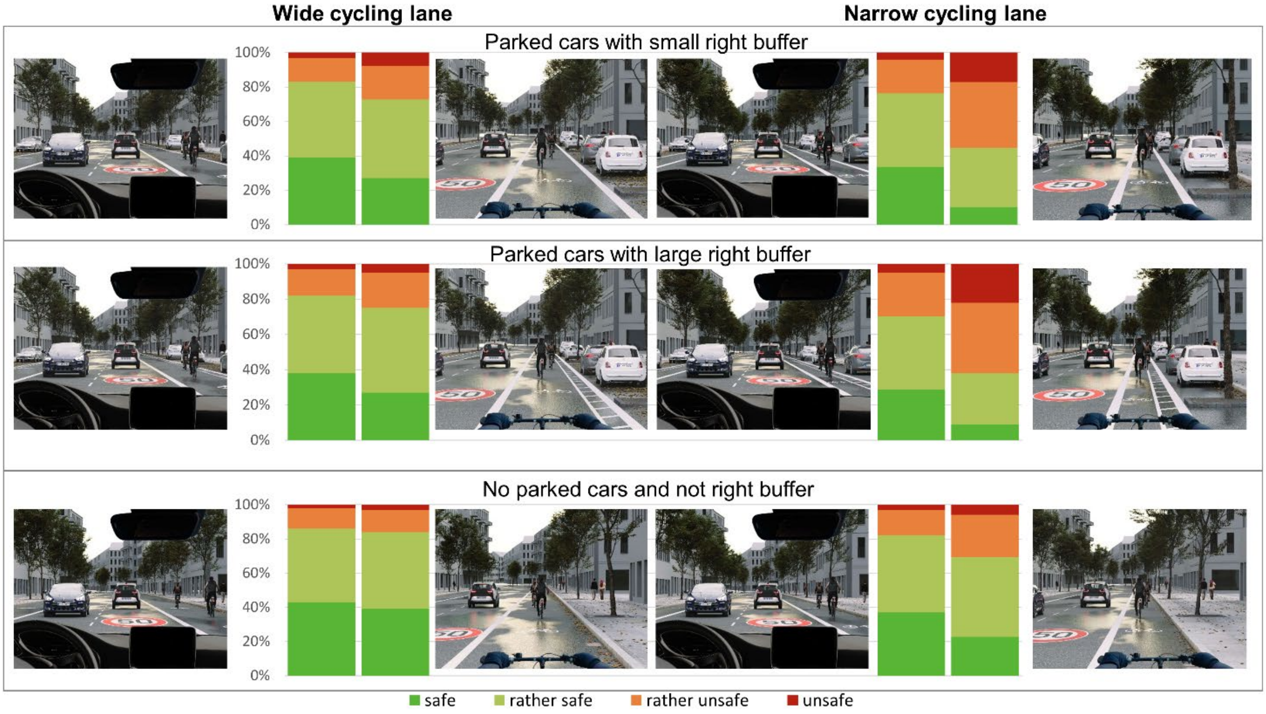


Figure 2. Distribution of safety ratings in Case 2, separately for perspective, cycling lane width, and right buffer.

REFERENCES

[1] T. Götschi, A. Castro, M. Deforth, L. Miranda-Moreno, and S. Zangenehpour, "Towards a comprehensive safety evaluation of cycling infrastructure including objective and subjective measures," *J. Transp. Health*, vol. 8, pp. 44–54, Mar. 2018, doi: 10.1016/j.jth.2017.12.003.

[2] S. A. Useche, L. Montoro, J. Sanmartin, and F. Alonso, "Healthy but risky: A descriptive study on cyclists' encouraging and discouraging factors for using bicycles, habits and safety outcomes," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 62, pp. 587–598, Apr. 2019, doi: 10.1016/j.trf.2019.02.014.

[3] R. von Stülpnagel and N. Binnig, "How safe do you feel? - A large-scale survey concerning the subjective safety associated with different kinds of cycling lanes," *Accid. Anal. Prev.*, vol. 167, pp. 1–10, 2022, doi: 106577.

[4] N. McNeil, C. M. Monsere, and J. Dill, "The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists," *Transp. Res. Rec.*, vol. 2520, no. 1, pp. 132–142, 2015.

[5] C. Castro, I. Muela, P. Doncel, and P. García-Fernández, "Hazard Perception and Prediction test for walking, riding a bike and driving a car: 'Understanding of the global traffic situation,'" *PLOS ONE*, vol. 15, no. 10, p. e0238605, Oct. 2020, doi: 10.1371/journal.pone.0238605.

[6] A.-M. Kummeneje and T. Rundmo, "Attitudes, risk perception and risk-taking behaviour among regular cyclists in Norway," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 69, pp. 135–150, Feb. 2020, doi: 10.1016/j.trf.2020.01.007.

[7] R. von Stülpnagel and H. Rintelen, "Cyclists', car drivers', and pedestrians' assumptions about subjective safety in shared traffic situations," under review.

Towards Understanding the Safety-in-Numbers Effect - A Road-Based Approach

R. von Stülpnagel*, J. Ehlers#, A. Liebscher†

* Abteilung für Kognitionswissenschaft
Universität Freiburg
Hebelstr. 10, 79104 Freiburg, Germany
email: rul.von.stuelpnagel@cognition.uni-freiburg.de

#Institute of Highway Engineering
RWTH Aachen University
Mies-van-der-Rohe Str. 1, 52074 Aachen, Germany
email: ehlers@isac.rwth-aachen.de

†HUK-COBURG Datenservice und Dienstleistungen GmbH
Willi-Hussong-Straße 2, 96444 Coburg, Germany
email: andre.liebscher@hdd-dienste.de

Keywords: safety in numbers, road types, cycling volume, car volume, crash statistics.

1 INTRODUCTION

The 'Safety in Numbers' (SiN) effect proposes that when the volume of cycling traffic increases, the number of crashes increases less (relative to the cycling volume). A meta-analysis supported the general idea of a SiN effect, but also highlighted the heterogeneity of its strength ([1], [2]). The mechanisms producing the SiN effect are still unknown. Possible explanations are (i) that safer street regulations and designs are more likely to exist in societies with more walking and bicycling; (ii) changes in the behavior of people walking or cycling; or (iii) changes in the behavior of drivers. However, all of these explanations have their shortcomings [3]. The authors of the meta-analysis also conclude that the SiN effect is stronger at the macro-level than at the micro-level, but bears no clear relationship to the quality of the cycling infrastructure. A recent approach aimed at linking the SiN effect to specific road types featuring different combinations of speed zones and cycling infrastructures [4]. This study provided preliminary evidence for a SiN effect for those road types with a high average cycling volume (and cycling boulevards in particular). However, this study did not distinguish between street segments and intersections, and did also not account for the local car traffic volume.

In this paper, we outline a work-in-progress research addressing the mentioned shortcomings. In addition to the crash-based SiN effect (i.e. the actually observed number of incidents, relative to the number of cyclists), we also aim at investigating a possible 'subjective' SiN effect (based on the number of reports about subjectively dangerous cycling locations crowdsourced from the general population, relative to the number of cyclists). The underlying reasoning is that cyclists may feel subjectively safer and less anxious to be overlooked by car drivers, the more other cyclists travel along with them. All data are currently aggregated. Results will be available for the conference.

2 DATA SOURCES AND METHODS

2.1 Study area

Our investigation is focused on two German cities, Aachen (about 260.000 inhabitants, modal split cycling: 11 %) and Bonn (327.000 inhabitants, modal split cycling: 16 %). The road network, which is retrieved from OpenStreetMap (OSM), forms the basis on which all information is aggregated. All public roads accessible by motor vehicles are considered for this study. As the risk of cycling-related crashes and the types of crashes differ greatly between junctions and road segments, the road network is subdivided accordingly into junctions and the sections in between. A junction is defined as two roads crossing or touching each other. If the distance between two junctions is less than 25 m, the junctions are merged. The complexity of a junction is defined by the number of segments that compose the junction. The road sections between junctions are divided into segments of up to 25 m in length.

Speed limits are estimated based on vehicle telematics data (see 2.5) because the corresponding data in OSM is partly missing or outdated. For junctions, the minimum and maximum speed limits of the corresponding roads are considered. Cycling facilities are retrieved from OSM and matched to the road network. The cycling facilities are classified into seven categories:

- bicycle_lane: Cycle lane markings on the road
- bicycle_boulevard: Roads that prioritize bicycle traffic but permit motor traffic
- bicycle_separated: Separated cycle tracks with less than 12.5 m distance to the road
- bicycle_separated_far: Separated cycle tracks with distance to the road equal or greater than 12.5 m
- bicycle_opposite: One-way streets where cycling is allowed in the opposite direction
- bicycle_buslane: Shared bike and bus lanes
- bicycle_none: No cycling facilities

Furthermore, the road model includes information about road class, traffic signals, bus stops, tram stops, and tram tracks. These data are retrieved from OSM and are matched to the closest road segment or junction.

2.2 Crash statistics

Crash statistics are sourced from the German federal office of statistics (unfallatlas.statistikportal.de). This data set contains all crashes with personal injury reported to the police. We selected all crashes of cyclists with vehicles, pedestrians, or cyclists within the study area occurring in a 3-year interval (2019-2021), and linked them to the respective road or junction segment. In total, 987 bicycle crashes occurred in Aachen and 1424 bicycle crashes in Bonn during this time period. We do not account for crash type or injury severity.

2.3 Reports about subjectively dangerous locations

Complementing the crash data, we included reports from the website www.gefahrenstellen.de, where road users can mark dangerous locations on an interactive map and provide additional information in a standardized format (e.g. the source of danger or the road user at risk). Users can also comment and support existing reports (for details see [5]). We included reports from a similar time period as the crash data (2018-2021). A total of 939 danger spots with a support count of 4,516 were identified in Aachen, along with 759 danger spots with a support count of 1,847 in Bonn. Each report and the number of supports was linked to the respective road or junction segment. An in-depth analysis of the individual report is beyond the scope of our investigation. However, reports from crowdsourcing projects concerned with cycling safety have been found representative for a larger population [6].

2.4 Cycling volume

Cycling volume data were collected as part of the ‘City-Cycling’ campaign (www.city-cycling.org/home) during a three-week period in the summer of 2022. During the campaign, cycling activities of several thousand participants were tracked and collected with a smartphone app. The data was further processed and projected onto the OSM road network (see [7]). The resulting cycling volume provides a solid estimate of the relative frequencies for each road and junction segment.

2.5 Car traffic volume and speed limits

The car traffic volume (and information about speed limits) were provided by HUK-COBURG, a leading provider of motor insurance in Germany and a pioneer in applied telematics. The HUK-COBURG telematics system can capture kinematic and positional data through an in-car sensor and a smartphone App. This system analyses the behaviour of participating customers with regard to braking, cornering speed, and acceleration, and rewards a safe driving style with a discount on their insurance premium [8]. For our study, the HUK-COBURG Datenservice und Dienstleistungen GmbH aggregated anonymized driving data from a 1-year period (April 2021 - Mai 2022) to provide an estimate of the average daily traffic load (DTV). Using the telematics data, DTV values were computed for each individual road and junction segment, resulting in a granular representation also for small side streets. The telematics-based DTV values were validated with official measurements from traffic census, showing a high level of congruence. Anonymized telematics data were also used to define the speed limit of each road segment through the 85th percentile of the measured speed distribution of the moving traffic on that segment.

2.6 Statistical approach

The planned statistical analysis consists of generalized linear models. The ratio of crashes (and reports about subjectively dangerous locations, respectively) to cyclists per road/junction segment is the dependent variable. The main predictor is the cycling volume itself. A negative effect (i.e. a higher cycling volume predicting a lower crash-ratio) would support the assumption of a SiN effect in general. We will extend the initial models with various infrastructure features (e.g. complexity of junctions, speed limits, cycling facilities, etc.) and the volume of motorized private transport. Interaction terms between these variables and cycling volume allow to examine whether and to what extent the SiN effect is affected by the various road attributes.

3 RESULTS

The data sources described above are currently aggregated. Results will be available for the conference.

4 CONCLUSIONS

The approach outlined in this paper promises detailed insights into the so-far only poorly understood SiN effect. It also extends the analysis of the crash-based SiN effect to a possible ‘subjective’ SiN effect, thus providing additional insights into the relationship between objective and subjective cycling risks. The inclusion and analysis of highly detailed information about both cycling- and car-traffic volume on a street-level is particularly novel. Our results have the potential to provide urban planners and decision makers with guidelines supporting a safe and inviting urban cycling infrastructure.

REFERENCES

[1] R. Elvik and T. Bjørnskau, “How accurately does the public perceive differences in transport risks?,” Accid. Anal. Prev., vol. 37, no. 6, pp. 1005–1011, Nov. 2005, doi: 10.1016/j.aap.2005.05.003.

[2] R. Elvik and R. Goel, “Safety-in-numbers: An updated meta-analysis of estimates,” Accid. Anal. Prev., vol. 129, pp. 136–147, Aug. 2019, doi: 10.1016/j.aap.2019.05.019.

[3] P. L. Jacobsen, D. R. Ragland, and C. Komanoff, “Safety in Numbers for walkers and bicyclists: exploring the mechanisms,” Inj. Prev., vol. 21, no. 4, pp. 217–220, Aug. 2015, doi: 10.1136/injuryprev-2015-041635.

[4] R. von Stülpnagel and M. Bauder, “Is the ‘Safety in Numbers’ effect tied to specific road types? - A GIS-based approach,” in Contributions to the 10th International Cycling Safety Conference (ICSC2022), T. Petzoldt, R. Gerike, J. Anke, M. Ringhand, and B. Schröter, Eds., Dresden, Germany, 2022. doi: https://doi.org/10.25368/2022.368.

[5] J. Olma, T. Bode, J. Ehlers, and C. Sutter, “Road Users’ Reports on Danger Spots: The Crowd as an Underestimated Expert?,” Safety, vol. 8, no. 4, Art. no. 4, Dec. 2022, doi: 10.3390/safety8040070.

[6] R. von Stülpnagel and J. Krukar, “Risk perception during urban cycling: An assessment of crowdsourced and authoritative data,” Accid. Anal. Prev., vol. 121, pp. 109–117, Dec. 2018, doi: 10.1016/j.aap.2018.09.009.

[7] S. Lißner and S. Huber, “Facing the needs for clean bicycle data – a bicycle-specific approach of GPS data processing,” Eur. Transp. Res. Rev., vol. 13, no. 1, 2021, doi: 10.1186/s12544-020-00462-2.

[8] C. P. Holland and D. John, “HUK-COBURG: The Implementation of an AI-Enabled Behavioural Insurance Business Model using Geo-Spatial Data,” in Proceedings of the 56th Hawaii International Conference on System Sciences, 2023, pp. 5082–5091.

Older and Younger Cyclists: Exploring the relationship between neuropsychological task performance and inner-city cycling behaviour

F. Westerhuis*, D. de Waard#

*Faculty of Behavioural and Social Sciences
University of Groningen
Grote Kruisstraat 2/1, 9712 TS, Groningen,
The Netherlands
email: f.westerhuis@rug.nl

Faculty of Behavioural and Social Sciences
University of Groningen
Grote Kruisstraat 2/1, 9712 TS, Groningen,
The Netherlands
email: d.de.waard@rug.nl

Keywords: ageing, cognition, observation, mental effort, city cycling.

1 INTRODUCTION

A considerable proportion of Dutch inner-city traffic consists of cyclists. For this reason, the infrastructure in the Netherlands is one of the most cyclist-orientated in the world [1]. Many Dutch people use their bicycles for everyday activities such as recreating, going to friends and family, shopping, or commuting [2]. Unfortunately, however, the popularity of cycling also brings a major disadvantage: the number of cycling crashes and fatalities in the Netherlands have substantially risen over the past years [3]. Cyclists remain very vulnerable road users and there is still much to improve with regard to their safety.

Research indicates that older cyclists have an increased risk of being severely injured or killed after a bicycle crash [3,4,5]. There are multiple possible mechanisms behind this increased risk, either associated with age-related decline in physical or cognitive abilities, increased physical fragility, or a combination of these [5]. Because cycling is a highly effective means of transportation, and also contributes to healthy ageing, it is important to support older cyclists and prevent crashes from occurring [6]. With regard to cognition, research has shown that age-related decline in executive functioning, reaction speed, and information processing speed may be related to the increased crash risk of older cyclists [5]. Even though it is known that (older) cyclists may compensate for such impairments, for example by avoiding crowded times or situations, selecting (or avoiding) specific types of infrastructure, or taking more time while cycling (i.e., decreasing speed), there is little information available about the relationship between specific cognitive performance measures, age, and concrete on-road cycling behaviour. For this reason, the aim of this study is twofold: (1) to compare cycling behaviour of older and younger cyclists through inner-city traffic and (2) to explore potential relationships between cognitive test performance and cycling manoeuvres in a realistic traffic context.

2 METHODS

In 2017 and 2018, we performed studies in which older and younger cyclists performed three neuropsychological tasks, followed by a bicycle ride on their own bicycle. During the bicycle ride, the participant's cycling behaviour was observed and measured while cycling a predefined route through the city of Groningen. In addition, the participants answered multiple questions about their experience during the ride and their own cycling behaviour.

2.1 Participants

A total of 34 older and 41 younger cyclists participated in the study. Participants were recruited by the informal network of the researchers and through the word of mouth. The mean age of the older cyclists was

69.6 (SD: 5.0) years and the younger cyclists were on average 21.1 (SD: 1.6) years old. The main requirement for participation was the ability to cycle independently through city traffic and having an age under 25 years or above 60 years for the younger and older cyclists, respectively.

2.2 Lab tasks

At the start of the session, each participant first performed three neuropsychological tasks on a laptop (Vienna Test System; Schuhfried [7]). With these tasks, neuropsychological abilities such as attention (Trail Making Test; TMT), reaction time (RT), and building an overview of traffic situations (Adaptive Tachistoscopic Traffic Perception Test; ATAVT) were measured.

2.3 Bicycle ride

After the neuropsychological tasks, each participant made a bicycle ride of approximately 6 km through the city of Groningen on his or her own bicycle. During this ride, cycling behaviour was video recorded with a small GPS action camera mounted on the handlebars of the bicycle. The participants did not know the route beforehand and a researcher provided turn-by-turn instructions (through a walkie-talkie) while cycling behind the participant. The researcher's bicycle was instrumented with a similar camera as well to observe the participant's behaviour from behind (e.g., head movements, indicating direction with the arms). The route consisted of multiple types of infrastructure (e.g., one and two-directional cycle paths, roads shared with motorized traffic, intersections with and without traffic lights, and a roundabout). After passing three intersections on which the participants made a left-hand turn, they were asked to shortly park their bicycle and evaluate the invested mental effort while performing that particular manoeuvre.

2.4 Analyses

Lateral Position (LP), amount of swerving (Standard Deviation of the Lateral Position; SDLP), and speed (km/h) were determined based on the recorded video and GPS data. Behaviour of older and younger cyclists is compared on different types of infrastructure and correlations between neuropsychological test scores and in-traffic manoeuvres will be analysed.

3 RESULTS

The first preliminary analyses show that the younger participants completed the ATAVT and TMT-B task in significantly less time than the older participants. The mean reaction times of the younger participants were significantly shorter as well. The overall "Traffic Overview" scores on the ATAVT, however, does not differ between the older and younger participants. With regard to cycling behaviour, older cyclists approached an intersection on which they turned left significantly slower than younger cyclists. Furthermore, only in the older cyclists group, a significant moderate correlation was found between the approaching speed before the intersection, and the time to complete the TMT-B test. This relationship was not found in the younger cyclists group.

4 CONCLUSIONS

The results may potentially be used to support older cyclists (with cognitive decline) by means of a targeted approach.

REFERENCES

[1] P. Schepers, D. Twisk, E. Fishman, A. Fyhri, and A. Jensen, "The Dutch road to a high level of cycling safety", *Safety Science 92* (2017), pp. 264-273.
[2] Kennisinstituut voor Mobiliteitsbeleid, "Mobiliteitsbeeld 2019", Ministery of Infrastructure and Watermanagement, The Hague, 2019.
[3] Centraal Bureau voor de Statistiek (CBS), "Meer verkeersdoden in 2022, vooral fietsende 75-plussers vaker slachtoffer", *Centraal Bureau voor de Statistiek* (2023), retrieved on 19-03-2023 from

https://www.cbs.nl/nl-nl/nieuws/2023/16/meer-verkeersdoden-in-2022-vooral-fietsende-75-plussers-vaker-slachtoffer
[4] I. Krul, H. Valkenberg, S. Asscherman, C. Stam and K. Klein Wolt, “Fietsongevallen en snor-/ bromfietsongevallen in Nederland: SEH-bezoeken: inzicht in oorzaken gevolgen en risicogroepen”, VeiligheidNL, Amsterdam, 2022.
[5] J.P. Schepers, W.A.M. Weijermars, M.J. Boele, A. Dijkstra and N.M. Bos, “Oudere fietsers: Ongevallen met oudere fietsers en factoren die daarbij een rol spelen”, SWOV, The Hague, 2020.
[6] F. Westerhuis, *Advancing the Age of Cycling*, PhD Thesis University of Groningen, Groningen, 2021.
[7] G. Schuhfried, “Vienna Test System, Psychological Assessment”, Moedling, Schuhfried, 2013.

Enhancing Cycling Safety with Advanced Analysis of Accident Data: Techniques for Evaluating the Pre-Crash-Phase

Angela Schubert*, Marcus Petzold*, Thomas Unger*, Henrik Liers*

* VUFO - Institute for Traffic Accident Research at TU Dresden
Semperstrasse 2a, 01069 Dresden, Germany
email: angela.schubert@vufo.de, marcus.petzold@vufo.de, thomas.unger@vufo.de, henrik.liers@vufo.de

Keywords: traffic accident data, GIDAS, GIDAS-PCM, conflict situation, scenario, cycling safety, pre-crash.

1 OBJECTIVE

The road safety of cyclists is a major concern for many individuals and organizations around the world. We will focus on exploring in-depth accident data and how the findings can be used to improve the safety for cyclists. We will delve into the ways in which detailed accident data can be used to identify patterns and trends, understand the causes of accidents, and help to develop effective strategies to prevent future incidents. These valuable insights can support several stakeholders to derive safety strategies, e.g., city planners, policymakers, researchers, and cyclists themselves. We will explore how data analytics and accident scenario evaluations can be leveraged to support the development of vehicle connectivity, and hence to avoid bicycle accidents. Our aim is to spark new ideas and approaches that can ultimately make public roads safer for all.

2 DATA SOURCE

Data from the German In-Depth Accident Study (GIDAS) database is used for this analysis. Since 1999, GIDAS has been collecting data on accidents with personal damage in two investigation areas in Germany (Dresden and Hanover) and their surroundings. For each accident, investigators record about 3,500 individual data points directly on the spot and in the hospital. Additionally, the entire accident sequence is reconstructed in high detail, starting with the accident initiation phase and the reactions of the involved participants, followed by the collision up to the final position of the involved participants. Characteristic variables such as braking behavior, initial and collision speed of the involved road users are determined. A detailed sketch of the accident scene is made, and the involved participants are interviewed after consent. After the application of a weighting procedure, GIDAS data can be considered as representative for the German accident scenario.

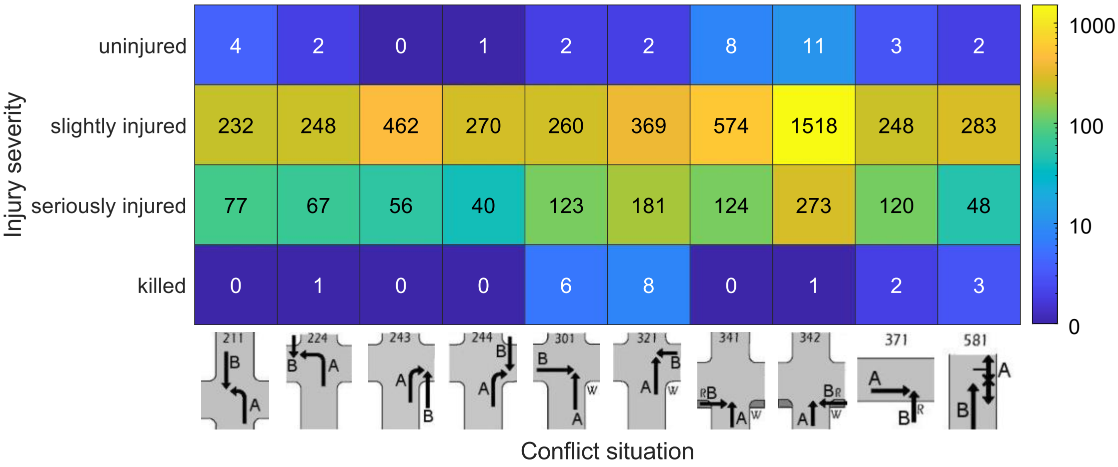
The pre-crash phase, defined as the sequence before the first collision, is stored in a database called GIDAS-PCM (Pre-Crash-Matrix). The datasets include the movement behavior and a replication of the environment like vision-obscuring objects and road markings (displayed in Figure 1). This provides information about the position of the accident participants over time.

Figure 1: Visualisation of the pre-crash-phase of a crossing bicycle with right of way from bicycle lane right and straight (green – bicycle, red – passenger car, ocher – buildings)

The GIDAS database currently contains 14,920 cyclists who were involved in crashes from 1999 to 2022, from which 3,445 are included in the GIDAS-PCM.

3 ANALYSIS OF CONFLICT SITUATIONS

In the GIDAS database, the accident type [1] is coded, which characterizes in detail the conflict situation that caused the accident. Based on this accident type, we identified the ten most frequent conflict situations in car-to-bicycle accidents. Using the available information about the injury severity of the involved cyclists, the conflicts in which the most severe injuries occur can be determined as shown in Figure 2.



	211	224	243	244	301	321	341	342	371	581
uninjured	4	2	0	1	2	2	8	11	3	2
slightly injured	232	248	462	270	260	369	574	1518	248	283
seriously injured	77	67	56	40	123	181	124	273	120	48
killed	0	1	0	0	6	8	0	1	2	3

Figure 2: The top-ten conflict situations plotted against the injury severity of the cyclist.

The most frequent conflict situation, also for serious injuries, is the crossing bicycle coming from the right from a bicycle lane or sidewalk. Subsequently, we evaluated the movement trajectories, speeds and braking behavior before the collision for this conflict scenario.

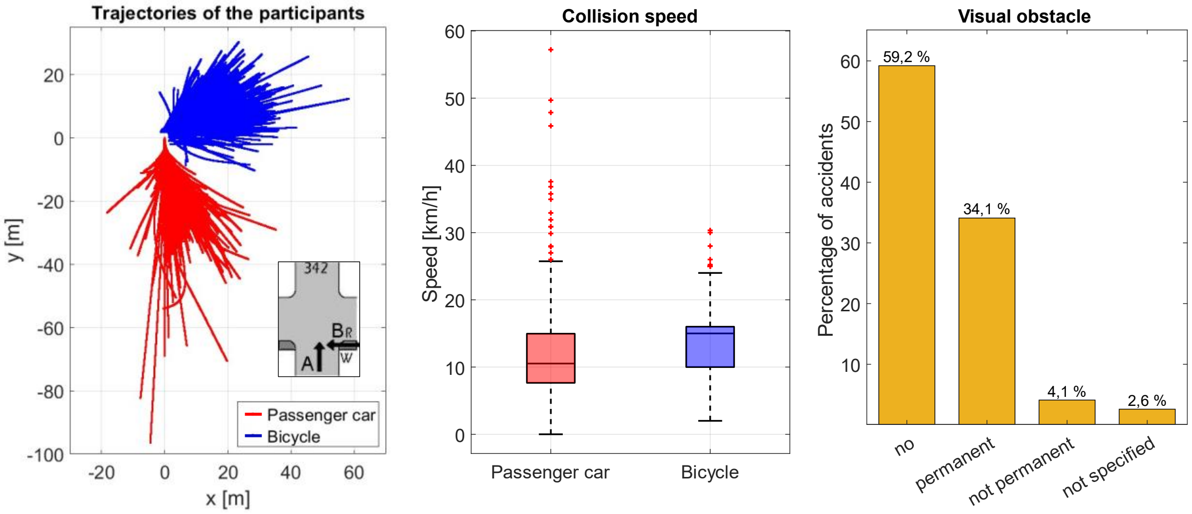


Figure 3: Trajectories, boxplot of velocities, and frequency of visual obstructions for the most frequent conflict situation between cyclists and passenger cars - crossing bicycle coming from the right from a bicycle lane or sidewalk (342)

By evaluating the movement behavior in conjunction with an environmental analysis and evaluation of the participant interviews, specific causes of accidents can be identified, which can concern e.g., the infrastructure and traffic routing, visual obstructions, and/or incorrect behavior of all participants (Figure 3) [2]. This methodology is also transferable to single bicycle accidents, which have increased in frequency in recent years.

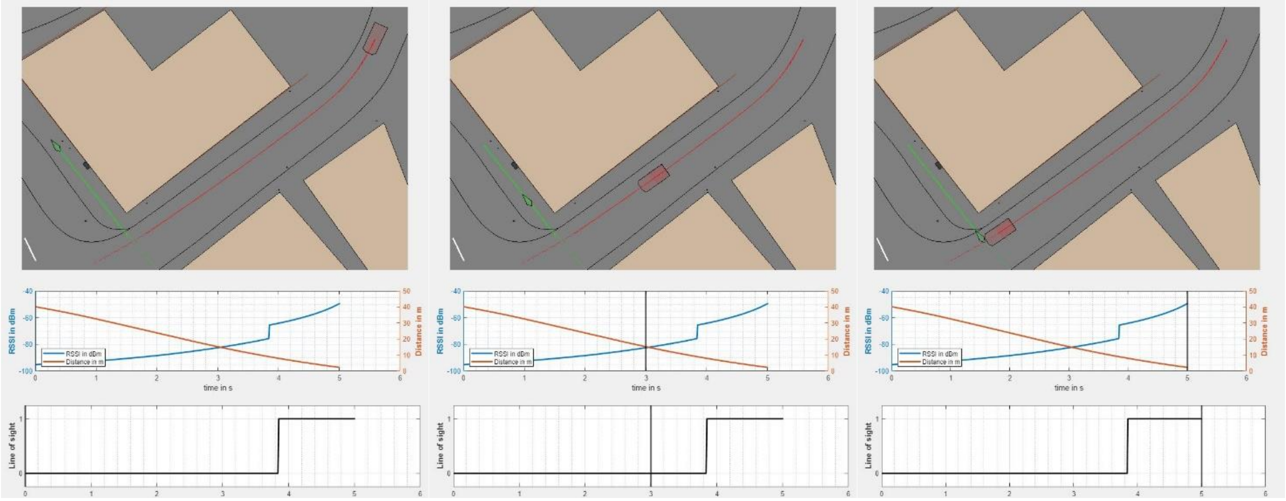


Figure 4: Radio-based communication model between road users: Received Signal Strength Indicator (RSSI) - blue, distance of road users – red, line of sight - black

Furthermore, we have developed a methodology to calculate the Time-To-Collision based on the current movement behavior and to evaluate the criticality of the situation in the course of the pre-collision accident phase in order to assess a scenario. This could be used to find suitable safety strategies for collision avoidance, e.g. ADAS, connective systems as well as the design of bicycle routing and the change of the human behavior. To apply connective systems in conflict scenarios, we designed a software-based method that complements the pre-crash data sets with modeled values for signal reception strengths for radio-based communication between road users (Figure 4) [3][4]. This would allow the cyclist to be warned about the passenger car, which is not visible until shortly before the collision.

4 SIGNIFICANCE

The study concludes that in-depth accident data can provide valuable insights into cycling safety and help to develop effective countermeasures to reduce the number of accidents and improve the overall safety of urban cycling.

REFERENCES

[1] GDV, Unfallforschung der Versicherer. (2016). *Unfalltypen-Katalog - Leitfaden zur Bestimmung des Unfalltyps.* Berlin. Retrieved from https://www.udv.de/resource/blob/80022/89b4d80028aacf8cab649d3a3c6157a0/unfalltypenkatalog-data.pdf

[2] Petzold, M. (2021). Derivation of Scenario-based Test and Inspection Catalogs based on real Accident Data. *carhs SafetyWeek.* Würzburg. Retrieved from https://www.vufo.de/wp-content/uploads/2021/12/SafetyUpDate2021_16_Petzold_VUFO.pdf

[3] Richter, R., & Petzold, M. (2022). V2X Communication as a Tool for Accident Prevention. *Car 2 Car Forum .* Dresden.

[4] Werner, M. (2017). *Nachrichtentechnik: Eine Einführung für alle Studiengänge* (8 ed.). Wiesbaden: Springer Vieweg.

Required field of view of a sensor for an advanced driving assistance system to prevent heavy-goods-vehicle to bicycle accidents

E. Tomasch*, H. Hoschopf*, K. Ausserer#, J. Rieß#

*Vehicle Safety Institute
Graz University of Technology
Inffeldgasse 13/6, 8010, Graz, Austria
ernst.tomasch@tugraz.at
hoschopf@tugraz.at

#Factum-apptec ventures GmbH
Slamastraße 43, 1230, Vienna, Austria
karin.ausserer@factum.at
jannik.riess@factum.at

Keywords: Heavy Good Vehicles, Advanced Assistance Systems, Blind Spot Monitoring

1 INTRODUCTION

Although the number of traffic fatalities in the EU is decreasing, about 20,000 people still die on the roads in the EU [1]. Approximately 1,900 cyclists are killed every year and the number of cyclists killed remains almost constant over the past years. Passenger cars are the most frequent opponent of fatally injured cyclists in the EU. Collisions with heavy goods vehicle (HGV), however, are more severe due to the high mass and the likelihood of being run over [2–7]. 7 % of the fatal cyclists are victims in collision with heavy goods vehicles. The most frequent crash scenario are right-turning HGVs and the cyclists hit by the front or right side of the vehicle [6]. A major cause of truck versus bicyclist crashes is the inadequate visibility conditions when bicyclists are in the vehicle's blind spot [3,6,8,9].

There are different ways to reduce the number of cyclists killed. The risk can be reduced by increasing the danger awareness of all parties involved, i.e. vehicle drivers as well as cyclists (e.g. blind spot problematic [3]. Likewise, infrastructure measures (e.g. separate signal phases [10,11]) can be taken. Advance driver assistance systems (ADAS) can also positively influence the avoidance of accidents with cyclists (e.g. blind spot monitoring [12]). ADAS are expected to be highly effective in preventing accidents. The European Commission has therefore decided that new vehicles may only be registered with vulnerable road user detection and warning systems in 2022 [13].

The extent to which these systems might influence bicycle accidents has not yet been adequately studied. The objective of the study is to investigate the minimum longitudinal and lateral view of an ADAS in preventing heavy goods vehicle versus bicycle accidents.

2 METHOD

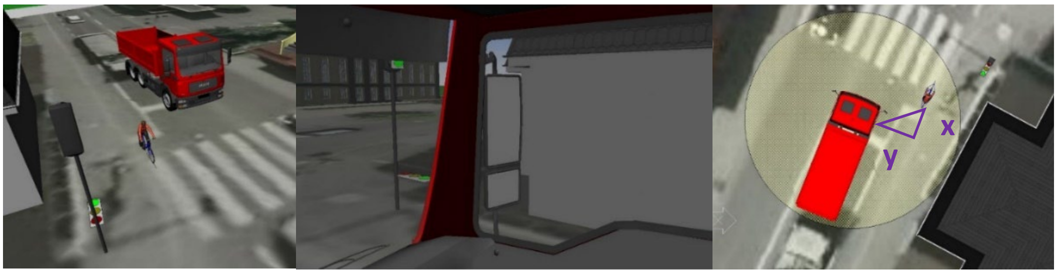


Figure 1: Junction accident with turning to right HGV crossing the bicycle' path (left: front overview; mid: driver's view and obstructed cyclist due to A-pillar; right: top view of the accident scene and the sketch of an ADAS system view)

The methodology used is referred to as prospective effectiveness assessment [14]. In this approach, real traffic accidents are reconstructed to build the baseline. In a second step the reconstructed accidents are simulated again but the vehicles are virtually equipped with an ADAS. This simulation is called treatment.

Within the treatment simulation the minimum longitudinal and lateral view of an ADAS is evaluated able to completely avoid a collision. A symptomatic accident is given in Figure 1. The HGV intends to turn right at the intersection and the cyclist is going straight. The cyclist is obstructed by the right A-pillar of the HGV and is thus not visible to the driver. An ADAS is positioned on the HGV and is continuously monitoring the blind spot. Two different systems were analysed: a) a warning and b) an autonomous strategy. For both strategies the requirements on the system in longitudinal and lateral direction (field of view) of the sensor were examined (Figure 1 right).

Table 1: Intervention strategies of different systems to avoid a collision for the assessment of the minimum requirements

	Unit	Warning system	Autonomous system
Reaction time	[s]	0.8	0.2
Build up time brake	[s]	0.5	0.5
Braking acceleration	[m/s²]	5	5

The accidents used in this study are based on the road accident database CEDATU (Central Database for In-Depth Accident Analysis) [15]. 38 accidents of HGV with cyclists were available. Most of them are accident scenarios in which the HGV was turning to right and the cyclist going straight (Figure 2, left). Further, crossing accidents and accidents at entrances and accidents in which the HGV is turning to right or left are of importance. Overtaking accidents and lane change accidents are second most important in the national statistics but underrepresented in the CEDATU sample. In about 60% of accidents in Austria, the cyclist is in an area that is not sufficiently visible from the truck, i.e. the accident can be associated to the blind spot.

3 RESULTS

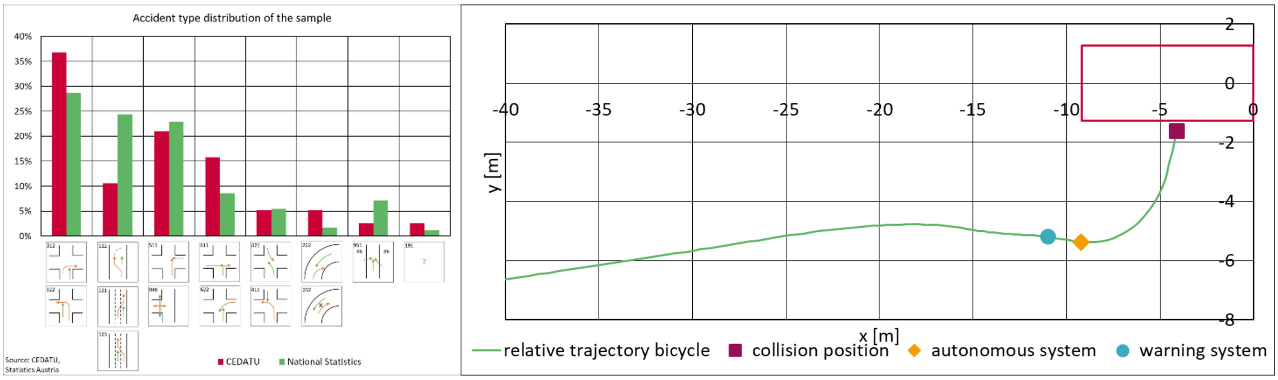


Figure 2: Accident type distribution of the investigated sample (left) and relative trajectory of the cyclist in relation to the truck with the collision position and the field of view requirements for a sensor to avoid a collision for warning systems and autonomous intervening systems (right)

Figure 2 (right) shows the relative trajectory of a cyclist in relation to the truck as an example of an accident with a truck turning right and a cyclist going straight ahead. The collision position was on the right side of the truck. With the assumptions made in the Table 1, a warning system would require a view of 11 metres longitudinal and 5.2 metres lateral. An autonomously intervening system would need 9 metres in longitudinal direction and a lateral view of 5.5 metres to avoid this collision.

4 CONCLUSIONS

The driving path of a HGV differs significantly from that of a passenger car. In order to turn right at an intersection, a truck may have to move out to the left, as the driver has to take into account the trajectory of the trailer.

According to the manufacturers' specifications, systems become active only at a speed of 10 km/h. About one third of the trucks were accelerating from a stopped position (e.g. at a junction) and failed to see the cyclist. For these accidents, even an assistance system would not be effective. In particular, if cyclists are outside of the field of view, it is not possible to avoid the collision after the sensor has been activated.

At the time it becomes apparent that the HGV and cyclist are crossing each other's path, it is not possible to stop in time before the collision due to physical limitations. To avoid these accidents, the cyclist's driving path would require to be known in advance.

For optimum effectiveness, the appropriate lateral zones must remain free from obstructions, i.e. parked vehicles, vegetation, etc.

5 ACKNOWLEDGEMENT

This study was funded by the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) by grants of the Austrian Road Safety Fund (VSF).

REFERENCES

[1] European Commission, Collision matrix: Road Traffic Fatalities in the EU in 2021, Brussles, Belgium, 2023, February.

[2] M. McCarthy, K. Gilbert, Cyclist road deaths in London 1985–1992: Drivers, vehicles, manoeuvres and injuries, Accid. Anal. Prev. 28 (1996) 275–279. https://doi.org/10.1016/0001-4575(95)00061-5.

[3] W. Niewoehner, A.F. Berg, Endangerment of Pedestrians and Bicyclists at Intersections by Right Turning Trucks: Proceedings - 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, D.C., June 6-9, 2005, Washington DC, 2005.

[4] A.D. Ackery, B.A. McLellan, D.A. Redelmeier, Bicyclist deaths and striking vehicles in the USA, Inj. Prev. 18 (2012) 22–26. https://doi.org/10.1136/injuryprev-2011-040066.

[5] M. Bíl, M. Bílová, M. Dobiáš, R. Andrášik, Circumstances and causes of fatal cycling crashes in the Czech Republic, Traffic Inj Prev 17 (2016) 394–399. https://doi.org/10.1080/15389588.2015.1094183.

[6] S. Kockum, R. Örtlund, A. Ekfjorden, P. Wells, Volvo Trucks Safety Report 2017, 2017.

[7] A. Edwards, A. Barrow, S. O'Connell, V. Krishnamurthy, R. Khatry, N. Hylands, M. McCarthy, S. Helman, I. Knight, Analysis of bus collisions and identification of countermeasures, Report status/version: first.first, TRL, Wokingham, Berkshire, United Kingdom, 2018.

[8] P. Evgenikos, G. Yannis, K. Folla, R. Bauer, K. Machata, C. Brandstaetter, Characteristics and Causes of Heavy Goods Vehicles and Buses Accidents in Europe, Transportation Research Procedia 14 (2016) 2158–2167. https://doi.org/10.1016/j.trpro.2016.05.231.

[9] S. Summerskill, R. Marshall, Understanding direct and indirect driver vision in heavy goods vehicles - Summary Report, Loughborough University, 2016.

[10] T. Richter, J. Sachs, Turning accidents between cars and trucks and cyclists driving straight ahead, Transportation Research Procedia 25 (2017) 1946–1954. https://doi.org/10.1016/j.trpro.2017.05.219.

[11] P. Pokorny, K. Pitera, Truck-bicycle safety: an overview of methods of study, risk factors and research needs, Eur. Transp. Res. Rev. 11 (2019). https://doi.org/10.1186/s12544-019-0371-7.

[12] H. Hoschopf, E. Tomasch, Limitations and challenges of avoiding HGV-VRU accidents through advanced driver assistance systems, in: 8th International Conference on ESAR "Expert Symposium on Accident Research", Hannover, 2018.

[13] European Commission, Road safety: Commission welcomes agreement on new EU rules to help save lives, Brussels, 2019.

[14] P. Wimmer, M. Düring, H. Chajmowicz, F. Granum, J. King, H. Kolk, O. Op den Camp, P. Scognamiglio, M. Wagner, Toward harmonizing prospective effectiveness assessment for road safety: Comparing tools in standard test case simulations, Traffic Inj Prev 20 (2019) S139-S145. https://doi.org/10.1080/15389588.2019.1616086.

[15] E. Tomasch, H. Steffan, M. Darok, Retrospective accident investigation using information from court, in: Transport Research Arena Europe 2008 (TRA), Ljubljana, Slovenia, 2008.

Injuries with e-bikes: young cyclists at risk

K. Klein Wolt[*], **I. Krul**[#]

[*]VeiligheidNL
Overschiestraat 65, 1062 XD, Amsterdam, the Netherlands
email: k.kleinwolt@veiligheid.nl

[#]VeiligheidNL
Overschiestraat 65, 1062 XD, Amsterdam, the Netherlands
email: i.krul@veiligheid.nl

Keywords: cycling accidents, injury prevention, young cyclists, e-bikes.

1 INTRODUCTION

For years now, cyclists form the largest group of people (67%) visiting the Emergency Department after a traffic accident [1]. In the period 2011-2020 the number of serious injuries with cyclists has increased with 28%, see figure 1.

One fifth of the cycling victims is aged between 12-24 years old. A current development is the increase of electric bicycles (i.e. e-bikes). This increase is also seen in the number of traffic victims riding an e-bike that visit Emergency Departments. Besides a strong increase among people aged 55 years or older, an increase in e-bike victims can also be seen among the age group of 12-24 years. However, it is still unknown what causes these traffic accidents among youngsters riding an e-bike, and if the chances of visiting an Emergency Department are higher when riding an e-bike compared to riding a normal bicycle.

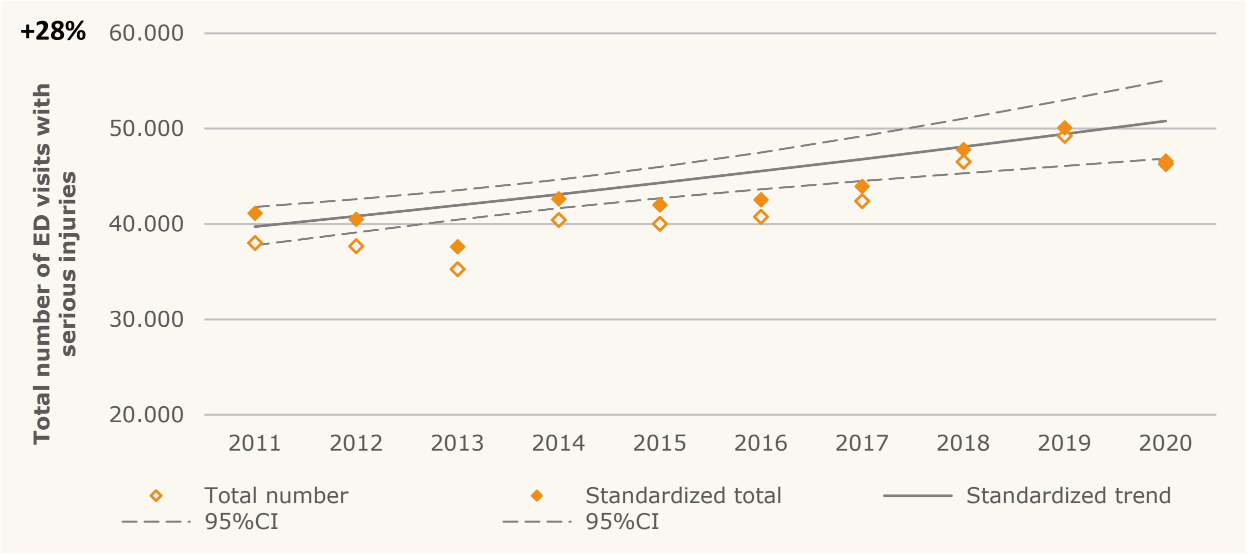


Figure 1: Traffic injuries; yearly number of Emergency Department visits with serious injuries due to a cycling accident, corrected for changes in demographics[1,2]

2 METHOD

Information on traffic victims on Emergency Departments are obtained from the Dutch Injury Surveillance System (DISS) of VeiligheidNL. This is a unique national accident register, consisting of a continuous data collection from Emergency Departments of a representative number of hospitals in the Netherlands. In order to get an up-to-date overview of causes and consequences of traffic accidents involving cyclists and mopeds, VeiligheidNL conducts periodic research among victims of traffic accidents. The most recent study appeared in 2022 [3]. Victims of bicycle accidents who have been treated in one of the Emergency Departments participating in DISS, have been send a questionnaire about their accident. In this questionnaire the victims could indicate in detail how the accident occurred, what role other road users played, but also, for example, the role of infrastructure and the weather. More than 10,000 victims of cycling accidents received the questionnaire. To gain insight into the risks, a comparison was also made between bicycle and moped riders who had had an accident and a representative group (motorized-)bicycle and moped riders who had not had an accident.

3 RESULTS

Between September 2020 and October 2021, a total of 4,208 victims (bicycle and moped) filled in the questionnaire (response rate 39%). Twenty percent of the youngsters aged 12-24 years, rode an e-bike during the traffic accident. In the control group, a total of 3,102 people filled in the questionnaire, of which 21% owned an e-bike. Our first analysis has shown that for the age group 12-24 years, a slight increase in injuries with e-bikes was observed since 2016, but strongly surged in 2021 to a few hundred e-bike victims per year on the Emergency Departments. Further data (i.e. influence of speed, smartphone use and driving under the influence of alcohol or medication) on e-bike accidents among youngsters are currently being analyzed and will be presented at the ICSC in November 2023. We will also look at differences between driving an e-bike compared to a normal bicycle among 12-24 year olds.

4 CONCLUSIONS

Even though e-bikes already exist for some time, we now see an increase in the number of traffic accidents involving youngsters riding an e-bike. VeiligheidNL is currently analyzing this increase in accidents with youngsters and will present their findings at the conference. Knowledge about causes of these traffic accidents can reduce the number of victims by using a risk-based approach.

REFERENCES

[1] Letsel Informatie Systeem 2021, VeiligheidNL.
[2] Bevolkingsstatistiek 2011-2020, Centraal Bureau voor de Statistiek.
[3] LIS-vervolgonderzoek Fietsongevallen en snor-/bromfietsongevallen in Nederland (2021), Letsel Informatie Systeem, VeiligheidNL.

Bicycle safety experienced by cyclists within city limits in The Netherlands

Jeanette van ‘t Zelfde

Royal Dutch Touring Club ANWB
Wassenaarseweg 220
2596EC Den Haag, The Netherlands
email: jvtzelfde@anwb.nl

Keywords: Experiences of cyclists, cyclists behaviour, attitudes of cyclists, cycling safety measures

1 INTRODUCTION

Cycling safety is an important issue in the Netherlands. Numbers of casualties and severe injuries rise, especially under the elderly. Authorities and professionals discuss the possible solutions and measures to be taken, like ‘Should cyclists wear helmets’? In these discussions the opinions of cyclists themselves are not included. Therefore the Royal Dutch Touring Club ANWB did a research among its cycling members to hear their experiences with cycling unsafety and to explore the support base of possible solutions and measures. The Royal Dutch Touring Club ANWB is a non-governmental organization with 5,1 million members with the following mission statement: ‘We want all our members to be on the way in a safe and enjoyable way in a sustainable society.’

2 THE RESEARCH

2.1 Research method

The research was conducted in our panel of ANWB-members. The target group was 18+ members that cycle at least once a month. The number of respondents is 6093. Fieldwork took place during two weeks in July 2022. Respondents filled in an online questionary. The research is representative for age and gender of ANWB-members.

2.2 Major results

__Different types of cyclists, bicycle use motives and judgement of own safety__

In the research we distinguish two groups, riders with a non-electric bicycle and riders with an e-bike (pedelec). They both ride a lot, 8 out of 10 riders ride several times a week. The pedelec is often used for recreational motives. The non-electric bicycle is mostly used for daily care duties.

Both groups stand out in the judgement of their own way of cycling, rated with an 8.4 for safety and an 8.6 for confidence. To ride safely 85% says to always use bicycle lights and 73% takes good care of their bicycle. Respondents with a pedelec tend to take more of these measures than the other bicyclists, and respondents with a pedelec also wear a helmet more often (13% vs 8%). Especially the older people with a pedelec wear helmets (66 year and older is 23%).

16% of the respondents were involved in a bicycle accident in the last three years, of which 50% was a one-sided accident.

Respondents do not fear the fines they could get when riding without bicycle lights, crossing a red light or riding in the wrong direction.

Feelings of unsafety

20% of the respondents always or often feel unsafe *because of other road users*. Situations in which this occurs is for example other road users being distracted by their telephone. A majority of 69% experience these unsafe feelings sometimes.

20% of respondents always or often feel unsafe *because they have to blend with other traffic*. Especially vehicles passing by too close and the velocity of other vehicles make cyclists feel unsafe.

The *difference in speeds and sizes* on cycle paths make 23% of cyclists always or often feel unsafe . This is especially the case for elder people.

The *maintenance of cycling paths* is important, although this point was addressed less (always or often 10%) in relation to unsafety.

Best measures according to cyclists

Respondents were asked to judge different kinds of cycling safety measures, within the themes of infrastructural improvements, law enforcement and new or adjustment of legislation.

Although the maintenance of cycling paths was a less addressed issue regarding feelings of unsafety, *infrastructural improvements* are the most popular cycling safety measures. Improving the quality of road surfaces and widening cycling paths are mentioned by at least half of the respondents. A third of respondents mention the removal of poles and other obstacles.

Law enforcement comes second, especially the enforcement of car speed limits, use of bicycle lights and red light crossing by cyclists.

New or adjustment of legislation comes third. One measure stands out here, 59% of respondents mention priority rules at roundabouts and crossings.

Finally respondents were asked their opinion on specific cycling safety measures. The enforcement of rules regarding the speed of pedelecs and enforcement of offences by cyclists were the two most popular measures according to 81% of respondents. 71% of respondents thought a maximum speed of 25km/hour would be a good measure to make cycling safer. An obligation to wear a helmet is less popular; 64% thinks children under 10 years should be obliged to wear a helmet, 50% is in favour of an obligation of helmets for pedelec riders (but only 35% of pedelec riders agree) and 37% say yes to an obligation for cyclists over 60 years old.

3 PUBLICATION OF THE RESEARCH

The Royal Dutch Touring Club ANWB published the results of this research in November 2022 (https://www.anwb.nl/nieuws/fiets/2022/november/fietsers-voelen-zich-niet-veilig-op-het-fietspad). It got good attention in the media. We use this research for public affairs purposes, convincing local governments to take measures to improve cycling safety within city limits.

4 CONCLUSIONS

I look forward to present this research at the International Cycling Safety Conference 2023. I think this research is important because cyclists themselves were asked to share their experiences with cycling safety and to give their opinion on possible cycling safety measures. Knowing their opinions will rise the support base for safety measures. Cycling safety is a matter of all stakeholders, including cyclists themselves!

REFERENCES

[1] BLAUW Research, *Hoe ervaren ANWB-leden de fietsveiligheid in ons fietsland?,* Rotterdam, 2022 https://www.anwb.nl/binaries/content/assets/anwb/pdf/belangenbehartiging/2022/2022-anwb-onderzoek-veilig-fietsen-def.pdf

Can crowdsourced large-scale near-crash data replace crash data? A comparison of models using both sources

K. Y. Chou, A. F. Jensen, K. H. Janstrup, M. Paulsen, O. A. Nielsen, T. K. Rasmussen

Department of Technology, Management and Economics
Technical University of Denmark
Bygningstorvet 116b, 2800 Kgs. Lyngby, Denmark
email: kuach@dtu.dk

Keywords: Bicycle near-crash, Crowdsourced data, Bicycle crash, Police data.

1 INTRODUCTION

Cycling is increasingly gaining attention as a sustainable transport alternative and bicycle safety is recognized as a main barrier for increasing cycling demand [1]. To explore the hotspots and potential causes of bicycle crashes, most studies used crash data recorded by police or hospitals. However, such crashes mostly involve severe injuries or insurance claims, whereas many minor crashes are often unreported [2]. To overcome the issue of underreporting, bicycle near-crashes, which are incidents that do not cause or only cause slight injuries [3], has been suggested to be surrogate measure for analyzing crash risks [4]. With sensors embedded in bicycles becoming more universal, large amounts of near-crash/crash data can be collected (e.g., [5]), making crowdsourced data a robust source to have precise and profound insights into bicycle safety studies [6]. However, there is still a lack of understanding of the characteristics of bicycle near-crashes, and only few studies conducted a comparative analysis between bicycle crashes and near-crashes (e.g., [7] and [8]). Therefore, this study aims to compare occurrence rates of crashes and near-crashes and to analyze their variation across different infrastructure types.

2 DATA AND METHODOLOGY

2.1 Data sources

Two datasets were used in this study. One is crowdsourced bicycle near- crash data from Hövding - a head protection airbag for cyclists worn around the neck [9]. A sensor in the helmet tracks the movement and acceleration of cyclists and continuously determines the current safety state. Safety states include *normal state* and three levels of *near-crashes* (i.e., to what extent the helmet is about to deploy). Overall, 129,818 near-crashes were recorded from 2019 to 2021 in Metropolitan Copenhagen. The other data source is crash data from the police, which contains conventional crashes reported to the police involving cyclists. Overall, 4,220 crashes were recorded in the same area and period.

2.2 Statistical models of bicycle near-crash and crash

To understand the risk of (near-)crashes and which infrastructure features affect the (near-)crashes risk, occurrence rates of (near-)crashes on each road segment were calculated by dividing the frequency of (near-) crashes by the total bicycle traffic (i.e., exposure). For Hövding near-crashes, the exposure was directly obtained from the users (i.e., we know where each Hövding user has traveled), making the risk assessment more precise [10,11]. For police crashes, however, we do not have such information available, and thus we approximate cyclist flows from a traffic model [12]. We then use a negative binomial (NB) model to model the (near-) crash rate. We chose to use a NB model since using a Poisson model caused overdispersion issues. Equation 1 shows the specification of the NB regression model, where the logarithm of occurrence rate is modeled by a linear combination of explanatory variables.

$$log(Rate_i) = log(\frac{10^5 \times (Near)Accident\ frequency_i}{Annual\ bicycle\ traffic_i \times Length_i}) = \beta_0 + \boldsymbol{\beta_1} \times \mathbf{Infrastructure_i} + \mathcal{E}_i \tag{1}$$

Here Occurrence $Rate$ denotes how many crashes or near-crashes that occur per 100,000 bicycle-kilometer traveled on each road segment i per year. $\mathbf{Infrastructure}$ denotes column vectors of infrastructure variables, including 15 road types, 4 surface types, and 8 point-based infrastructure types. β_0 denotes the intercept, and $\boldsymbol{\beta_1}$ is a row vector containing coefficients for infrastructure and $\mathcal{E}_i$ is the residual.

3 RESULTS AND DISCUSSION

Overall, we modeled Hövding near-crash rates and police crash rates. To address which infrastructure features that cause higher occurrence of near-crashes and crashes, we calculated the expected annual frequency of Hövding near-crashes and Police crashes shown in Figures 1a and 1b, respectively, by multiplying estimated (near-)crash rates with exposures. Generally, the expected number of near-crashes is far higher than the expected number of crashes, identifying risky locations. Compared to crashes, more near-crashes occurred on the small paths or roads that are mostly pedestrian-oriented. This tendency is especially obvious in the southern part of the city center. This might be because cyclists have a higher chance of having near-crashes with pedestrians on such paths or roads, while crashes were not severe enough to be reported to the police. Compared to near-crashes, crashes occurred more often at signalized intersections and roundabouts, which could be due to more cyclists-vehicle conflicts. Overall, bicycle near-crashes and crashes have different occurring patterns, emphasizing the value of stand-alone bicycle near-crash research.

Figure 1. Expected Annual frequency of (a) Hövding near-crash and (b) Police crash per road length

4 CONCLUSIONS

We used large-scale crowdsourced and conventional crash data to explore and compare how different infrastructure features affect the frequency of both bicycle near-crashes and bicycle crashes. We found that the considerable number of bicycles near-crashes available in the data can be used to reveal risky or uncomfortable locations that cannot be identified solely by crash data from police. It is well-known that conventional crash data lacks information about specific types of crashes, e.g., solo-crashes, due to underreporting. In this study, we found that near-crashes occurred frequently on pedestrian-oriented roads, while crashes occur frequently at intersections. Therefore, this study filled gaps in existing studies regarding bicycle near-crashes by focusing on modeling bicycle near-crashes across places with different infrastructure features and identifying unrevealed risky locations. Overall, this study concludes that bicycle crowdsourced near-crashes data and conventional crash data can be used complementarily to effectively disclose crashe-prone hotspots remaining unrevealed, making near-crashes valuable measures for policymakers to improve cycling safety.

REFERENCES

1. Buehler, R., & Pucher, J. (2022). Cycling through the COVID-19 Pandemic to a More Sustainable Transport Future: Evidence from Case Studies of 14 Large Bicycle-Friendly Cities in Europe and North America. *Sustainability*, *14*(12), 7293.
2. Laureshyn, A., Goede, M. de, Saunier, N., & Fyhri, A. (2017). Cross-comparison of three surrogate safety methods to diagnose cyclist safety problems at intersections in Norway. *Accident Analysis & Prevention*, *105*, 11–20.
3. S. Springer, M. Kreusslein, & J.F. Krems. (2020). Shedding Light on the Dark-Field of Cyclists' Safety Critical Events: A Feasibility Study in Germany. *International Cycling Safety Conference*.
4. Marín Puchades, V., Fassina, F., Fraboni, F., De Angelis, M., Prati, G., de Waard, D., & Pietrantoni, L. (2018). The role of perceived competence and risk perception in cycling near misses. *Safety Science*, *105*, 167–177.
5. Gupta, S., V, R., & A, S. (2022). Fall Accident Detection System for Bicycle Riders using Support Vector Machines. *2022 IEEE 11th International Conference on Communication Systems and Network Technologies (CSNT)*, 392–397.
6. Karakaya, A.-S., Hasenburg, J., & Bermbach, D. (2020). SimRa: Using crowdsourcing to identify near miss hotspots in bicycle traffic. *Pervasive and Mobile Computing*, *67*, 101197.
7. Strauss, J., Zangenehpour, S., Miranda-Moreno, L. F., & Saunier, N. (2017). Cyclist deceleration rate as surrogate safety measure in Montreal using smartphone GPS data. *Accident Analysis & Prevention*, *99*, 287–296.
8. Poulos, R. G., Hatfield, J., Rissel, C., Flack, L. K., Shaw, L., Grzebieta, R., & McIntosh, A. S. (2017). Near miss experiences of transport and recreational cyclists in New South Wales, Australia. Findings from a prospective cohort study. *Accident Analysis & Prevention*, *101*, 143–153.
9. Hövding. (2022). *Hövding's official website | Hövding—Airbag for urban cyclists*. https://hovding.com/
10. Saad, M., Abdel-Aty, M., Lee, J., & Cai, Q. (2019). Bicycle Safety Analysis at Intersections from Crowdsourced Data. *Transportation Research Record*, *2673*(4), 1–14.
11. Vanparijs, J., Int Panis, L., Meeusen, R., & de Geus, B. (2015). Exposure measurement in bicycle safety analysis: A review of the literature. *Accident Analysis & Prevention*, *84*, 9–19.
12. Paag, H., Kjems, S., & Hansen, C. O. (2019). COMPASS: Ny trafikmodel for Hovedstadsområdet. *Proceedings from the Annual Transport Conference at Aalborg University*, *26*(1), Article 1.

Coexisting on the Road: A Study on Drivers' Attitudes Toward Cyclists in Czechia

E. Adamovská[*], Z. Dytrt[#], J. Kočková[†], P. Skládaná[†], M. Šimeček[†]

[*]Division of Transport Technologies and Human Factor
Transport Research Centre
Líšeňská 33a, 636 00, Brno, Czech Republic
email: eva.adamovska@cdv.cz

[#] Division of Transport Technologies and Human Factor
Transport Research Centre
Líšeňská 33a, 636 00, Brno, Czech Republic
email: zdenek.dytrt@cdv.cz

[†]Division of Transport Technologies and Human Factor
Transport Research Centre
Líšeňská 33a, 636 00, Brno, Czech Republic
email: jana.kockova@cdv.cz,
pavlina.skladana@cdv.cz,
michal.simecek@cdv.cz

Keywords: attitudes towards cyclist, sharing the road, cyclist-driver interactions.

1 INTRODUCTION

The reluctance of individuals to choose a bicycle as a means of transport can be attributed to the fear of driving in traffic, as evidenced by numerous Czech and foreign studies. In order to achieve national and European sustainability objectives, the underlying reasons for this reluctance must be carefully examined and addressed.

To this end, our study employs both qualitative and quantitative research methods to investigate the attitudes of car drivers toward cyclists on Czech roads. Specifically, we explore drivers' perceptions of cyclists' legitimacy to use the road infrastructure, as well as any associated attitudes, stereotypes, and prejudices. Additionally, we examine the circumstances that shape drivers' attitudes toward cyclists to identify factors that may influence their behavior and actions.

By analyzing these data, our study seeks to provide a better understanding of drivers' attitudes toward vulnerable road users in the Czech Republic. These attitudes can significantly impact drivers' behavior toward cyclists, as previous research has suggested [1]. Therefore, by identifying the root causes of negative attitudes toward cyclists among drivers, our study aims to contribute to effective attitude change efforts and improve relations between individual participants in traffic, ultimately enhancing road safety.

2 METHODS

This research utilizes a mixed-methods approach that combines qualitative and quantitative data collection methods. The combination of these methods provides a comprehensive understanding of the current situation on Czech roads.

The qualitative phase of this research involved conducting two focus group interviews (2 x 8 participants) with car drivers with varying levels of driving experience. The focus groups aimed to explore how drivers perceive the presence of cyclists on the road, the emotions that such encounters evoke, and the attitudes that are activated. The group dynamics of the discussion allowed participants to recall their experiences of encountering cyclists in traffic. This qualitative phase of the research served as a precursor to the quantitative phase, aiding in formulating research questions, hypotheses, and the creation of the questionnaire.

The second phase of the research involved collecting quantitative data through an online survey completed by car drivers (n=500). The investigation sought to ascertain drivers' attitudes towards cyclists and their perceptions of cyclists' legitimacy on the road. Additionally, the investigation aimed to identify factors that influence drivers' attitudes towards cyclists and their perceived legitimacy, as identified in previous foreign research [2]. The study examines the perceived behavior of cyclists and drivers, cyclists' typology and perceived characteristics, communication between these two groups, the influence of infrastructure on drivers' attitudes, and drivers' attitudes towards other social issues such as the environment, politics, and autonomous mobility.

3 RESULTS

3.1 Qualitative research

The focus groups provided valuable insights into Czech drivers' perceptions of cyclists in traffic. Our research aimed to understand their attitudes towards cyclists, which have been previously found to be negative in studies such as Basford et al. [3] and a study conducted for the Department for Transport in London in 2010 [4]. These studies explained that drivers tend to blame cyclists for negative behavior while excusing themselves and other drivers, seeing cyclists as an "out-group." Our findings are consistent with these claims and highlight the role of fear of hurting cyclists in shaping drivers' attitudes towards them. Drivers' negative emotions towards cyclists were often triggered by perceived "careless" behavior, whether it be overly cautious or reckless.

Furthermore, participants perceived a lack of legitimacy for cyclists on the road, with almost all agreeing that it is problematic that cyclists do not have to attend a driving school. This contributes to the perception that cyclists are being favored, as police do not punish them as severely as motor vehicle drivers. Most participants believed that cyclists should not be considered equal road users and should be subject to stricter rules and enforcement. Infrastructure for cyclists was also a topic of discussion, with respondents advocating for separate protected bike lanes, as long as they are not at the expense of other modes of transport. Mutual communication between drivers and cyclists was seen as a challenge, with respondents frustrated by the perceived inability to communicate with cyclists about their intentions.

3.2 Quantitative research

This part of the research is in progress; the results will be available during the summer of 2023.

4 CONCLUSIONS

The findings of this study confirm the results of previous research that indicate some drivers hold negative attitudes towards cyclists. These negative attitudes appear to stem from several factors, including the vulnerability of cyclists, their perceived unpredictable behavior, and the belief that they do not belong on the road. These findings highlight the importance of addressing these negative attitudes towards cyclists in efforts to promote active and sustainable mobility, as well as enhance road safety for all users. Further results are needed to gain a deeper understanding of the root causes of these negative attitudes and develop effective interventions to change them.

REFERENCES

[1] 1 L. S. Fruhen, R. Flin, “Car driver attitudes, perceptions of social norms and aggressive driving behaviour towards cyclists”, *Accident Analysis & Prevention* 83 (2015), pp. 162-170.

[2] L. S. Fruhen, I. Rossen, and L. Kanse, “Changes in car drivers’ attitudes and behaviours, and cyclist numbers following the introduction of a cyclist minimum passing distance law”, *Accident Analysis & Prevention* 156 (2021).

[3] L. Basford, S. Reid, T. Lester, J. Thomson and A. Tolmie, “Drivers’ perceptions of cyclists”, Charging and Local Transport Division, Department for Transport. TRL Report 549. Transport Research Laboratory, Wokingham, UK, 2002.

[4] S. Christmas, S. Helman, S. Buttress, C. Newman and R. Hutchins, “Cycling, Safety and Sharing the Road: Qualitative Research with Cyclists and Other Road Users”, Road Safety Web Publication No. 17. Department for Transport: London, 2010.

The safety of group compared to individual cyclists when cars pass on urban roads in Queensland, Australia

E. M. Rubie[*], N. Haworth[*], N. Yamamoto[#]

[*]Centre for Accident Research and Road Safety - Queensland
Queensland University of Technology (QUT)
130 Victoria Park Road, Kelvin Grove 4059, Australia
email: rubielibby@gmail.com;
n.haworth@qut.edu.au,

[#]School of Psychology and Counselling
Queensland University of Technology (QUT)
Address, Kelvin Grove 4059, Australia
email: naohide.yamamoto@qut.edu.au

Keywords: group riding, lateral passing distance, overtaking, perceived risk, speed.

1 INTRODUCTION

Group cycling has a long history and is popular in many countries. Despite the popularity of riding in groups, the relative safety of groups compared to single cyclists has received little attention from cycling safety researchers (Heeremans et al., 2022). A recent systematic review of motor vehicle passing cyclists studies concluded that little is known about the relative safety of group cyclists compared to individual cyclists when motor vehicles pass (Rubie et al., 2020). The only known studies that have examined LPD, motor vehicle speed and group cycling have focused on two-lane rural roads (Garcia et al., 2020; Kay et al., 2014; López et al., 2020; Moll et al., 2021; Savolainen et al., 2012) but group cycling also occurs in urban and suburban areas (Bauman et al., 2018; Garcia et al., 2020; López et al., 2020). The current study examined the relative safety of groups compared to individual cyclists being passed on two urban roads in Queensland using video recordings. Three safety metrics were examined: lateral passing distance (LPD) between the (inner) cyclist and the motor vehicle, passing speed of the motor vehicle, and following behaviour of the motor vehicle. Four hypotheses were proposed based on previous research:

H1. When riding two-abreast, the LPD to the rider closest to the vehicle will be less than in passes of individual cyclists.

H2. When riding in single file, group cyclists will be passed with the same LPD as individual cyclists.

H3. The vehicle speed will be lower when passing group cyclists compared to individual cyclists.

H4. Group cyclists will have a higher rate of being followed than passed compared to individual cyclists.

2 METHOD

The passing events used in this study were recorded in May 2015 as part of the evaluation of the Minimum Passing Distance law in Queensland (Schramm et al., 2016). The passing manoeuvre was not broken down into the four passing stages described by Dozza et al. (2016) because the video data only showed short sections of road. Only passes by cars (including medium-sized SUVs) were included. To maximize video clarity, only passes between the hours of 6.30 am and 3.30 pm were used. Two sites were chosen which had sufficient passing events of individual and group riders that were close to the camera to facilitate measurement of passing distance. The low-speed site was a busy urban, 40 km/h two-lane road with provision for parking on both sides of the road, as well as many pedestrians. The high-speed site was a suburban arterial with a 70 km/h speed limit and a wide paved shoulder delineated by an unbroken line.

Motor vehicle speeds were calculated manually using the technique described by Apasnore et al. (2017). To measure lateral passing distance, the first step was to measure the roadway lane width using Google Maps measuring tool, once this was completed, a still image was generated showing the closest stage of the relevant passing event. Using Microsoft Paint 3D, straight lines were drawn on each image so the distance could be calculated.

Car following was defined as per Kassim et al. (2018) where a motor vehicle followed a cyclist or group of cyclists through the study area without attempting to pass. Passing events occurred if the motor vehicle passed in the study area. Group cyclists were matched to individual cyclists in time (within 30 minutes of the group cyclist pass), and when similar traffic factors were present.

2.3 Analysis

Descriptive statistics were reported for the number and characteristics of cyclists. To identify and model factors that influence LPD and motor vehicle speed for the two sites, General Linear Models (GLM) were applied (Field, 2018) using the backwards stepwise approach with alpha set at .05. Binary Logistic Regression (BLR) was applied (Field, 2018) to identify factors that influenced car following or passing behaviour.

3 RESULTS

On the low-speed road, 171 passes were analysed (108 individual, 51 single file group and 12 two-abreast). On the high-speed road, 72 passes were analysed (41 individual, 18 single file group, 13 two-abreast).

3.1 Lateral passing distance

LPDs were greater when cars passed group compared to individual cyclists on both the low- and high-speed roads. On the low-speed road, individual cyclists were passed 19 cm closer than two-abreast cyclists (after adjusting for parked and oncoming vehicles). The model for the low-speed road had a low predictive ability with an adjusted R^2 of 0.15, but the predictive ability for the high-speed road was greater (adjusted R^2 of 0.51). Cyclists riding two abreast received the largest LPD, 112 cm further than individual cyclists. Single file group cyclists were passed 98 cm closer than two-abreast cyclists. H1, that the rider closest to the vehicle (when riding two-abreast) will be passed with smaller LPD was not supported. H2, that single file group cyclists will be passed with the same LPD as individual cyclists was also not supported.

3.2 Motor vehicle speed

The descriptive statistics and the GLM showed that cars passed lycra cyclists faster than casually clothed cyclists (45.74 versus 39.82 km/h) on the low-speed road but there was no effect of group configuration. No statistically significant model could be found for the high-speed road. H3 is therefore not supported, motor vehicle speed was not lower when passing group cyclists compared to individual cyclists on the low-speed road, no conclusion can be made for the higher speed road.

3.3 Motor vehicle following behaviour

Group versus individual cycling status did not significantly influence driver choice of following versus passing a cyclist within the study area. Oncoming vehicles was the only significant factor in the final model. H4, that group cyclists will have higher rates of following compared to individual cyclists was therefore, not supported.

4 DISCUSSION

On the two-lane, low-speed urban road in this study, LPDs were greatest for cyclists riding two-abreast, followed by single-file groups, which had a smaller difference to individual riders. This finding contrasts with that reported for two-lane rural roads in Spain by Garcia et al. (2020). However, it is consistent with the results from urban roads in Western Australia where the risk of an unsafe event was lower for groups riding two abreast in the traffic lane or having all riders in the bicycle lane, compared to riding single file in the traffic lane (Fraser and Meuleners, 2020). One possibility is that drivers adopt different passing strategies on lower-speed roads because of a different perception of the risk to their vehicles of oncoming traffic. Similarly, the lack of significant differences motor vehicle speeds and following behaviour in passes of individual versus single-file group versus two-abreast riders is also inconsistent with the results presented by Garcia et al. (2020). There is a need for further research in urban areas with large samples of passing events.

5 CONCLUSIONS

Are group cyclists objectively safer when sharing roads with motor vehicles? This study suggests that group cyclists are passed at a greater distance but not more slowly on low-speed urban roads. Such a finding implies that increasing the distances prescribed in Minimum Passing Distance laws around the world may work better than attempts to make drivers to slow down when passing cyclists.

REFERENCES

[1] O. Heeremans, E. Rubie, M. King and O. Oviedo-Trespalacios, “Group cycling behaviours: A systematic review”, *Transportation Research Part F: Traffic Psychology and Behaviour* 91 (2022), pp. 26-44.

[2] E. Rubie, N. Haworth, D. Twisk and N. Yamamoto, “Influences on lateral passing distance when motor vehicles overtake bicycles: A systematic literature review”, *Transport Reviews* 6 (2020), pp. 754-773.

[3] A. Garcia, C. Llorca and J. Serra-Planelles, “Influence of peloton configuration on the interaction between sport cyclists and motor vehicles on two-lane rural roads” *Journal of Transportation Safety & Security* 12 (2020), pp. 136–150.

[4] J. J. Kay, P. T. Savolainen, T. J. Gates and T. K. Datta, “Driver behavior during bicycle passing maneuvers in response to a share the road sign treatment”, *Accident Analysis and Prevention* 70 (2014), pp. 92–99.

[5] G. López, A. M. Pérez-Zuriaga, S. Moll, A. García, “Analysis of Overtaking Maneuvers to Cycling Groups on Two-Lane Rural Roads using Objective and Subjective Risk”, *Transportation Research Record: Journal of the Transportation Research Board* 2674 (7) (2020), pp. 148-160.

[6] S. Moll, G. López, A. García, “Analysis of the Influence of Sport Cyclists on Narrow Two-Lane Rural Roads Using Instrumented Bicycles and Microsimulation”, *Sustainability* 13 (3) (2021), p. 1235.

[7] P. Savolainen, T. Gates, R. Todd, T. Datta, T. and J. Morena, “Lateral placement of motor vehicles when passing bicyclists”, *Transportation Research Record: Journal of the Transportation Research Board* 2314 (2012), pp. 14–21.

[8] A. E. Bauman, K. Blazek, L. Reece, W. Bellew, “The emergence and characteristics of the Australian Mamil”, *Medical Journal of Australia* 209 (11) (2018), pp. 490-494.

[9] A. Schramm, N. Haworth, K. C. Heesch and A. Watson and A. K. Debnath, *Evaluation of the Queensland minimum passing distance road rule*. (2016). https://eprints.qut.edu.au/94655/1/Final_Report_TMR_170316.pdf

[10] M. Dozza, R. Schindler, G. Bianchi-Piccinini and J. Karlsson, J., How do drivers overtake cyclists? *Accident Analysis & Prevention* 88 (2016), pp. 29–36.

[11] P. Apasnore, K. Ismail and A. Kassim, “Bicycle-vehicle interactions at mid-sections of mixed traffic streets: Examining passing distance and bicycle comfort perception”, *Accident Analysis & Prevention* 106 (2017), pp. 141–148.

[12] A. Kassim, K. Ismail and S. McGuire, “Operational evaluation of central sharrows and dooring zone treatment on road user behavior in Ottawa, Canada” *Transportation Research Record: Journal of the Transportation Research Board* 2672 (36) (2018), pp. 136–144.

[13] A. Field, *Discovering statistics using IBM SPSS Statistics* (5th ed.), Sage, 2018.

[14] M. L. Fraser and L. B. Meuleners, “Risk factors for unsafe events involving a motor vehicle for group riders (cyclists): A naturalistic case-crossover study” *Accident Analysis & Prevention* 146 (2020), pp. 105758.

On-Site Measurements and Model for Gust Loads on Cyclists induced by Vehicles in Overtaking Manoeuvres

C. Gromke[*], B. Ruck[*]

[*]Laboratory of Building and Environmental Aerodynamics
Institute for Hydromechanics
Karlsruhe Institute of Technology
Kaiserstrasse 12, 76131, Karlsruhe, Germany
email: gromke@kit.edu

Keywords: bicycle safety, overtaking vehicle, vehicle-induced load, aerodynamic side load.

1 INTRODUCTION

In overtaking maneuvers, road vehicles cause unsteady aerodynamic loads on cyclists. The total aerodynamic load can be decomposed into a load acting in driving direction and perpendicular to it. A schematic of the time history of the perpendicular load is shown in Figure 1. The strongest side (lateral) load F_{peak} occurs in an early phase of the overtaking maneuver and is perceived by the cyclist as a lateral pressure load [1], i.e. it acts to push the cyclist away from the overtaking vehicle. The peak pressure load F_{peak} is deemed relevant for cyclist safety as immediately upon its occurrence, the strength of the side load rapidly decreases and evokes an instantaneous reaction by the cyclist to readjust to the changing equilibrium conditions and to remain in balance.

The current contribution presents a model which allows to estimate the lateral aerodynamic peak pressure load F_{peak} in dependency on the type of the overtaking vehicle, its speed, the cyclist type, and the overtaking distance. The model was calibrated against loads measured in full-scale field experiments involving various cyclist types (adult person on touring bike with / without saddle bags – TB-nb / TB-wb (Fig. 1), adult person on racing bike – RB-nb, adolescent person on juvenile bike – CB-nb) and various vehicle types (station wagon, 3.5 t van, 7.5 t truck, 40 t semitrailer truck, tour bus).

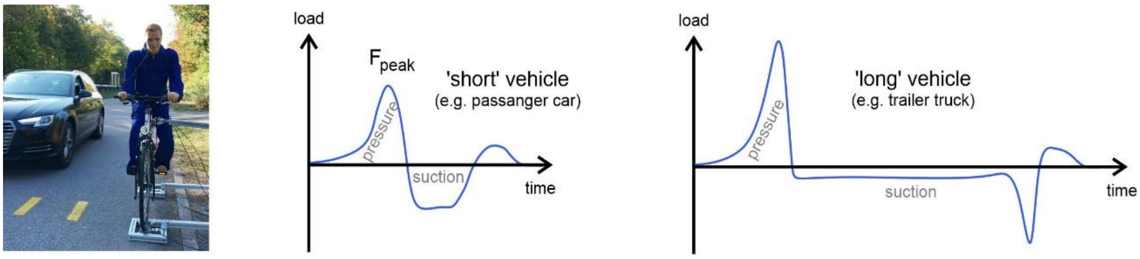


Figure 1: Life-size person dummy on a bicycle and schematic time histories of lateral load on cyclist in an overtaking manoeuver.

2 METHODS

Time histories of the overtaking vehicle-induced lateral aerodynamic load acting on life-size person dummies on bicycles (dummy-bike assemblies) were acquired in a field measurement campaign. Overtaking maneuvers were accomplished employing five vehicle types and four dummy-bike assemblies, fixed to a stationary rack using crossbars equipped with load cells, varying both vehicle speed (30 km/h < V_{veh} < 100 km/h) and overtaking distance (0.5 < d_y < 2.0). The overtaking distance d_y is defined as the spacing between the car envelope - excluding the protruding side mirror - and the central vertical plane of the dummy-bike assembly defined by the bicycle frame.

3 RESULTS

In a first step of the model development, the lateral aerodynamic peak pressure load F_{peak} obtained from the measurements was fitted by a quadratic relation according to

$$F_{peak} = c_1\, V_{veh}^2 \tag{1}$$

with V_{veh} the vehicle speed [m/s] and c_1 a pre-factor [kg/m] specific to a cyclist-vehicle type combination at overtaking distance d_y. Figure 2a shows as an example the measured lateral aerodynamic peak pressure load F_{peak} (symbols) and the fitted curves for the combination of the cyclist on the touring bike without bags (TB-nb) and the passenger car (car).

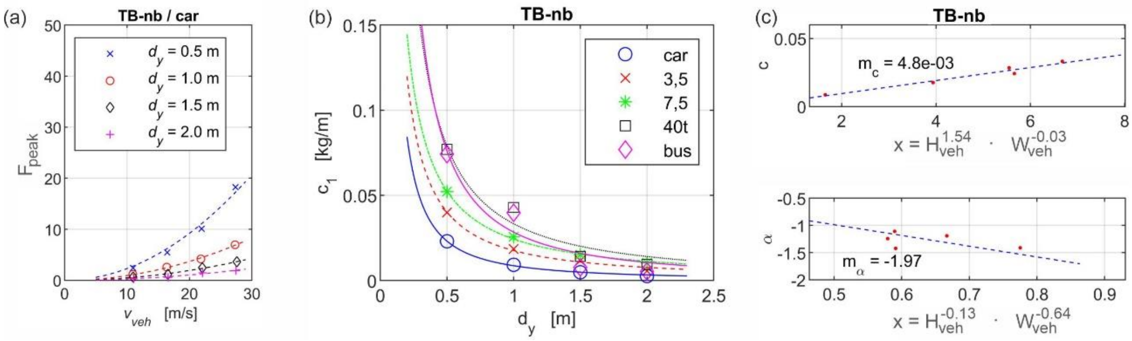


Figure 2: (a) Quadratic curve fits to F_{peak} accord. to Eq. (1), (b) curve fits to c_1 of Eq. (1), (c) curve fits to c and α of Eq. (2) based on Eqs. (3, 4).

The pre-factors c_1 for the cyclist on the touring bike without bags (TB-nb) and all five vehicle types versus the overtaking distance d_y are shown in Figure 2b. The symbols represent the pre-factors c_1 as obtained from fitting with Eq. (1) and the lines are curve fits obtained with a power function relation according to

$$c_1 = c\, d_y^{\alpha} \tag{2}$$

The form of the functional relationship between the pre-factor c_1 and overtaking distance d_y was inspired by the works of [2, 3, 4] who studied transient aerodynamic loads induced by vehicles on various nearby objects.

The next step was to determine the pre-factor c and the exponent α of Eq. (2). In this process, it appeared evident to relate both to characteristic geometric dimensions pertaining to the dummy-bike assembly and the vehicle. The key geometric dimensions which largely determine the lateral aerodynamic peak pressure load F_{peak} are the projected frontal area of the vehicle $A_{veh,fro}$ expressed by the product of the vehicle width W_{veh} and height H_{veh}, and the projected lateral area of the cyclist $A_{cyc,lat}$. Hence, in a next step, the values for c and α obtained from curve fits according to Eq. (2) and specific to a certain cyclist type were displayed against products of powers of H_{veh} and W_{veh} according to

$$c = m_c\, \left(H_{veh}^{c_H} \cdot W_{veh}^{c_W}\right) \tag{3}$$

$$\alpha = m_\alpha\, \left(H_{veh}^{\alpha_H} \cdot W_{veh}^{\alpha_W}\right) \tag{4}$$

Based on systematic variations of the exponent pairs c_H & c_W and α_H & α_W and furthermore employing least square fits to the predicted and observed values of c and α according to Eqs. (3, 4) and Eq. (2), respectively, the following best-fit values for the exponents were obtained $c_H = 1.54$, $c_W = -0.03$, $\alpha_H = -0.13$, and $\alpha_W = -0.64$ (valid for all cyclist types). The resulting values for the slope of the linear fit curves were m_c = 4.1e-3, 6.4e-3, 3.6e-3, 2.9e-3 and m_α = -2.35, -2.08, -2.27, -2.23 for the cyclist types TB-nb, TB-wb, RB-nb, and CB-nb, respectively. Figure. 2c presents values of the observed pre-factor c and exponent α (dots) versus predicted linear fit curves (dashed lines) according to Eqs. (3, 4) over abscissae scaled with the best-fit exponent values for the cyclist on the touring bike without bags (TB-nb). It finally remains to relate the pre-factors m_c and m_α to characteristic geometric dimensions of the dummy-bike assembly and the vehicle. For m_c this was achieved by formulating a linear relation with the cyclist lateral area $A_{cyc,lat}$ according to

$$m_c = m_{c,pf}\ A_{cyc,lat} \tag{5}$$

with $m_{c,pf}$ = 0.0049 and for m_α by calculating the mean according to

$$\overline{m}_\alpha = \frac{1}{4}\sum m_\alpha = -2.23. \tag{6}$$

The combination of Eqs. (1-6) finally provides the mathematical model for the lateral aerodynamic peak pressure load F_{peak} according to

$$F_{peak} = 0.0049 \cdot A_{cyc,lat}\ \cdot\ \left(H_{veh}^{1.54} \cdot W_{veh}^{-0.03}\right)\ \cdot\ d_y^{\,-2.23\left(H_{veh}^{-0.13}\ \cdot\ W_{veh}^{0.64}\right)}\ \cdot\ V_{veh}^{\,2} \tag{7}$$

Figure 3 shows for selected combinations of cyclist-vehicle types model-predicted lateral aerodynamic peak pressure loads (lines) and measured loads (symbols). A comparison reveals an overall appropriate performance of the model.

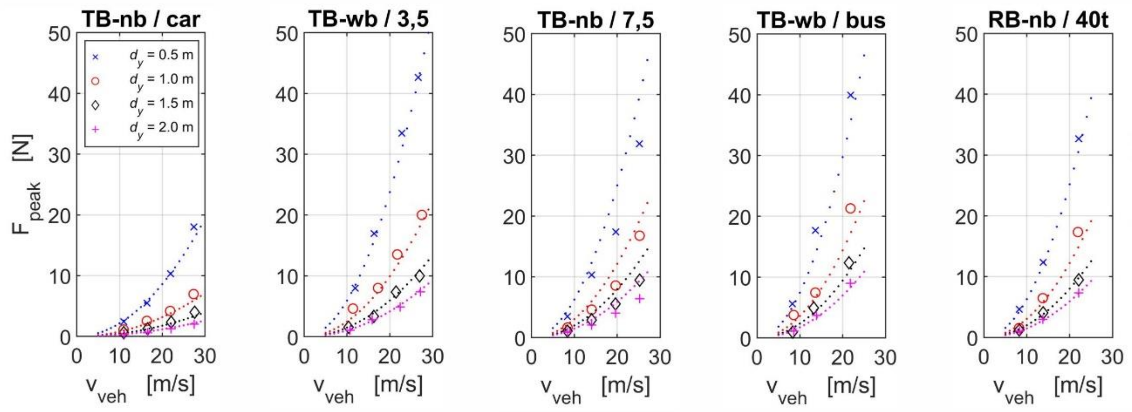


Figure 3: Lateral aerodynamic peak pressure loads F_{peak} for selected combinations of cyclist-vehicle types. Measurement data (symbols) and model-predicted data accord. to Eq. (7) (lines).

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of the Deutsche Forschungsgemeinschaft DFG (German Research Foundation) under grant Ru 345/32-3.

REFERENCES

[1] C. Gromke, B. Ruck, “Passenger car-induced lateral aerodynamic loads on cyclists during overtaking”, *Journal of Wind Engineering and Industrial Aerodynamics* 209 (2021), 104489.

[2] P. Lichtneger, B. Ruck, “Full scale experiments on vehicle induced transient loads on road-side plates”, *Journal of Wind Engineering and Industrial Aerodynamics* 136 (2015), pp. 73-81.

[3] A. Sanz-Andrés, J. Santiago-Prowald, C. Baker, A. Quinn, “Vehicle-induced loads on traffic sign panels”, *Journal of Wind Engineering and Industrial Aerodynamics* 91 (2003), pp. 925-942.

[4] A. Sanz-Andrés, A. Laverón, C. Baker, A. Quinn, “Vehicle induced loads on pedestrian barriers”, *Journal of Wind Engineering and Industrial Aerodynamics* 92 (2004), pp. 413-426.

Assessing Cycling Infrastructure and Bike-Transit Accessibility Through Shortest Path Routing

R. Passmore*, K. Watkins#, R. Guensler †

*School of Civil and Environmental Engineering
Georgia Institute of Technology
788 Atlantic Drive NW, 30332, Atlanta GA, U.S.A.
email: tanner.passmore@gatech.edu

#School of Civil and Environmental Engineering
Georgia Institute of Technology
788 Atlantic Drive NW, 30332, Atlanta, GA, U.S.A.
email: randall.guensler@ce.gatech.edu

†School of Civil and Environmental Engineering
University of California Davis
480 Bainer Hall Dr, 95616 Davis CA, U.S.A.
email: kewatkins@ucdavis.edu

Keywords: Shortest Path Routing, Cycling Route Choice, First/Last Mile.

1 INTRODUCTION

According to the U.S. 2017 National Household Travel Survey (NHTS), about 46% of all single occupancy motor vehicle trips in the U.S. are three miles or less; yet NHTS survey results indicate that only 1% of all trips are accomplished by bicycle [1]. This mismatch is suspected to be in part due to the real and perceived danger imposed on cyclists when they share the same right-of-way with motor vehicles [2]. Many current cycling design guides encourage building separated cycling infrastructure when vehicle speeds are high to ensure that the design is suitable for cyclists of “all ages and abilities.” Research shows that separated cycling infrastructure (e.g., cycletracks, protected bike lanes) can lead to increased ridership and reduced crash risk [3, 4]. Research also suggests that people, regardless of cycling frequency or ability, state that they would be more willing to try cycling on roads with bicycle infrastructure that provides a buffer or separation from car traffic [5].

Cities are building this infrastructure, yet planners and engineers need to know how to prioritize cycling infrastructure projects that stand to have the greatest impact on the actual and perceived safety of cycling. Additionally, planners and engineers need to be able to communicate these impacts to decision-makers and the public. This research addresses these problems by outlining a framework for assessing new and existing infrastructure through BikewaySim, a shortest path calculator for cycling.

2 LITERATURE REVIEW

Over the past decade, researchers have utilized GPS-recorded cycling trips to investigate cyclists’ revealed positive and negative preferences for particular road attributes, such as the presence of a bike lane (positive), presence of on-street parking (negative), speed limit (negative for higher speed limits), and number of lanes (negative for more lanes). These studies have used discrete choice modeling to assess how cyclists choose routes based on trade-offs in utility for particular road attributes [6, 7, 8]. These studies show that cyclists prefer routes that are shorter, have fewer steep hills, have a higher percentage of bicycle infrastructure (both separated infrastructure and traditional bike lanes), and have fewer turns (especially left turns).

Results from cycling route choice models are interpreted by converting model coefficients into average marginal rates of substitution (MRS). MRS values represent how much more of or less of an attribute a cyclist would trade for a one unit increase in another attribute to maintain the same utility. Typically, the MRS is calculated with respect to distance so that a change in an attribute is seen as a distance reduction or addition.

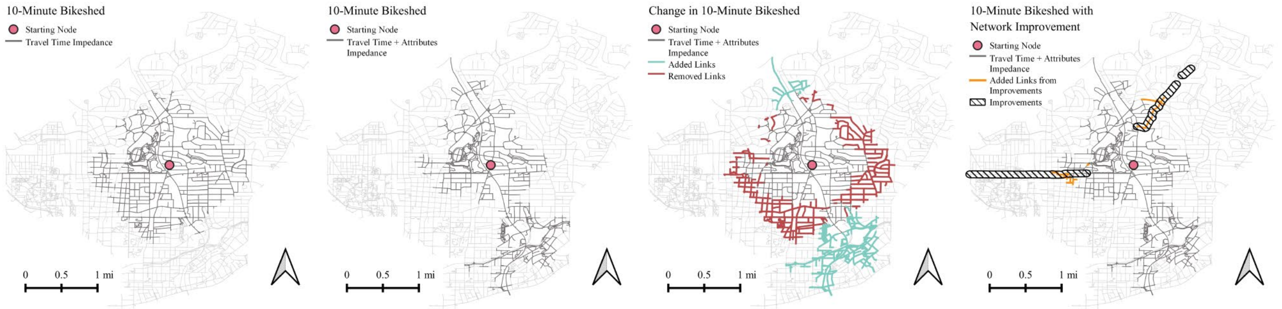
For example, an MRS of -0.5 for a 1-unit increase in the proportion of the route on a bike path would have the same effect as shortening the length of the route by 50%. However, more research is needed to address how these MRS values can be applied in shortest path routing for cycling infrastructure planning. Controlling for differences across route choice studies with respect to the variables employed and the intercorrelation of variables affecting route choice will be a statistically challenging task. Additionally, there is a need for developing metrics and visualizations that convey the impact of new infrastructure. To that end, this research provides a framework for assessing how new cycling infrastructure contributes to decreasing traffic stress and increasing bikeability (i.e., the attractiveness of, and accessibility provided by, cycling); so that infrastructure alternatives that stand to have the greatest impact are selected over those that would be less effective.

3 METHODOLOGY

This framework utilizes BikewaySim to find the shortest route through a network, given the preferences that cyclists have for road attributes (e.g., traffic speeds, cycling infrastructure, hills, traffic signals, etc.). BikewaySim is a shortest path model that takes in a network graph with link attributes, allows a user to specify custom impedance functions, and then outputs metrics and visuals for the 'shortest' path (lowest impedance path) between any origin-destination pair. To calculate the shortest path, BikewaySim relies on link impedance functions. Impedance, expressed in minutes, represents the friction associated with travel (i.e., travelers want to minimize impedance). For this research two impedance functions are used. The first impedance was link travel time, and the second impedance considered both travel time and cyclists' preferences for road attributes (specifically regarding bike facility presence and type, speed limit, and the number of vehicle lanes). These two impedance functions were used to calculate shortest paths for 28,392 possible origin-destination pairs. Additionally, two networks, one representing the existing street network and the other representing the existing street network with new cycling infrastructure were used. The results were used to create four visualizations: bikesheds, individual routing, betweenness centrality, and zonal statistics.

Calculated bikesheds are shown in Figure 1. Bikesheds represent the extent of the road network one can access by bike within specified constraints. For this study, the bikesheds were limited to every location that one could reach in ten minutes at a speed of 8.0 miles per hour. Figure 1a shows the bikeshed using the existing street network and the travel time impedance and Figure 1b shows the bikeshed using the existing street network and the time and attributes impedance. The difference in accessible links when going from Figure 1a to Figure 1b is shown in Figure 1c. Links that have been added and removed from the bikeshed in moving from the time-only impedance to time and attributes impedance are shown in blue and red, respectively. When links are removed, either the links removed or the links leading up to the links that were removed had a higher impedance when attribute impedance was included (reaching these links may involve traversing high-stress links). When links are added, the new links or the links leading up to these new links, had a lower impedance when attribute impedance was included. For example, reaching these links may involve traversing dedicated multi-use paths, streets with cycling infrastructure, or low-speed streets (i.e.; links that people may be willing to travel further on compared to high-stress links). The expansion in the south area of the bikeshed is due to the presence of two extensive multi-use path trails in that area. The bikesheds were then re-calculated to include two major network improvements. The orange lines in Figure 1d represent links added from these improvements. This example highlights one way in which BikewaySim's visualizations can be used to assess the impacts of infrastructure improvements on bikeability.

This is just one of the visualizations within the proposed network assessment framework. The others within the framework (betweenness centrality, individual routing, and zonal statistics) all offer additional insight into the potential impacts of cycling infrastructure. BikewaySim can also be paired with a transit shortest path calculator, called TransitSim, to assess how new cycling infrastructure increases the accessibility of cycling as a first/last mile mode to/from transit.



(a) (b) (c) (d)

Figure 1: 10-minute bikesheds

4 CONCLUSIONS

Rising cycling and micro-mobility fatalities and injuries have put increased pressure on cities to expedite their plans to construct cycling networks build outs. While cities will build infrastructure, there is a need for systematic planning of safe and connected cycling networks. While BikewaySim does not create the most optimal bicycle network, it can inform decision-makers about the effects of potential infrastructure improvements. In addition, it has other applications in assessing the accessibility of bicycle trips as a first/last mile mode.

REFERENCES

[1] Federal Highway Administration, "National Household Travel Survey," 2017.

[2] J. Pucher and R. Buehler, City Cycling, MIT Press Ltd, 2012.

[3] J. DiGioia, K. E. Watkins, Y. Xu, M. Rodgers and R. Guensler, "Safety impacts of bicycle infrastructure: A critical review," *Journal of Safety Research,* vol. 61, p. 105–119, June 2017.

[4] B. Fields, A. L. Cradock, J. L. Barrett, T. Hull and S. J. Melly, "Active transportation pilot program evaluation: A longitudinal assessment of bicycle facility density changes on use in Minneapolis," *Transportation Research Interdisciplinary Perspectives,* vol. 14, p. 100604, June 2022.

[5] C. Clark, P. Mokhtarian, G. Circella and K. Watkins, "User Preferences for Bicycle Infrastructure in Communities with Emerging Cycling Cultures," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 2673, pp. 89-102, December 2019.

[6] G. Menghini, N. Carrasco, N. Schüssler and K. W. Axhausen, "Route choice of cyclists in Zurich," *Transportation Research Part A: Policy and Practice,* vol. 44, no. 9, pp. 754-765, 2010.

[7] J. Hood, E. Sall and B. Charlton, "A GPS-based bicycle route choice model for San Francisco, California," *Transportation Letters,* vol. 3, no. 1, pp. 63-75, January 2011.

[8] J. Broach, J. Dill and J. Gliebe, "Where do cyclists ride? A route choice model developed with revealed preference GPS data," *Transportation Research Part A: Policy and Practice,* vol. 46, no. 10, pp. 1730-1740, December 2012.

Bicycle simulator validation study: A methodological approach

M. Suing*, **P. Seiniger#**, **M. Bierbach#**, **A. C. Kiehl***, **H. Ma***, **S. Pliquett†**, **F. Surges***

*Road User Behavior and Mobility (Section U3)
#Active Vehicle Safety and Driver Assistance Systems (Section F1)
†Highway Design, Traffic Flow and Traffic Control (Section V1)

Federal Highway Research Institute (BASt)
Bruederstrasse 53, 51427, Bergisch Gladbach, Germany
email: suing@bast.de, seiniger@bast.de, bierbach@bast.de, ma@bast.de, pliquett@bast.de, surges@bast.de

Keywords: bicycle simulator, validation study, bicycle dynamic, experimental research, measurement technology.

1 INTRODUCTION

Compared to car driving simulators, experience with bicycle simulators used in experimental research studies has so far been very limited and is still characterized by their pioneering nature. Accordingly, studies on validation of bicycle simulators are still rare [1, 2, 3]. However, in order to transfer findings from behavioral studies with bicycle simulators to real traffic, sufficient validity must be confirmed.

The aim of the validation study presented here is to examine both the physical-technical validity (i.e., the implementation of the bicycle dynamic in the simulation) and the behavioral validity (i.e., the subjects' cycling behavior and experience while using the bicycle simulator). Objective and subjective measurement will be used to assess how accurately the simulator replicates a real-world bicycle dynamic and cycling experience. A special focus is placed on aspects such as acceleration, braking, steering, lean angle, as well as the cognitive load when performing the cycling tasks.

In the presentation of the study, the focus will be placed on the methodological approach.

2 METHODS

2.1 Bicycle simulator and real bike

The bicycle simulator of the BASt was developed by the Würzburg Institute for Traffic Sciences (Würzburger Institut für Verkehrswissenschaften, WIVW), as well as the SILAB simulator software. A 'real' Cube trekking bike equipped with sensor technology serves as a mockup. The mockup is mounted on a passive slightly movable carrier plate with the front wheel resting on a turntable and the rear wheel attached to a roller dynamometer. The virtual environment is presented to the subjects via ten large-format displays that allow a 300º horizontal and a 100º vertical field of view. During steering, the lean angle of the bike is simulated visually by the inclination of the horizon line. Via headphones, the subject can hear the noises of other road users, background noises and also navigation announcements and instructions from the test guides (via microphone).

For the real-world test rides, an identical Cube trekking bike is used: Bike with a low step-in, 50 frame size, 28 tire size and electric hub gears. The bicycle is equipped with measurement technology (see 2.3).

2.2 Procedure

To validate the bicycle simulator, comparative rides with the real bicycle and with the bicycle simulator will be carried out in the summer of 2023. The real-world test rides will take place on the BASt test area (Figure 1), on which three different test sequences will be marked. These three test sequences are reconstructed accordingly in the simulation (Figure 2).

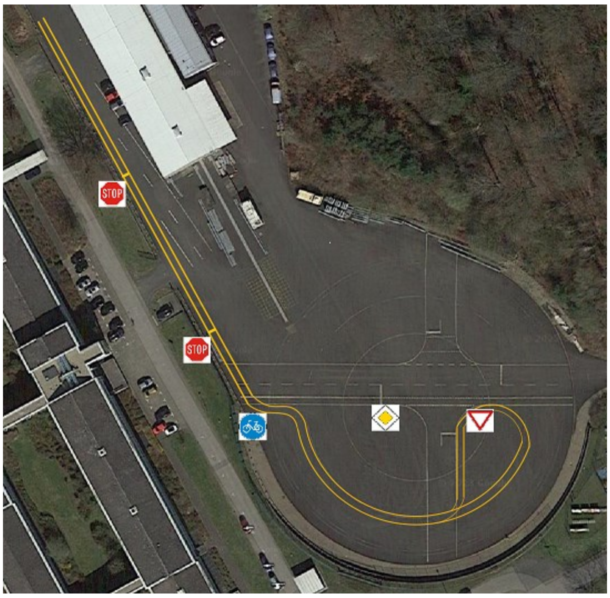


Figure 1: BASt test area for real-word test rides

Figure 2: Bicycle simulator and reconstructed test area

Test sequence I - Yellow marking (see figure 1): This sequence consists of a narrow route (width: 1,44 m) with a straight section (length: 100 m), a slightly curved chicane, a semicircle (diameter: 60 m) and a turning circle. Short outward and return journeys are to be made on this yellow-marked route under different conditions:
- Cycling at free and predefined speed with and without additional cognitive load task
- Mastering planned and unplanned braking maneuvers
- Lane keeping on narrow, yellow line with and without additional cognitive load task.

Test sequence II - White road marking (see figure 1): The following cycling tasks are to be performed under consideration of traffic regulations:
- Right turn from the main road into the side road
- Left turn from the side road into the main road
- Straight cycling past parked cars at the kerbside.

Test sequence III: Slalom course
- The test subjects are to cycle as fast as possible around a slalom course marked out by pylons.

2.3 Data collection

The following aspects of bicycle dynamics are measured:
- Acceleration: Speed, pedaling force and cadence
- Braking: reaction time, brake lever actuation force, braking duration, braking distance
- Steering: steering and lean angle, lane keeping and distance keeping (to parked cars)

These data are automatically recorded in the simulation by the Silab software.

The following measurement technology is used for the real bicycle:
- Data acquisition system with sensors for driving dynamics: GPS + 6DoF-IMU, roll angle, steering angle, brake pressure, pedal cadence and force.
- Video technology (measurement of lane keeping, behavioral observation of cycling errors)

For data postprocessing MATLAB will be used.

In addition, subjects will be asked about the following behavioral aspects:
- Perception of and ability to control speed, braking and steering
- Cognitive load
- Simulator sickness

2.4 Sample

Before the subjects ride the test sequences, a familiarization training session on the bicycle simulator will be conducted on a separate date. For this purpose, n = 50 subjects aged 18–65 years will be invited. The subjects who pass the familiarization training and do not suffer from excessive simulator sickness will be invited to the actual test ride. This sample should be at least n = 40. The test rides will take place during the summer months of 2023.

3 RECOMMENDATIONS FOR FUTURE STUDIES

Based on the findings, suitable use cases for behavioral studies with the bicycle simulator will be identified and possible questions to be investigated will be discussed.

REFERENCES

[1] D. Martinez Garcia, K. Gröne, L. Quante, M. Fischer, S. Thal, and R. Henze “Parameter tuning of a bicycle simulator for a realistic riding behaviour and motion perception”, *Proceedings of the Driving Simulation Conference 2022 Europe*, Strasbourg, France.

[2] S. O´Hern, “Validation of a bicycle simulator for road safety research”, *Accident Analysis and Prevention 100* (2017), pp. 53 -58.

[3] S. O´Hern, *Evaluation of evidence-based infrastructure for safer cycling*, Thesis at Monash University, Accident Research Centre, 2018.

Bicycle Exposure Models Using Bayesian Updating

R. T. Panik[*], K. Watkins[†], I. Tien[#]

[*]School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Dr NW, Atlanta, GA 30332, U.S.A.
email: rtpanik@gmail.com

[†]School of Civil and Environmental Engineering
University of California – Davis
One Shields Avenue, Davis, CA 95616, U.S.A.
email: kewatkins@ucdavis.edu

[#]School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Dr NW, Atlanta, GA 30332, U.S.A.
email: itien@ce.gatech.edu

Keywords: bicycle activity, exposure models, Bayesian modelling.

1 INTRODUCTION

Traffic safety is a crisis in the United States, especially for people biking and walking. While less than 1% of all trips are made by bicycle, more than 2% of the total reported traffic deaths are bicyclists, indicating an over-representation of cyclists in crash statistics [1]. The number of crashes in the U.S. has been increasing in recent years; even though overall traffic fatalities declined between 2004 and 2019, bicyclist fatalities have increased, both in terms of the absolute numbers of deaths and as a share of all traffic deaths [2], [3].

Despite the many bicycle and pedestrian crashes, injuries, and fatalities occurring on publicly owned assets, transportation agencies and local governments have been unsuccessful at reducing crashes. While there are many reasons for this depending on the agency and locality, *one of the more prominent challenges is that agencies and decision-makers have sparse information about how and when people are biking in the transportation systems* – which limits what they can know and do about transportation safety problems. Without measures of exposure, engineers cannot create policies, or prioritize infrastructure projects with the goal of reducing *risk*, injury, and death. We will test a new methodology for estimating bicyclist volumes in this work. Using the state of Georgia (located in the southeast United States) as a case study, we will test the feasibility of generating exposure models using crowd-sourced data and Bayesian methods.

2 CONTEXT

Like the U.S. overall, Georgia and its largest city, Atlanta, have had troubling patterns of bicycle crashes in the last several years [4]. As with most states in the U.S., Georgia does not systematically monitor its roadway network for bicyclist traffic, even though vehicular travel is measured (or estimated) on all state-owned assets. Traditionally, non-motorized count programs are typically designed and operated at state, regional, or municipal levels of government, often within a department of transportation or a regional transportation governance [5]. While state and local agencies collect non-motorized traffic counts for warrants and traffic impact analyses that are useful in themselves, these opportunistic counts do not capture enough information to inform safety initiatives; they are not regularly used to inform safety projects, nor are they used to direct network-level understanding of non-motorized activity. There is a clear need for new methods for estimating pedestrian and bicycle volumes in Georgia's transportation system – preferably methods that make use of existing resources and minimize additional data collection needs.

3 DATA AND METHODS

This work tests a method for using Strava Metro data to estimate patterns of bicycle activity in Atlanta and Georgia. Strava is a free smart phone application and social media platform that people use to track human-powered recreational and commute trips, including bike trips. Strava Metro is the research and data division of Strava [6], which provides researchers and public agencies with high-resolution data on non-motorized travel. These data contain segment-level hourly volumes for an entire roadway network – a notable advantage over other third-party (i.e., privately developed) datasets, which often can only generate area-level estimates of bike activity. A challenge of using Strava data, however, is that it does not capture all bike trips; it is inherently incomplete given that it is self-selected, and the data are biased towards young, white males [7]. This bias is systematic, however, and Strava data has been shown to produce good-quality estimates of AADB when calibrated with counts collected from a variety of roadway types [8]–[10].

We investigate novel ways of using Strava data to estimate highly granular daily and hourly segment-level biking volumes along a variety of roadway segments through a Bayesian lens. Often bike volumes are calculated as point estimates (e.g., annual average daily biking, or AADB) for simplicity, and these estimates are rarely available in Georgia. Average-based estimates may also be dubious; bike activity is highly varied throughout a day/day of week and often has bimodal hourly distributions, depriving average daily values of much meaning. A Bayesian approach applied to segment-level Strava Metro data, however, would allow us to generate distributions of daily and hourly estimates that can provide more detail of biking activity over many segments. Because Strava Metro data represents some of the bicycle traffic on roadways – albeit imperfectly – it can be viewed as a prior distribution in an empirical Bayesian model:

$$\mathrm{P}(\Theta|\mathrm{Y_t}) \propto P(Y_t|\Theta)\mathrm{P}(\Theta) \tag{1}$$

where $\boldsymbol{Y_t} = (\boldsymbol{y_1}, \dots \boldsymbol{y_n})$ are the observed counts of bicycles per time increment $\boldsymbol{t}$, $\boldsymbol{P}(\boldsymbol{\Theta})$ is the prior distribution of daily bicycle volumes per segment that is empirically derived with hyper-parameters estimated from a subsection of Strava Metro segment data, and $\mathbf{P}(\boldsymbol{\Theta}|\mathbf{Y_t})$ is the posterior probability distribution. The posterior probability distribution will be used to create posterior predictive distributions, which will then be compared to distributions of activity seen in the Strava Metro data.

This work investigates the feasibility of this Bayesian-based approach for estimating cycling volumes. Data used to update the model will be collected to update this model as this project progresses. Counts will be conducted in Summer 2023 at a variety of locations, where the locations are selected to represent a cross-section of bicycle traffic and roadway contexts. The locations will be selected by dynamic time series clustering (specifically, dynamic time warping, DTW) on a subsection of Strava segments. The DTW approach minimizes the square root of the sum of squared distances between one pattern of activity and another, given one distribution of activity $\boldsymbol{X} = (\boldsymbol{x_0} \dots, \boldsymbol{x_n})$ and another distribution of activity $\boldsymbol{Y} = (\boldsymbol{y_0} \dots, \boldsymbol{y_n})$.

$$DTW(x, y) = min\sqrt{\sum_{(i,j)\in\pi} d(x_i, y_i)^2} \tag{2}$$

where π is a list of indexed pairs (i_k, j_k), with $0 \leq i_k < n$ and $0 \leq j_k < m$, and these indexed pairs begin with (i_0, j_0) and end with (i_{n-1}, j_{m-1}). We will experiment with shape-based and k-means algorithms for clustering, selecting the measures that perform best on a variety of indicators.

Once the Strava Metro segments have been clustered, a sample of 20 randomly selected segments (dispersed over the clusters) will be designated for observational data collection. The local transportation agency will collect 48-hour counts of bicycle volumes reported in number of cyclists per hour at these segments. The counts will be separated into training and testing data. The training counts will be used to update the Bayesian model ($\boldsymbol{Y_t} = (\boldsymbol{y_1}, \dots \boldsymbol{y_n})$), generating posterior and predictive distributions for each of the 20 segments. These posterior distributions will then be compared to the testing counts of hourly bicycle volumes. Results from these analyses will confirm or deny the applicability of Strava Metro data to be used by the Georgia Department of Transportation to inform bike project prioritization and safety models.

This methodological exploration builds on existing literature of non-motorized traffic monitoring safety modeling in several ways. First, methods for non-motorized traffic monitoring in the U.S. follow the same approach as vehicular traffic monitoring: control counts conducted over a long period are used to create adjustment factors that extrapolate short term counts into AADB estimates [12]. But this approach is not amenable to highly variable data, and it historically is difficult for agencies to create counting programs to conduct these counts in the first place. Our approach may develop estimates that more realistically capture variation of bike activity using easily accessible data. Second, having more information about where and when people are biking will inform transportation agencies' understanding of risk. As the project develops, we will investigate ways of using our estimates of biking data to crash prediction models that are calibrated by exposure to crashes – a needed improvement in crash modeling that can accurately inform safety projects.

REFERENCES

[1] K. Nordback, S. Kothuri, D. Johnstone, G. Lindsey, S. Ryan, and J. Raw, "Minimizing Annual Average Daily Nonmotorized Traffic Estimation Errors: How Many Counters Are Needed per Factor Group?," *Transp Res Rec*, vol. 2673, no. 10, pp. 295–310, Jan. 2019, doi: 10.1177/0361198119848699.

[2] M. Wallace, C. Kitson, M. Ormstrup, J. Cherian, and J. H. Saleh, "Pedestrian and light transit accidents: An examination of street redesigns in Atlanta and their safety outcomes," *Transp Policy*, vol. 9, no. 2, pp. 538–554, Jun. 2021, doi: 10.1016/J.CSTP.2021.02.009.

[3] P. B. Ohlms, L. E. Dougald, and H. E. MacKnight, "Bicycle and Pedestrian Count Programs: Scan of Current U.S. Practice," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2673, no. 3, pp. 74–85, Mar. 2019, doi: 10.1177/0361198119834924.

[4] "Georgia Governor's Office of Highway Safety." https://www.gahighwaysafety.org/research/ (accessed Sep. 06, 2020).

[5] "NCHRP 08-36 Task 141: Evaluation of Walk and Bicycle Demand Modeling Practice," Washington, D.C., May 2019. Accessed: Feb. 12, 2023

[6] "Strava Metro Home," *Strava Metro*, 2020. https://metro.strava.com/metro/home (accessed Sep. 21, 2020).

[7] M. D. Garber, K. E. Watkins, and M. R. Kramer, "Comparing bicyclists who use smartphone apps to record rides with those who do not: Implications for representativeness and selection bias," *J Transp Health*, vol. 15, p. 100661, Dec. 2019, doi: 10.1016/j.jth.2019.100661.

[8] K. Lee and I. N. Sener, "Strava Metro data for bicycle monitoring: a literature review," *Transp Rev*, vol. 41, no. 1, pp. 27–47, 2021, doi: 10.1080/01441647.2020.1798558.

[9] T. Nelson, C. Ferster, K. Laberee, D. Fuller, and M. Winters, "Crowdsourced data for bicycling research and practice," *Transp Rev*, vol. 41, no. 1, pp. 97–114, 2021, doi: 10.1080/01441647.2020.1806943.

[10] B. Dadashova, G. P. Griffin, S. Das, S. Turner, and B. Sherman, "Estimation of Average Annual Daily Bicycle Counts using Crowdsourced Strava Data," *Transportation Research Record*, p. 036119812094601, Sep. 2020, doi: 10.1177/0361198120946016.

[11] T. Nelson *et al.*, "Generalized model for mapping bicycle ridership with crowdsourced data," *Transp Res Part C Emerg Technol*, vol. 125, p. 102981, Apr. 2021, doi: 10.1016/J.TRC.2021.102981.

[12] *Traffic Monitoring Guide*, 2013th ed. Washington, D.C.: Federal Highway Administration, 2013. Accessed: Feb. 09, 2023. [Online]. Available: https://www.fhwa.dot.gov/policyinformation/tmguide/2013_TMG_Chapter_7.docx

Acceptance in numbers? – Determinants of cyclists' choices on where to cycle in mixed traffic situations

S. Hantschel[*], B. Schröter[#], R. Gerike[†]

[*]Chair of Integrated Transport Planning and Traffic Engineering
Dresden University of Technology
01062 Dresden, Germany
Email: sebastian.hantschel@tu-dresden.de

[#]Chair of Integrated Transport Planning and Traffic Engineering
Dresden University of Technology
01062 Dresden, Germany
Email: regine.gerike@tu-dresden.de

[†]Chair of Integrated Transport Planning and Traffic Engineering
Dresden University of Technology
01062 Dresden, Germany
Email: bettina.schroeter@tu-dresden.de

Keywords: cycling behaviour, mixed traffic, design.

1 INTRODUCTION

Stakeholders in many municipalities worldwide are committed to promoting cycling and improving cycling provision. Scarcity of space is a major issue in most of these cities particularly for main streets which have significant movement and place functions. Multiple demands exist at these streets including moving pedestrians, cyclists and motorised vehicles, parking, people waiting at public transport stops or staying in the street for place activities. Mixing cyclists and motorised vehicles at the same space in the carriageway might be the only possible solution for cycling provision in these contexts which is applied in many German cities. Mixed traffic solutions for cycling for this study means that there is either no marking at all for cycling or bicycle pictograms. Marked advisory lanes are also considered as mixed traffic solutions in some references [1] but not part of this study.

Schröter et al. [2] show in their overview of international guidelines on cycling provision that other European countries such as The Netherlands or Sweden are stricter than Germany and only allow for mixing cyclists and motorised vehicles in residential streets with low volumes and speed of motorised traffic. Existing studies on cycling provision in mixed traffic therefore mainly come from Austria, Germany and the U.S. These studies either focus on acceptance or on safety. Acceptance is usually measured as the proportion of cyclists riding on the carriageway (vs. the sidewalk): Cyclists might be legally requested to cycle in the carriageway next to the cars but prefer to cycle at the sidewalk even though they are not allowed to do this, just because they feel that this is safer for them. Low acceptance might then impact negatively on safety, e.g., by causing conflicts with pedestrians or when crossing intersections at the sidewalk, which is not prepared for cyclists. Studies on acceptance only apply descriptive and monocausal analysis methods to investigate the effects of single characteristics (e.g. speed limit, the existence of shared lane markings) on acceptance, e.g. [3,4].

The aim is to evaluate the acceptance of cycling in mixed traffic which we also measure as the proportion of cyclists riding on the carriageway versus on the sidewalk. It is based on a unique dataset of video observations on cyclist behaviour, exposure and infrastructure variables which allows for detailed descriptive and model-based analyses.

2 DATA

The empirical work in this study is based on video observations at 334 locations with a total length of 151 km located in 13 cities in Germany. Location is defined as one side of a street at a street section including the sidewalk and the part of the carriageway that is used to move towards the same direction. 321 of these locations have no marking for cyclists at all, 13 have bicycle pictograms. A total of 47.009 cyclists (39.839 cyclists on the carriageway and 7.170 cyclists on the sidewalk) are recorded at these locations in the years between 2012 and 2019. Children and adults accompanying children are not included in the analysis, because they are requested to ride on the sidewalk until the age of eight and allowed to ride on the sidewalk until the age of ten years according to German law. Older cyclists are requested to cycle in the carriageway. Exposure data is collected on cyclist volumes at the carriageway and the sidewalk as well as on volumes of motorised vehicles and pedestrians. Additionally, infrastructure characteristics such as the number and widths of lanes, speed limit, the presence of parking as well as the types and usage of adjacent buildings are mapped.

3 METHODS

This study is based methodologically on the combination of descriptive analysis followed by regression modelling. Logistic regression models are applied to account for the binary character of the dependent variable on whether or not to cycle on the carriageway. The distribution of the dependent variable is assumed to be skewed towards one because legally, cyclists are requested to cycle on the carriageway. Formula (1) shows the basic form of the binary logistic model to explain the probability that cyclists ride on the carriageway that was applied for this study:

$$\log\frac{\pi_i}{1-\pi_i} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k \qquad (1)1$$

with

π_i Probability of cyclists riding on the carriageway
x_k Explanatory variables to be multiplied by the regression coefficients β_k

4 RESULTS

Table 1 shows the model results for the proportion of cyclists on the carriageway. Volumes of motorised vehicles, lane widths > 3,00 m and city type have a significant negative influence on the acceptance of cycling on the carriageway. Cyclist volumes, shared lane markings and a speed limit < 50 km/h are found to significantly increase the likelihood to cycle on the carriageway. It is interesting that with increasing cyclist volumes, the proportion of cyclists on the carriageway also increases, which could be interpreted as ‘acceptance in numbers’ effect.

Table 1: Results of the logistic regression-model for the proportion of cyclists on the carriageway

Variable	Unit/ Characteristics	Regression-coefficient β[1]		SE	OR	p[2]
Constant term	-	2,557	****	0,268	12,901	****
Cyclist volumes in the direction of i	Rf/h	0,011	****	0,002	-	****
Volume of motorised vehicles in the direction of i	Vehicle/h	-0,003	****	0,000	-	****
Shared lane markings (bicycle pictograms)	no	Ref.			Ref.	0,0547
	yes	0,581	*	0,287	1,787	
Lane width	< 3,00 m	Ref.			Ref.	0,0869
	3,00 to 3,50 m	-0,720	**	0,228	0,487	
	> 3,50 m	-0,714	**	0,238	0,490	
Speed limit	50 km/h	Ref.			Ref.	***
	< 50 km/h	0,498	***	0,132	1,645	
City type	city	Ref.			Ref.	**
	town	-0,584	***	0,169	0,558	
McF-R^2 = 0,43						
AIC = 4.002,07						

[1] Significance of the coefficient (forest test) * < .05 ** < .01 *** .001 **** < .0001
[2] Significance model effect (likelihood ratio test) * p < .05 ** p < .01 *** p < .001 **** p < .0001

The logistic regression model shows a good model fit with an McF-R^2 of 0,43. The unexplained variance is assumed to result from user characteristics such as socio-demographic variables or levels of cycling practice as well as further variables such surface quality which are not considered in this study.

Model results are used in the next step to forecast the acceptance of cycling on the carriageway in different scenarios with varying volumes of motorised traffic, speed limits and the existence of bicycle pictograms as shown in Figure 1. For other significant variables a fixed value is set. Cycling in mixed traffic without bicycle pictograms should only be recommended in combination with traffic volumes of maximum 400 vehicles per hour and a speed limit of < 50 km/h to achieve a proportion of cyclists on the carriageway of 90 %. The marking of bicycle pictograms increases acceptance.

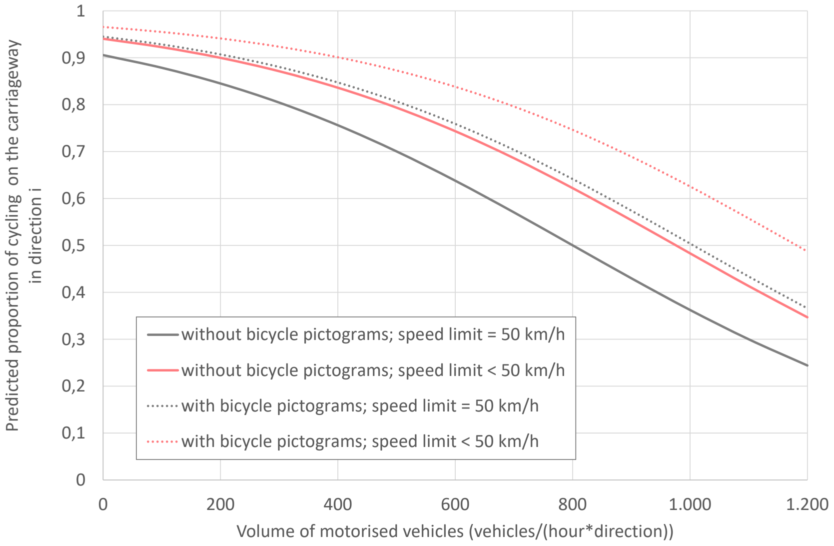


Figure 1: Predicted proportions of cyclists on the carriageway based on model results

5 CONCLUSIONS

This study shows cyclists' sensitivities to their environment in mixed traffic situations. Cyclists do not follow the rules which request them to cycle in the carriageway when they do not feel safe. They prefer to cycle on the sidewalk with negative impacts on their own comfort and safety but also for pedestrians and possibly further user groups. Speed limits of < 50 km/h and lower volumes of motorised traffic significantly increase the acceptance. Bicycle volumes also have a positive effect which indicates an 'acceptance-in-numbers' effect. The logistic regression model developed in this study could help to update guidelines on cycling provision but it should be complemented by empirical analyses of safety implications.

REFERENCES

[1] S. Hantschel, Einflussfaktoren auf die Akzeptanz und die Verkehrssicherheit des Radverkehrs im Mischverkehr auf innerstädtischen Hauptverkehrsstraßen. doctoral thesis, 2022. nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-820735.

[2] B. Schröter, S. Hantschel, C. Koszowski, R. Buehler, P. Schepers, J. Weber, R. Wittwer et al., Guidance and Practice in Planning Cycling Facilities in Europe—An Overview, Sustainability 13 (2021) 9560, 10.3390/su13179560. www.mdpi.com/1243208.

[3] W.W. Hunter, L. Thomas, R. Srinivasan, C.A. Martell, Evaluation of Shared Lane Markings, 2010.

[4] A. Koppers, J. Gerlach, T. Leven, S. Ruf, C. Hagemeister, Radfahren bei beengten Verhältnissen – Wirkung von Piktogrammen und Hinweisschildern auf Fahrverhalten und Verkehrssicherheit, Wuppertal, Dresden, 2021. nationaler-radverkehrsplan.de/de/praxis/wirkung-von-piktogrammen-und-hinweisschildern-auf.

Kick-plate test for assessing bicycle dynamics and tyre effect

G. Dell'Orto*,#, L. Alizadehsaravi*, R. Happee*, J. K. Moore*

*Faculty of Mechanical Engineering 3mE
Delft University of Technology
Mekelweg 2, 2628 CD, Delft, The Netherlands

#Department of Mechanical Engineering
Politecnico di Milano
Via La Masa 1, 20156, Milan, Italy

Corresponding author: G. Dell'Orto, g.dellorto@tudelft.nl

Keywords: bicycle, rider, safety, dynamics, tyre.

1 INTRODUCTION

Cycling is nowadays considered as a crucial means of achieving the climate-neutral goals set by the EU and United Nations for 2050 [1]. In this context, we expect a significant increase in the promotion and use of bicycles in the coming years. However, by increasing the number of cyclists, concerns about cycling safety may grow as well, highlighting the need for a strong understanding of bicycle dynamics to prevent falls and unexpected dynamic instabilities.

The rider's ability to stabilize the bicycle in an undesired state, such as when it is rolled by a gust of wind, steered when hitting a pothole, or slipping on icy road, depends on both the rider's neuromuscular control and the bicycle's dynamics. Tyres play a significant role in the latter, generating the lateral forces necessary for proper bicycle handling. Variation in the tyre compound, tread pattern, manufacturing process etc. as well as working parameters such as inflation pressure or vertical load also affect a rider's ability to stabilize the bicycle [2]. To understand the impact of this variations, we have measured the lateral characteristics of a large batch of tyres representative of the ones commonly used on contemporary bicycles. We performed measurements through *VeTyT* ("Velo Tyre Testing"), a test-rig specifically designed for bicycle tyres (Figure 1) [3,4].

In this study, our aim is to investigate how changes in tyre properties can affect the rider's control behavior. We plan to evaluate the stability of bicycle-rider models with tyre contribution by applying perturbation to the initial state of the system and studying the dynamics over time. Furthermore, we aim to replicate the same perturbations on a real bicycle to validate our models. To do so, we have implemented a "kick-plate" test for bicycles. This allows us to consistently perturb the bicyclist while simultaneously generating large slip angles. In this way, we can elicit nonlinear effects of the tyres.

2 METHODS

Kick-plate tests for cars are typically performed in dedicated circuits to study vehicle handling and train drivers to address dangerous situations. Following a similar conceptualization, we designed a portable kick-plate device at the Technical University of Delft specifically for testing bicycles in different scenarios (Figure 2). The device consists of a moving platform made of steel and actuated by compressed gas springs. The motion is limited in one direction only by means of linear guides. The displacement can be adjusted up to 150 mm, and a trigger system implemented in Arduino environment actuates the motion by unlocking the springs, to create a step input disturbance in a second on the rear wheel.

Tests will be performed with instrumented commercial bicycles and a balance assist bicycle [5], both equipped with IMU sensors and a torque sensor to record the torque applied by the rider to the handlebar.

Figure 1: VeTyT test-rig used to measure lateral characteristics of bicycle tyres.

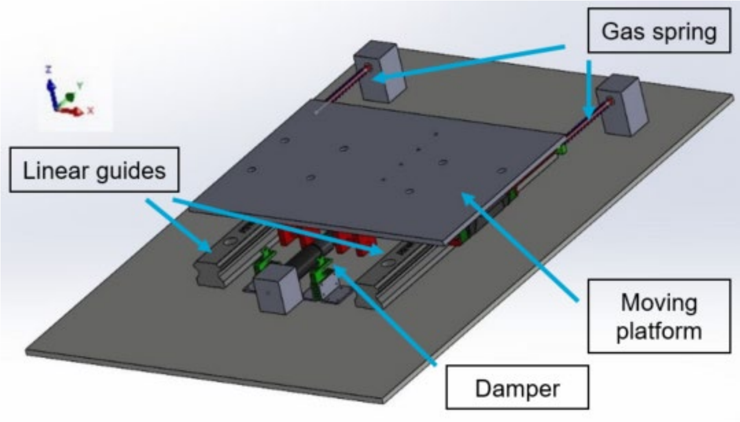


Figure 2: Kick-plate device design.

Figure 3 shows a nonlinear simulation at an initial speed of 6 m/s of the Carvallo-Whipple bicycle model extended to include the linear effects of side slip, camber, and relaxation length on tyre lateral force and self-aligning torque. A basic human controller has been also added to stabilize the bike.

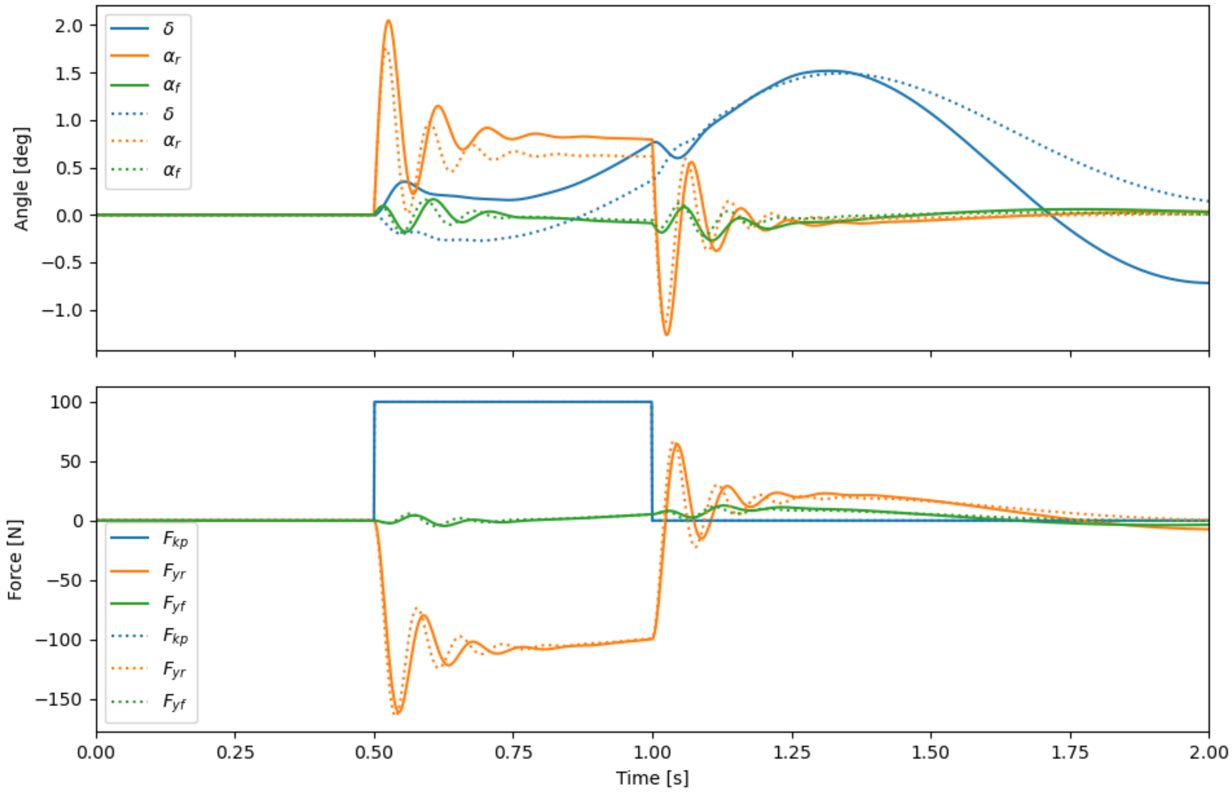


Figure 3: Non-linear simulations led on modified Carvallo-Whipple model, adding the tyre contribution.

We activate the kick plate on the rear wheel with a 100 N pulse F_{kp} and show the response on steer angle δ, front and rear side slip (α_f, α_r), front and rear lateral forces $F_{y,f}$, $F_{y,r}$ respectively. The dotted lines show the response when the slip and camber coefficients are reduced by 30%, representing expected differences when a tyre is deflated from 5 bar to 3 bar.

3 CONCLUSIONS

Bicycle tyres may affect the stability of bicycle-rider models. To investigate this further, we have modeled the kick-plate platform for applying a lateral disturbance to the contact point between the tyre and the ground. We have set the test protocol and are currently in the process of prototyping the kick-plate device.
The result of our study may set a new benchmark for the implementation of homologation rules for micromobility vehicles in the near future.

The project was partially financed and supported by the TKI/ClickNL 'De Fiets van de Toekomst' grant and Royal Dutch Gazelle.

We would like to thank Jasper Van Aernsbergen, Jip Smalbroek, Lieve McGee, Luc Roosmalen, and Nick Verhoeks who are actively cooperating to realize the kick-plate test, as part of their thesis project. Thanks to Andrew Dressel for assistance in the tyre modeling and Sierd Heida for providing tyre for testing.

REFERENCES

[1] EU Parliament, “European Parliament - Developing an EU Cycling Strategy”, *Resolution B9-0102/2023*

[2] V. E. Bulsink, A. Doria, D. Van De Belt, and B. Koopman, “The effect of tyre and rider properties on the stability of a bicycle,” Adv. Mech. Eng., vol. 7, no. 12, Dec. 2015, doi.org/10.1177/1687814015622596

[3] G. Dell’Orto, F. Ballo, G. Mastinu, “Experimental methods to measure the lateral characteristics of bicycle tyres – a review,” Vehicle System Dynamics, 1–23. doi.org/10.1080/00423114.2022.2144388

[4] G. Dell’Orto, F. Ballo, G. Mastinu, M. Gobbi, “Bicycle tyres – development of a new test-rig to measure mechanical characteristics”, *Measurement*, 202, 111813 doi.org/10.1016/j.measurement.2022.111813

[5] Alizadehsaravi L., J. K. Moore, “The effects of a steer assist system on bicycle postural control in real-life safety challenges”, *10th Annual International Cycling Safety Conference, Dresden*, 2022 doi.org/10.25368/2022.496

Project Cycling Life – a large-scale RCT to evaluate the safety effect of daytime running lights on bicycles

H. Lahrmann*, T.K.O. Madsen*, A.B.Tallaksen*, A.V. Olesen*,

* Traffic Research Group – Aalborg University
Thomas Manns Vej 23, DK 9220 Aalborg OE, Denmark
email: hsl@build.aau.dk

Keywords: cyclist, accident, crash, traffic safety, daytime running light, randomised controlled trial, RCT, visibility.

INTRODUCTION

In Denmark, almost 2,000 cyclists per million inhabitants are treated every year following multi-party accidents with other road users [1]. Previous research has shown that improving the visibility of cyclists has a significant safety impact on the number of multi-party accidents [2][3]. [2] was also a randomized controlled trial (RCT) with daytime running lights and showed 47% fewer multi-party accidents.

The aim of this "Project Cycling Life" has been to repeat the RCT [2], but with a new and more powerful driving light, and thus again to investigate how cyclists' use of daytime running lights affects cyclists' accident risk in multi-party accidents. The project has hypothesized that the use of daytime running lights will make cyclists more visible in the traffic scene and thus achieve a reduction in the number of multi-party accidents.

1 METHOD

Participants were recruited through the project website www.cykelliv.dk. The website was promoted through a variety of social media channels and a press release. Within a month we had 5,380 participants in the project, half of whom received the light for a deposit of 13 EURO, and with the option to buy the light for 13 EURO after the trial. The other half was the control group, and this group could buy the light for 13 EURO after the trial - The market price of the light is 80 EURO. See the pictures to the right.

Figure 1 NOVA daytime running lights from the company Reelight

The project ran over 13 months, with participants receiving a monthly email containing a link to a questionnaire asking them if they had cycled in the previous month and if they experienced any accidents while cycling.

At the end of the study, the number of months that participants in the two groups had actively reported cycling and the number of cycling accidents was recorded. The accident rate in the test and control groups was then calculated as the ratio of the number of multi-party accidents to the number of 'active' months, and the effect was calculated as the ratio of these.

2 RESULTS

2.1 Reported accidents

In total, participants reported for 36,503 months, and 230 accidents were reported, of which 60 accidents were accidents in which the participant sustained more serious injuries than bruises, which were defined as personal injury accidents. 135 of the accidents were multi-party accidents, of which 34 were personal injury accidents, and 95 were single-party accidents, of which 26 were personal injury accidents. Table 1 shows the reported accidents broken down by several parameters.

Table 1: Accident characteristics. Personal injury accidents cover accidents where the participant has sustained injuries more serious than bruising.

Accident characteristics	**Test Group**		**Control group**	
	All accidents	Personal injury accidents	All accidents	Personal injury-accidents
Accidents in total	121	25	109	35
Type				
Single accidents	59	14	36	12
Multi-party accidents	62	11	73	23
Season				
Winter (October-March)	79	18	70	22
Summer (April-September)	42	7	39	13
Lighting conditions				
Daylight	87	14	80	28
Twilight	12	3	8	1
Dark	22	8	21	6

2.2 Safety effect of driving lights

The participants in this project know which group they belong to, and they know the hypothesis of the project. Therefore, the results may be affected by demand characteristics. To get an idea of this bias, we have corrected the results with a correction factor formed from the participants' reporting of single accidents. The assessment has been that a possible bias in the reporting would also include the single accidents, as the participants would otherwise have realized that their "demand characteristics" would only include the multi-party accidents and not the single accidents.

Table 2 and Table 3 show the corrected effects of daytime running lights on multi-party accidents, broken down into personal injury accidents and all accidents respectively. The column IRR (Incidence Rate Ratio which is the effect measure) should be read in such a way that at a value of 1.00 there is no effect, values below 1 indicate a decrease in the number of accidents - e.g., a value of 0.75 indicates a decrease of 25% - and values above 1 indicate a corresponding increase. The 95% CI(IRR) column shows the 95% confidence interval for the IRR, and only if the confidence interval does not include the value 1 is either the decrease or the increase statistically significant.

The project's main finding from Tables 2 and 3 is that the group driving with lights had 30% fewer multi-party accidents and 25% fewer multi-party accidents with injury. However, none of the results are statistically significant.

Table 2: Incidence rates, incidence rate ratios (IRR), and 95% confidence intervals for multi-party injury accidents, corrected for over-reporting in the test group.

Multi-party accidents involving personal injury (corrected)						
Multi-vehicle accidents involving personal injury	Number of accidents		Incidence rate * 1.000		IRR	95% CI (IRR)
	Test Group	Control group	Test Group (Corrected)	Control group		

All	11	23	0,84	1,11	0,75	[0,23; 2,47]
Winter	6	15	0,80	1,28	0,63	[0,16; 2,40]
Summer	5	8	0,88	0,90	0,98	[0,23; 4,25]
Daylight	7	17	0,53	0,82	0,65	[0,18; 2,36]
Twilight	2	0	0,15	0,00	-	[- ; -]
Dark	2	6	0,15	0,29	0,52	[0,08; 3,36]
Motorized counterpart	5	7	0,38	0,34	1,12	[0,25; 4,97]
VRU counterpart	6	16	0,46	0,77	0,59	[0,16; 2,24]

Table 3: Incidence rates, incidence rate ratios (IRR), and 95% confidence intervals for all multi-party accidents, corrected for overreporting in the test group.

All multi-party accidents (corrected)						
Multi-party accidents	Number of accidents		Incidence rate * 1.000		IRR	95% CI (IRR)
	Test group	Control group	Test Group (Corrected)	Control group		
All	62	73	2,48	3,53	0,70	[0,39; 1,28]
Winter	34	47	2,39	3,99	0,60	[0,31; 1,16]
Summer	28	26	2,60	2,91	0,89	[0,43; 1,85]
Daylight	52	51	2,08	2,46	0,84	[0,45; 1,58]
Twilight	4	5	0,16	0,24	0,66	[0,16; 2,70]
Dark	6	17	0,24	0,82	0,29	[0,10; 0,84]
Motorized counterpart	23	22	0,92	1,06	0,87	[0,40; 1,86]
VRU counterpart	39	51	1,56	2,46	0,63	[0,33; 1,21]

3 CONCLUSIONS

Project Cycling Life investigated the safety effect of a fixed daytime running light on bikes through a RCT with 5,380 participants, half of whom cycled with the light, for 13 months and the other half were controls. The project showed that the group going with daytime running lights had 30% fewer multi-party accidents and 25% fewer multi-party accidents with injuries. However, neither of the effects were statistically significant.

4 REFERENCES

[1] Olesen AV, Lahrmann H, Madsen TKO, Hels T, Lauritsen J. Hvor mange kommer til skade i trafikken? estimering af antal personskader efter trafikulykker i Danmark baseret på selvrapportering igennem en befolkningsundersøgelse. Danish Journal of Transportation Research 2022 mar. 17;4(1):1-15. 6956. doi: 10.5278/ojs.djtr.v4i1.6956

[2] Madsen JCO, Andersen T, Lahrmann H. Safety effects of permanent running lights for bicycles: A controlled experiment. Accident Analysis & Prevention. 2013 jan.;50:820-829. doi: 10.1016/j.aap.2012.07.006

[3] Lahrmann H, Madsen TKO, Olesen AV, Madsen JCO, Hels T. The effect of a yellow bicycle jacket on cyclist accidents. Safety Science. 2018 okt. 1;108:209-217. doi: 10.1016/j.ssci.2017.08.001

Designing public education campaigns to reduce dehumanisation of cyclists

N. L. Haworth*, A. Delbosc#, A. Schramm*, N. Haslam†

* Centre for Accident Research and Road Safety –
Queensland (CARRS-Q)
Queensland University of Technology
130 Victoria Park Road, Kelvin Grove 4059, Australia
email: n.haworth@qut.edu.au,
a.schramm@qut.edu.au

Institute of Transport Studies
Monash University
23 College Walk, Clayton 3800, Australia
email: a.delbosc@monash.edu

†School of Psychological Sciences
University of Melbourne
Parkville 3000, Australia
email: nhaslam@unimelb.edu.au

Keywords: dehumanisation, attitudes, aggression, public education, cyclist.

1 INTRODUCTION

A range of studies has found that attitudes toward cyclists in low cycling countries are predominantly negative. Worryingly, negative attitudes toward cyclists are associated with self-reported aggression and hostility toward cyclists. Public references to violence against cyclists are not uncommon and rarely given the same condemnation as, for example, violence toward women or bullying [1].

In a pilot study, the authors [2] found that around half of non-cyclists held dehumanising beliefs about cyclists. Dehumanisation means treating people as if they are less than fully human, or not fully evolved, and it is usually applied to racial or ethnic groups, homeless people or psychiatric patients. On-road cyclists look and act differently to 'humans': they move in a mechanical way and their faces are not often seen by motorists. Critically, these dehumanising beliefs were correlated with negative attitudes to cyclists and with self-reported aggression such as throwing objects at cyclists or using a car to deliberately block a cyclist.

The current study explores ways to reduce the dehumanisation of cyclists through public education. If we can put a human face to cyclists, we may improve attitudes, increase support for cycling infrastructure, increase willingness to try cycling and reduce aggression directed at on-road cyclists. It may increase community willingness to support the investment in safe cycling infrastructure, reducing the likelihood of conflict in the first place. This could result in a reduction in cyclist road trauma or an increase in public acceptance of cyclists as legitimate road users.

2 RESEARCH METHODS

The research team designed a questionnaire that ostensibly tested reactions to a proposed media campaign promoting the new law requiring drivers to provide at least a metre between their vehicle and cyclists. Two aspects of the campaign poster were manipulated: whether the image showed the rider face-on and whether the image was a photograph or a graphical version of the photo. Half of the participants were shown the photograph and then the graphical version, both from the front. The remaining participants were shown both versions from the rear. Based on past research, it was expected that both the photographic version and the front-on images would be more 'humanising' than images from the rear or graphical images.

After viewing the images, participants were asked a range of questions measuring:

- Evaluation ratings of the poster designs (clarity, memorability and effectiveness)
- Attitudes to cyclists using the Attitudes to Cyclists Scale (ATCS), developed by Rissel et al. [3]

- Aggression and harassment toward cyclists (how often they shouted at cyclists, threw objects at cyclists, etc) [4]
- Two different measures of dehumanisation of cyclists, including the Dehumanisation Trait Scale [5] and the Blatant Dehumanisation Slider [6]
- How often respondents drove a car or rode a bicycle (to classify people as cyclists, who ride a bicycle at least monthly, or drivers, who haven't ridden a bike in the last year but drive a car at least monthly)

For the attitude and dehumanisation scales, participants were asked to rate 'riders like this' (in the poster). The survey was advertised via paid Facebook ads as well as newsletters, ACT government email and social media. A total of 379 people commenced the survey, with a final result of 267 responses (168 cyclists and 98 drivers) after data cleaning and removal of incomplete responses.

3 RESULTS

This paper will focus on the results regarding how the design of the posters influenced attitudes and dehumanising beliefs. For each poster, the mean score on the Attitudes to Cyclists Scale was significantly higher (F(1, 243)=44.572, p<.01) for cyclists than drivers. The design of the image (front or rear view, photo or graphic) had no effect on attitude ratings. However, there was a statistically significant interaction (F(1, 243)=6.372, p<.05) in which drivers reported more positive attitudes to the cyclist shown from the front than from the rear (25.0 vs 22.8), while this was not evident for the cyclist participants (28.1 vs 28.6).

In contrast, poster design had a significant impact on measures of dehumanisation. The two measures of dehumanisation found similar results, so we focus on the Blatant Dehumanisation (Ape to Human) Scale (where higher values represent lower levels of dehumanisation). The statistical analysis of these scores showed that participants who were cyclists rated the cyclist shown in the posters as more human than did the driver participants (91.6 vs 82.9, F(1, 240)=7.444, p<.01). The rider in the photographic posters was rated as more human than the rider in the graphical posters (89.6 vs 87.8, F(1, 240)=11.831, p<.01). However, overall there was no statistically significant difference between the scores for the front and rear versions of the posters, although this did appear to have an effect on drivers.

4 DISCUSSION

Based on previous research, it was predicted that the lowest levels of dehumanisation would be reported for campaign posters showing face-on photographs of cyclists. The results from this study showed that using photographs did lead to lower levels of dehumanisation compared to using graphical representations of riders. However, the reduction in dehumanisation resulting from showing the front of the rider instead of the back was not statistically significant. These results suggest that using photographs in campaigns is more humanising than using graphical images, but that whether the rider is shown from the front or the back makes little difference. While past research in other domains has shown that faces are humanising, we could speculate that the current findings reflect that drivers see riders from the back before passing, and so the rearview depiction may seem more relevant to the message being portrayed in the poster.

Interestingly, there was little effect on poster design on attitudes to "riders like this". The scores on the Attitudes to Cyclists Scale (ATCS) did not differ between the photographic and graphical posters or between those showing the rider from the front versus the rear. The only difference found was that drivers (but not cyclist participants) reported more positive attitudes to the rider shown from the front than the rear. This difference could indicate that attitudes to cyclists are more static and fixed, or at least that they are not sensitive to small changes in how cyclists are portrayed. However, the dehumanisation measures appear to be more sensitive to context and portrayal of people on bicycles.

The overall prevalence of dehumanizing beliefs is still concerning, with over half of respondents rating the bike riders in the posters as less than 100% human on the Blatant Dehumanisation Scale. Regardless of the campaign design, people who ride bicycles themselves had more positive attitudes and more humanizing beliefs toward other cyclists. This suggests that if we can get more people riding, we may set off a virtuous cycle that erodes dehumanizing beliefs and increases support for safe cycling infrastructure.

5 CONCLUSIONS

How cyclists are portrayed in public education efforts may influence the level of dehumanization, with the results suggesting that photographs of cyclists may contribute to lower levels of dehumanisation compared to using graphical representations. While past research has shown that faces are humanising, the rear view may be more relevant for messages about passing riders. However, the type of image did not appear to influence attitudes to cyclists, suggesting that attitudes are more static and fixed.

ACKNOWLEDGEMENTS

This research was funded by the ACT Government Road Safety Fund Grants Program. The research team would like to thank Dr Rod Katz for his assistance in preparing the photographs for this study. We would also like to thank our participants for their time and interest.

REFERENCES

[1] M. Johnson. Why do we still hear people joke about hitting cyclists? 2014. [Online]. Available: https://theconversation.com/why-do-we-still-hear-people-joke-about-hitting-cyclists-31214

[2] A. Delbosc, F. Naznin, N. Haslam and N. Haworth, “Dehumanization of cyclists predicts self-reported aggressive behaviour toward them: A pilot study”, *Transportation Research Part F* 62 (2019), pp. 681–689.

[3] C. Rissel, F. Campbell, B. Ashley and L. Jackson, “Driver Road Rule Knowledge and Attitudes towards Cyclists”, Australian Journal of Primary Health, 8(2) (2002), pp. 66–69.

[4] K.C. Heesch, S. Sahlvquist and J. Garrard, “Cyclists’ experiences of harassment from motorists: Findings from a survey of cyclists in Queensland, Australia”, *Preventive Medicine* 53 (2011), pp. 417-420.

[5] B. Bastian, N. Haslam, “Excluded from humanity: The dehumanizing effects of social ostracism”, *Journal of Experimental Social Psychology* 46 (2010), pp. 107-113.

[6] N. Kteily, E. Bruneau, A. Waytz and S. Cotterill, “The ascent of man: Theoretical and empirical evidence for blatant dehumanization”, *Journal of Personality and Social Psychology* 109(5) (2015), pp. 901-931.

Review of the literature on the safety of micromobility

V. Petraki, K.Deliali*, G. Yannis

Department of Transportation Planning and Engineering
National Technical University of Athens
5 Heroon Polytechniou str., 15773, Athens, Greece
*email: kdeliali@mail.ntua.gr

Department of Transportation Planning and Engineering
National Technical University of Athens
5 Heroon Polytechniou str., 15773, Athens, Greece
email: vpetraki@mail.ntua.gr

Department of Transportation Planning and Engineering
National Technical University of Athens
5 Heroon Polytechniou str., 15773, Athens, Greece
email: geyannis@central.ntua.gr

Keywords: micromobility, road safety, injuries, risk factors, modal shift.

1 INTRODUCTION

The introduction of micromobility services such as electrically assisted scooters (e-scooters) and cycles (e-bikes) in many cities is leading to significant changes in urban transportation on a daily basis, bringing new and pressing challenges for policymakers at the national level. In 2019, 3.7 million e-bikes were sold and, by 2030 e-bike sales are expected to reach 17 million annually in the EU28 while e-scooter market is anticipated to be driven by increasing e-scooter sharing services. The rise of micromobility share highlights the necessity of examining its safety. This paper aims to analyze the most recent safety trends of e-scooters and e-bikes based on the existing literature focusing on the traffic safety impact of both shared and owned e-scooters and e-bikes. For this purpose, an extensive review of the scientific and "grey" literature was conducted. Findings at the international level regarding the two modes were summarized and synthesized. Lastly, the overall conclusions and policy recommendations are discussed.

2 METHODOLOGY

Up to the time of the abstract submission, eighty-one (81) relevant studies were identified and considered appropriate for this review. The number of reviewed studies is expected to grow as more papers/reports are published and the authors aim at presenting the most updated overview. Among those, four peer review papers were identified while about 10% of the remaining studies are reports published by policy organizations, governmental organizations, or service providers. The year of publication of the e-scooter studies ranges between 2018 and 2023. Most of those studies is based on the 2018-2020 data. On the contrary, resources on e-bikes are dated from 2007 to 2022 and are based on data from the same period.

3 MICROMOBILITY CRASH AND INJURY

In the framework of this paper the traffic safety of e-scooters and e-bike operations were investigated based on 58 studies and analyses.

2.1 Safety of e-scooters operations

E-scooter safety is a topic that has garnered significant attention in recent years. The majority of the literature on e-scooter safety focuses on the injury severity levels that e-scooter riders are subject to, as well e-scooter risk considering various exposure measures.

By synthesizing the literature, it is evident that when a crash involves an e-scooter then it is quite rare not to have an injury (6-27%), with the injuries mostly affecting the upper body and head. Most of the time (61-

76%) it results in a minor injury (e.g., scratch) while severe injuries correspond to 18 to 33% of the times. Falls specifically account for a significant number of crashes (~80%) and injuries (64-85%). Several research findings demonstrate that the more a person is using an e-scooter the more their safety with this mode is improved.

It is important to note that in their majority e-scooter reported injuries are due to single-user crashes. Single-user e-scooter injuries mostly involve the rider and secondly, pedestrians who either are hit by a moving e-scooter (29.5%) or they trip over a parked e-scooter. Specifically, pedestrians, compared to other road users, are considerably affected by e-scooters partially because in some countries, e-scooters had to use the sidewalk, or in other contexts, e-scooterists ride on the sidewalk, especially in the absence of bike lanes. Pedestrian injuries make up 1 to 10% of all injuries related to e-scooters, which is a result of pedestrians sharing the same space with e-scooter riders. While e-scooter and motor vehicle collisions account for a relatively small portion of injuries (8-19%) they are mostly responsible for e-scooter fatalities (~85% of fatalities).

The literature on e-scooter safety identifies several risk factors, including reduced lighting conditions, riding under the influence of alcohol, poor road infrastructure, and riding on sidewalks. Helmet use is also low among injured riders, and head and face injuries are common among e-scooter injuries. E-scooter providers have developed measures to address some of these risk factors, such as app-based features to detect rider sobriety levels, speed restriction software, night lights, and noise features. Cities are also implementing bike lane networks and car-free/low-car/low-speed zones to encourage micromobility modes. Education and communication can improve user compliance and behavior, and helmet laws have been found to be effective in improving user behavior and compliance.

2.2 Safety of e-bikes operations

E-bikes are becoming increasingly popular worldwide, having several benefits, including enabling a more diverse population to ride a bike and leading to health benefits due to the shift from motorized vehicles. The literature on the safety of e-bikes is relatively sparse and mainly covers the pre-pandemic era. Existing studies tend to be concentrated in certain European countries, some US states, and China. For this review a total of twelve (12) studies on e-bikes were analyzed, ten (10) of which are scientific papers, one (1) is review (white paper), and one is a report.

Crash and injury data as well as exposure data for bikes are much more abundant and reliable compared to e-scooter data. Bikes are still disproportionally affected by crashes in relation to other vehicles. Safety data exist from earlier (e.g., before 2018) implementations of e-bikes; there are mixed findings of the safety of e-bikes compared to bikes, especially between EU and US studies. However, these earlier data do not capture e-bike great post-pandemic expansion (e.g., use in logistics).

Several studies in European countries where e-bikes are allowed to offer pedal assistance up to 25 km/h showed that e-bike crashes are in general equally severe as conventional bike crashes. Crash and injury risk factors associated with e-bikes are similar to those of conventional bikes and e-scooters, namely: nighttime riding, alcohol consumption, riding on roads with high speeds and no bike, and helmet use. However, the literature on these factors is sparse and does not allow for proper estimation of their overall effect.

4 SURROGATE SAFETY

Given the fact that e-scooters and e-bikes have been only recently massively deployed, crash data is not always readily available to allow for reliable safety analysis, the use of surrogate safety data is expected to provide insightful information on the crash mechanism. The findings from these studies can be used to complement crash- and injury-based studies for a deeper understanding of the risk factors associated with e-scooters and e-bikes operations. For e-scooters and e-bikes eleven (11) surrogate safety studies have been identified and reviewed for this analysis.

The findings on surrogate safety data for e-scooters reveal that pedestrians experience greater impact by e-scooter trips. When e-scooter riders travel on bike lanes, their speed is comparable to but slightly higher than that of conventional bikes. E-scooters require a longer braking distance compared to bikes, which affects conflicting interactions. E-scooters also develop higher speeds in low-traffic streets compared to sidewalks.

The research on surrogate safety for e-bikes is limited and mainly based on old research without a common methodological framework and aiming to investigate the safety performance of e-bikes compared to conventional ones. Based on two studies in China and one in Germany, the conflict rate of e-bikes is higher than conventional bikes without taking into account the fault. On sidewalks and bike lanes, the probability of conflicts and interactions involving e-bikes is not significantly different from conventional bikes.

5 SAFETY IMPLICATIONS OF MODAL SHIFT

To investigate the modal shift from car, public transport, and other active modes to e-scooters and e-bikes and asses modal shift findings in relation to safety, more than twenty (>20) papers and publications from 2007 to 2022, with a focus on region and transport mode were taken into account.

The highest modal shift from cars to e-scooters and e-bikes was observed in the US, where shared e-scooter users replace 46.3% of their car trips and e-bike users replace 57%. In European cities, e-scooters are most likely to replace walking trips followed by public transport trips, while e-bikes are causing a considerable substitution of cars, public transport, and conventional bike trips. The substitution rate of riding e-scooters for public transport trips is significantly higher in Europe (33.6%) compared to the US and New Zealand, while public transport is reported as the most common mode to combine e-scooters with mainly in European cities. In China, a significant substitution of public transport (54%) is observed with e-bike usage, while auto trips do not seem to be significantly affected.

A modal shift from auto (private car, taxis, TNCs) to micromobility is expected to improve micromobility as the number of motorized vehicles on the road decreases and so, micromobility modes are exposed to risky interactions. However, the case that micromobility takes users out of public transport is not considered beneficial for safety as public transport has high safety level.

6 CONCLUSION

This study aimed to analyze the most recent safety trends of e-scooters and e-bikes internationally, based on the existing literature. Most existing studies rely on the analysis of crash and injury data to assess the safety of the two micromobility modes, while several studies have relied on surrogate safety measures. A wide body of literature has focused on the modal shift caused by the introduction of e-scooters and e-bikes.

Micromobility safety results are not black and white; they depend on infrastructure, traffic volumes and speed and safety culture. Future efforts in the understanding of micromobility safety should focus on constantly renewing the findings from the literature to capture as early as possible the current trends. Additionally, efforts should focus on extracting real-world datasets and conducting analyses to capture safety trends, modal split and shift, etc. that can improve current knowledge.

Overall, addressing e-scooter and e-bikes safety requires a combination of measures, including improving infrastructure, promoting responsible behavior through education and communication, and implementing regulations such as helmet laws.

7 REFERENCES

As this is a review paper, references are omitted from this abstract due to space constraints.

Examining the crash risk factors associated with cycling: findings from four Dutch cities

T. Uijtdewilligen[*], M. B. Ulak[#], G. J. Wijlhuizen[*], F. Bijleveld[*], K. T. Geurs[#], A. Dijkstra[*]

[*]SWOV Institute for Road Safety Research
Henri Faasdreef 312
PO Box 93113, 2509 AC The Hague, the Netherlands
email: teun.uijtdewilligen@swov.nl;
gert.jan.wijlhuizen@swov.nl; frits.bijleveld@swov.nl;
atze.dijkstra@swov.nl

[#]Faculty of Engineering Technology,
Department of Civil Engineering
University of Twente
PO Box 217, 7500 AE Enschede, the Netherlands
email: m.b.ulak@utwente.nl; k.t.geurs@utwente.nl

Keywords: Bicycle safety, Hourly resolution, Exposure, Network Structure, Cycling infrastructure.

1 INTRODUCTION

Due to investments in cycling infrastructure and promotion of cycling as a green and healthy mode of transport, cycling gains popularity in many cities around the globe. These growing cycling levels lead to an increasing number of severe and fatal bicycle crashes, particularly in urban areas where more than half of the fatal crashes in the European Union occurred [1]. Therefore, understanding the factors affecting bicycle safety in urban areas is crucial to improve the wellbeing of cyclists and further promote cycling as a sustainable and healthy mode of transport. This paper aims to contribute to safer urban cycling by examining bicycle crash risk factors in Dutch cities.

Bicycle crashes have a strong spatial and temporal character as these crashes tend to cluster at specific locations which is influenced by temporal variation in these crashes [2]. It is therefore important to consider this heterogeneity of crashes in space and time when investigating bicycle safety. To address this nature of bicycle crashes, the current study uses a high-resolution spatiotemporal dataset with hourly variation in bicycle crashes and exposure metrics on each road section of the cycling network. Other examined risk factors are network structure, cycling infrastructure, speed limits, and proximity of popular destinations for cyclists. Moreover, to provide transferability of the results, the cycling networks of the four largest Dutch cities are analyzed simultaneously.

2 DATA AND METHODS

2.1 Study area

The study area covers the four largest Dutch cities: Amsterdam, Utrecht, Rotterdam, and The Hague. The infrastructure of Amsterdam and Utrecht is characterized by being more cycling-friendly, while in Rotterdam and The Hague the infrastructure is more car-oriented. This is also illustrated by the difference in cycling levels. These are the highest in Amsterdam and Utrecht, with around 40% of the short trips (1-7 km) made by bicycle and 25% by car. In Rotterdam and The Hague this is 30% for both the bicycle and the car [3].

2.2 Data

The crash data includes all police-reported injury (light or severe) and fatal crashes involving at least one cyclist and that occurred on road sections and intersections in the analysed networks between 2015 and 2019. The data for the predictors comes from a large variety of data sources, which is a consequence of analysing four cities in one study. For example, the data for the exposure metrics comes from GPS tracks, local hourly bicycle count data, local transport models, and local hourly motorised vehicle count data.

2.3 Methods

The network-wide hourly exposure to cyclists is estimated by calibrating the hourly bicycle GPS data with the local bicycle count data. For motorised vehicles, the average relative hourly volumes from the local count stations are multiplied by the estimated weekly average volumes obtained from the local transport models. To investigate the effect of network structure on bicycle safety, intersection density and betweenness centrality are retrieved. The latter shows the degree of a network being reliant on a number of road sections [4]. Lastly, due to the hourly disaggregation of bicycle crashes, the number of zeros increased and the crashes are distributed over all hours of the week (168 hours). As a result, nearly all hours where at least one bicycle crash occurred only have one crash. This makes the bicycle crashes virtually a binary variable as there is either a crash or no crash. Therefore, logistic regression is used to estimate the probability of a bicycle crash occurring, defined as bicycle crash risk.

3 RESULTS

The focus of the results is on the main findings adopted from a general model that combines the data from all four cities. City-specific results are also presented as there are some significant differences between the studied cities. However, it is noteworthy that, despite the large variety of data sources (that may cause these differences to some extent), most results are quite robust across the cities. Figure 1 presents the standardized coefficient estimates for the significant variables of the general model and the four city-specific models.

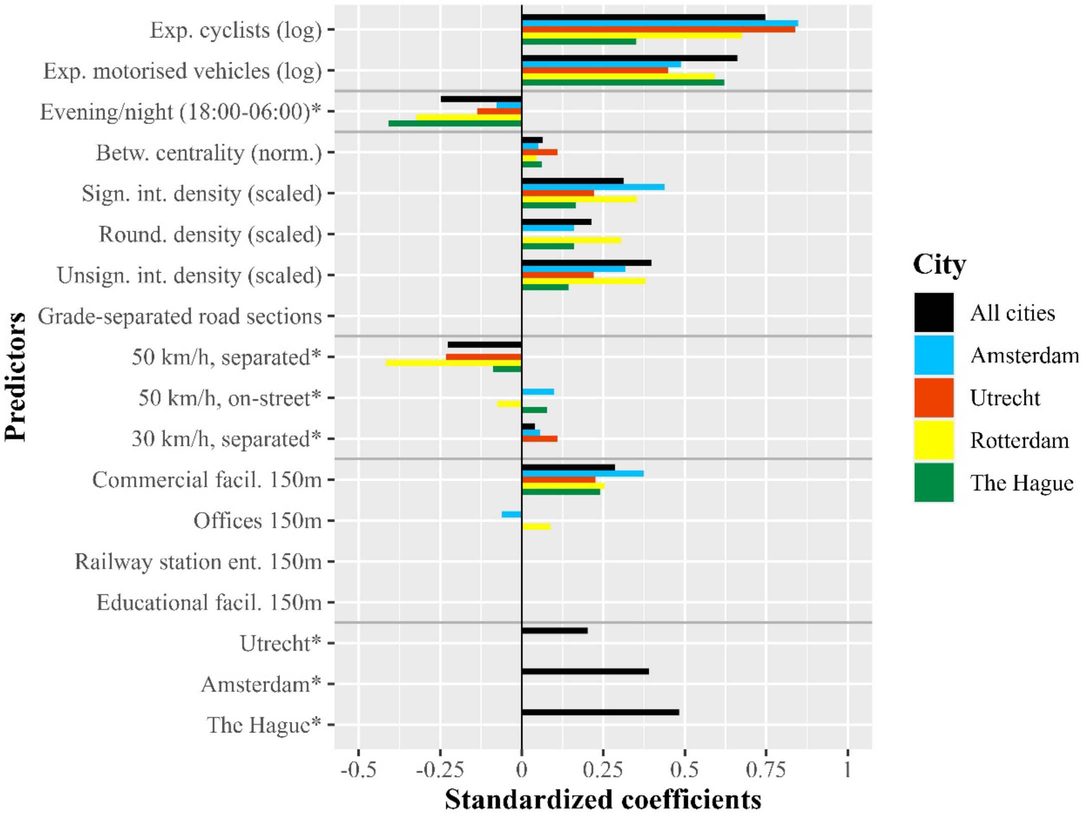


*Figure 1: Results of the five logistic regression models. *Reference: for evening/night (18:00-06:00) is morning/day (06:00-18:00); for cycling infrastructure is 30 km/h with on-street cycling facilities; for municipality is Rotterdam.*

Both the exposure to cyclists and the exposure to motorized vehicles show a strong impact on bicycle safety in all cities. The results indicate that hours with larger exposure levels lead to a higher bicycle crash risk. Furthermore, it can be noticed that a relative increase in the exposure to cyclists has a slightly larger impact than the same relative increase in exposure to motorized vehicles. Moreover, bicycle crash risk is lower during the evening/night hours (18:00-06:00) than during the morning/day hours (06:00-18:00).

The betweenness centrality indicator has a relatively low impact on bicycle safety and results imply that the more central the road section is, the slight higher the bicycle crash risk. One reason might be that at road sections with high centrality, many routes come together, leading to increased interactions and conflicts between road users. The intersection density variables have an average impact on bicycle safety. The results indicate that bicycle crash risk is higher where there are more intersections per kilometer.

For the cycling infrastructure variables, the results indicate that bicycle crash risk on 50 km/h roads with separated bicycle tracks is lower than the reference (30 km/h roads with on-street cycling facilities). This might be caused by the fact that for three out of the four cities only the higher volume 30 km/h roads are included and that such roads may have negative implications for bicycle safety. Secondly, no significant relationship between 50 km/h roads with on-street cycling facilities and bicycle crash risk is found in the general model. This result may be caused by the contradictory city-specific findings, as bicycle crash risk on this road type is higher than the reference in Amsterdam and The Hague, it is lower in Rotterdam, and in Utrecht no significant relationship is found. Lastly, the results show a counter-intuitive higher crash risk at 30 km/h with separated bicycle tracks compared to the reference, but the impact on bicycle safety is low. Presumably, these roads are designed as 50 km/h roads with separated bicycle tracks, which may cause speeding as the design does not fit the intended speed limit.

It is shown that cycling within 150 meters network distance of commercial facilities has a relatively strong impact on bicycle safety. The findings imply that in shopping areas bicycle crash risk is higher, presumably due to increased numbers of pedestrians or other road users. For the other destination types, this study found no significant relationship with bicycle safety in the general model.

4 COCNLUSIONS

The main conclusions of the study are as follows:

1. The exposure variables (cyclist and motorized vehicles) have the largest effect on bicycle crash risk.
2. Bicycle crash risk is lower during the evening and night hours than during the daytime hours.
3. The most central road sections (i.e., betweenness centrality) in the cycling network have a higher bicycle crash risk, but the overall impact of centrality is limited.
4. The higher the intersection density, the higher the bicycle crash risk.
5. Compared to 30 km/h roads with on-street cycling facilities, bicycle crash risk on 50 km/h roads with separated bicycle tracks is lower.
6. 30 km/h roads with separated bicycle tracks have a higher bicycle crash risk than 30 km/h roads with on-street cycling facilities, but the impact on bicycle safety is limited.
7. Roads close to commercial facilities have a higher bicycle crash risk than roads further away. The impact of commercial facilities on bicycle safety is relatively high.

REFERENCES

[1] European Commision, *Annual statistical report on road safety in the EU, 2021. European Road Safety Observatory,* European Commission, Directorate General for Transport, Brussels, 2022.

[2] M. Loidl, C. Traun, and G. Wallentin, "Spatial patterns and temporal dynamics of urban bicycle crashes-A case study from Salzburg (Austria)", *Journal of Transport Geography* 52 (2016), pp. 38-50.

[3] O. Jonkeren, H. Wust, and M. de Haas, *Mobiliteit in stedelijk Nederland [Mobility in Dutch urban areas],* KiM Netherlands Institute for Transport Policy Analysis, The Hague, 2019.

[4] M. B. Kamel and T. Sayed, "The impact of bike network indicators on bike kilometers traveled and bike safety: A network theory approach", *Environment and Planning B: Urban Analytics and City Science* 48(7) (2020), pp. 1-18.

How Smooth is Your Ride?

A Comparison of Sensors and Methods for Surface Quality Assessment using IMUs

M. Beeking*, H. Wies*, M. Steinmaßl*, K. Rehrl*

*Mobility & Transport Analytics Group
Salzburg Research Forschungsgesellschaft m.b.H.
Jakob Haringer Straße 5/3, 5020 Salzburg, Austria
moritz.beeking@salzburgresearch.at
hannah.wies@salzburgresearch.at
markus.steinmassl@salzburgresearch.at
karl.rehrl@salzburgresearch.at

Keywords: surface roughness, cycling comfort, sensor bike, infrastructure assessment, inertial measurement unit (IMU).

1 INTRODUCTION

Comfort is an important factor for people's decision to ride a bicycle [1] [2, pp. 68-70]. The surface roughness of bicycle infrastructure is a well-established measure of bicycle comfort [3] [4]. Most works on measuring the surface roughness of bicycle infrastructure use acceleration data collected with inertial measurement units (IMUs) [5], being part of dedicated devices [6] [7] or smartphones [8] [9] [10]. In most cases, authors use vertical acceleration values, either by installing the IMU in such a way that one axis is perpendicular to the ground plane [6] [10], or by calculating the resulting vertical acceleration from all three axes [8] [9]. Some works use all three axes of the accelerometer directly [11]. Different methods have been applied to derive and quantify the roughness or comfort of the corresponding riding surface from acceleration. The International Roughness Index (IRI) [12, pp. 45-52] is a well-established roughness measure. Therefore, some works try to directly calculate it [9], while some consider closely related measures [6] [11]. Other works introduce own comfort measures not related to the IRI [8] [10].

While the findings of some of these works have been previously compared [5], a proper comparison of methods and their characteristics has not been conducted yet. Therefore, the aim of this work is to provide insights on the properties of different combinations of acceleration sensors and calculation methods for roughness and comfort. To this end, these combinations will be applied to the same test routes and the resulting assessments compared.

2 EXPERIMENT DESIGN

For creating a test data set to compare the assessments of different combinations of sensors and methods for roughness calculation, data from both a smartphone and a dedicated IMU will be collected during the same test rides. This data set will comprise asphalt, gravel, and cobblestone surfaces of different conditions. It will be made publicly available to allow for further method development and refinement.

Roughness or comfort are usually derived for short segments of the test routes. There are works using segments of 5 [10], 10 [8], 20 [9] or even 100 [6] meters. The collected data will first be mapped onto a graph representation of the road network and then cut into these segments. Subsequently, the vertical acceleration component will be isolated and processed further using different methods from literature listed in section 2.2. Some of these produce numerical assessments like the IRI [9] or the dynamic comfort index (DCI) [6], others yield ordinal classes [8] [10]. Nonparametric statistics will be used for the evaluation of stability and reliability as described in section 2.3. Evaluation of each sensor-method combination, including the effect of segment length, will be performed per segment with at least five test rides.

2.1 Used Sensors

For collecting the test dataset, both a Xiaomi Mi 9X smartphone and an industry-grade IMU built into the XSens MTI-680G[1] device are used. The selection of devices is based on different approaches for bicycle infrastructure assessment. Smartphone sensors, as well as low cost IMUs in shared bicycles, address the use case of acceleration data collected using a crowdsourcing approach. For example, providers of bicycle routing apps could integrate IMU measurements which result in detailed maps of surface roughness and comfort on users' bicycle routes. These maps could subsequently be used to refine the routing based on the roughness indicator. The use of a dedicated sensor, on the other hand, is more relevant for acquiring acceleration data during planned test rides. These are usually conducted by either research groups, civil engineering companies, or public bodies responsible for infrastructure maintenance. This work will provide insights on the results to be expected using a certain type of sensor, allowing to select the best suited ones for a given task.

2.2 Used Methods

Of the six works on pavement condition listed by [5], only the methods used to calculate the DCI by [6] and the method to classify each segment into one of six classes by [10] were selected for comparison. The other four listed works were disregarded, as two did not describe any method to derive a roughness measure, one used a profilometer instead of an IMU, and the methodology of the last one was considered both poorly designed and described. Instead, the method to calculate the IRI from accelerations by [9] was added as the IRI is a well-established metric. The classification approach by [8] was added as a second method with ordinal output. Last, the method by [11] to derive a comfort assessment from all three axes of an accelerometer was selected to cover all recent, well-cited works on the topic. Depending on the use case, opting for numerical or ordinal assessments is the more natural choice. The results of this work will provide recommendations for the best suited method for either.

2.3 Evaluation Metrics

For each combination of sensor and calculation method, the stability and reliability of the resulting assessments will be evaluated. This will also yield the optimal combination for a given task. As stability measure, the dispersion of derived roughness or comfort measures on the same segment is considered. For numerical assessments the coefficient of variation will be used as dispersion metric. For ordinal assessments the dispersion as defined by [13] will be used. This metric is of special interest for planned test rides, as it determines the number of required test rides to achieve a stable assessment. This number is a major contributor to the costs and effort required to assess a certain predefined network. Also, for crowdsourcing approaches, this metric can be used to derive a reliability measure for sections with few test rides.

As reliability measure, Spearman's rank correlation coefficient ρ [14, pp. 140-148] is considered. A major advantage of using rank correlation is the comparability of numerical and ordinal assessments. Using it as reliability measure assumes an assessment agreed upon by several combinations to most likely be an accurate estimate of the actual roughness or comfort of a given test section. Therefore, this metric can then be considered an accuracy estimation for the individual sensor-method combinations. Based on these two metrics, a recommendation of which combinations to use for dedicated test ride- as well as crowd sourcing approaches will be provided.

---

[1] https://www.movella.com/products/sensor-modules/xsens-mti-680g-rtk-gnss-ins

3 POSSIBLE RESULTS

Three central questions should be answered with this work:

1. For which applications, if any, is there an advantage in using dedicated, industry-grade IMUs over smartphones for the collection of acceleration data?
2. Which combination of sensor and calculation method yields which assessments and how consistent are they?
3. How many test rides are required for a reliable assessment per combination of sensor and method?

The results of this work can be used to different ends. Civil engineers are able to select suited methods for bicycle infrastructure assessment. Bicycle routing providers can use the results to enhance routing preferences for different user groups and bicycle categories. Researchers could select the most promising approach as basis for their future research. Furthermore, they can prototype methods using the provided data set. And last, the described evaluation methodology can be used to evaluate whether newly developed systems outperform existing ones.

REFERENCES

[1] F. Ayachi, J. Dorey and C. Guastavino, "Identifying factors of bicycle comfort: An online survey with enthusiast cyclists," *Applied Ergonomics,* vol. 46, 2014.

[2] H. Rik de Groot, Ed., Design manual for bicycle traffic, Ede: Crow, 2012.

[3] B. W. Landis, V. R. Vattikuti and M. Brannick, "Real-Time Human Perceptions: Toward a Bicycle Level of Service," *Transportation Research Record,* vol. 1578, pp. 119-126, 1997.

[4] C. Hoelzel, F. Höchtl and V. Senner, "Cycling comfort on different road surfaces," *Procedia Engineering,* vol. 34, pp. 479-484, 2012.

[5] A. Gadsby and K. Watkins, "Instrumented bikes and their use in studies on transportation behaviour, safety, and maintenance," *Transport Reviews,* vol. 40, no. 6, pp. 774-795, 2020.

[6] M. Bíl, R. Andrášik and J. Kubeček, "How comfortable are your cycling tracks? A new method for objective bicycle vibration measurement," *Transportation Research Part C: Emerging Technologies,* vol. 56, pp. 415-425, 2015.

[7] S. Litzenberger, T. Christensen, O. Hofstaetter and A. Sabo, "Prediction of Road Surface Quality during Cycling Using Smartphone Accelerometer Data," *Proceedings,* vol. 2, 2018.

[8] S. Kranzinger and S. Leitinger, "Eine Bestimmung der Oberflächenqualität von Fahrradinfrastruktur durch Smartphone-Beschleunigungsdaten mithilfe des k-means++-Algorithmus," *AGIT – Journal für Angewandte Geoinformatik,* pp. 104-116, 2021.

[9] K. Zang, J. Shen, H. Huang, M. Wan and J. Shi, "Assessing and Mapping of Road Surface Roughness based on GPS and Accelerometer Sensors on Bicycle-Mounted Smartphones," *Sensors,* vol. 18, 2018.

[10] J. Y. M. Nuñez, D. R. Bisconsini and A. N. Rodrigues da Silva, "Combining environmental quality assessment of bicycle infrastructures with vertical acceleration measurements," *Transportation Research Part A: Policy and Practice,* vol. 137, pp. 447-458, 2020.

[11] J. Gao, A. Sha, Y. Huang, L. Hu, Z. Tong and W. Jiang, "Evaluating the cycling comfort on urban roads based on cyclists' perception of vibration," *Journal of Cleaner Production,* vol. 192, pp. 531-541, 2018.

[12] M. W. Sayers and S. M. Karamihas, The Little Book of Profiling, Ann Arbor: University of Michigan, 1998.

[13] J. Blair and M. G. Lacy, "Statistics of ordinal variation," *Sociological Methods & Research,* vol. 28, no. 3, pp. 251-280, 2000.

[14] G. W. Corder, Nonparametric Statistics, Hoboken, New Jersey: Wiley, 2014.

Visual attention and riding behaviour of e-scooter and cyclist users in shared paths – system development and in field experiment

G. Pappalardo*, S. Cafiso*, J Wachnicka†, O. Giudice#, R. Leotta#, S. Battiato#

*Department of Civil Engineering and Architecture
University of Catania
Via S. Sofia, 64, 95131 Catania
email: giuseppina.pappalardo1@unict.it
dcafiso@unict.it

#Department of Mathematics and Computer Science
University of Catania
Via S. Sofia, 64, 95131, Catania
email: giudice@dmi.unict.it
roberto.leotta@ictlab.srl
battiato@dmi.unict.it

† Department of Highway and Transportation Engineering
Politechnika Gdańska
Gabriela Narutowicza 11/12, 80-229 Gdańsk, Poland
email: joanna.wachnicka@pg.edu.pl

Keywords: micro mobility, rider monitoring, Data acquisition, analysis & technology, sensors

1 INTRODUCTION

Micro-mobility in its different forms (walking, bike, e-scooter) is the sustainable and healthy but also the most vulnerable mode of transport in urban mobility. Therefore, safety of vulnerable road users is still a challenge. E-scooter is a new mode of micromobility which is showing high increase in the number of users and crashes. Although the lack of extended studies, the Italian "national Report on sharing mobility, 2022" [1], shows an increase of +250% in the travelled distance between 2020 and 2021 (41,2 Mkm in 2021) with 634 accidents against the 201 incidents recorded in the bike-sharing system. Today, the e-scooter micro-mobility shows the highest accident rate of 2.07 accident/100.000 km (0,74 for bike sharing system). E-scooters are in a relative unique position where they are small enough to negotiate pedestrian traffic, yet fast enough to travel on roadways [2]. This enables an e-scooter operator to change when and where he rides, e.g., from traveling on a sidewalk to riding in a clear traffic lane to avoid a group of pedestrians standing at an intersection. Such changes may catch nearby motorists off-guard, thereby increasing the risk of a collision with the e-scooter.

2 METHODOLOGY

Compared to the other mode of transport that are moving to always higher levels of automation, the micro-mobility vehicles (e.g. bicycle, e-scooters) suffer of a "digital divide" in terms of availability of technologies and sensors on board, often limited only to the smartphone capabilities (i.e. low frequency GPS, camera, accelerometers). That limits the opportunities for high dimension and quality data collection and analysis [3]. In such framework, an experimental test was carried out to collect data from different users with an instrumented e-scooter equipped with a multi sensor data acquisition system to define visual attention and rider behavior.

2.1 Acquisition system

A hardware architecture and processing system have been developed which acts as a data logger for different types of sensors. The system is modular and allows to acquire and synchronize high-frequency data from:

A. Sensors of physical data related to driving dynamics: a GNSS/INS solution that integrates a multiband RTK/GNSS receiver coupled with 6-axis inertial sensor to improve the accuracy of position also during GNSS interruptions and the frequency acquisition up to 20 Hz.

B. Sensors related to driver behavior and workload (eye tracker, EEG, HR): 3 wearable devices: 1) an earphone which, by means of a biometric sensor, allows continuous measurement of heart rate, oxygen saturation and blood pressure; 2) a headset that allows to measure the electrical activity of the brain in the EEG power spectra (Alpha waves, Beta waves); 3) an eye tracker consisting of glasses with an integrated video camera.

C. Cameras related to the Field of View: Two cameras can acquire high resolution videos at a frequency of 30 fps and 180° field of view (fov) which are synchronized with the other sensors.

2.2 Description of the experiment

The presented experiment test makes use of GNSS/INS system (A) to track at high resolution and precision the e-scooter and bicycle path. We apply a visual analytics-based method to inspect e-scooter' and cyclists' gaze behavior as well as video recordings and accelerometer data. This method using multi-modal data allows us to explore patterns and extract common eye movement strategies. Multiple eye tracking experiments exist that analyze cyclists' behavior [4-7], while more emerging is the topic related to e-scooter behavior [8]. In contrast to existing works, we are presenting a visual analytics-based approach to identify patterns in the field of view of cyclist by fusion of eye movement and video data in the context of riding speed and trajectory. The video stream together with the gaze estimation allow to develop a pipeline capable of extracting the semantic components of the scene and therefore obtaining a corresponding sequence of the fixated components over time (Figure 1). This sequence of object fixations is then correlated with other data on a time basis to extract patterns of riders' behaviors.

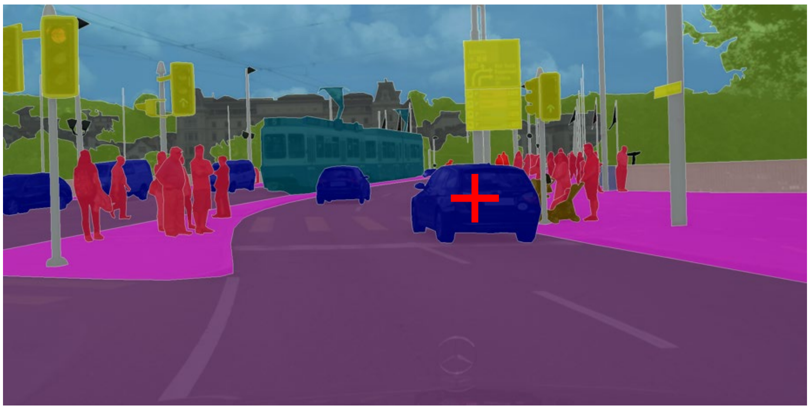


Figure 1 – Example of object segmentation from rider's perspective. The red cross shows the estimation of the rider's gaze. The stabilized gaze on time can be associated with the corresponding object (car in this case)

To investigate riders' behavior, we conducted an experiment, in which a panel of participants had to follow a predefined track—exclusive or shared with cyclist and pedestrians in an urban area in Poland. Testers were not informed about the purpose of the research but only about the working principles of the instrument and the route to ride on.

After the performance, they completed a survey about the experience. They have been asked to provide information regarding their perception of path quality, the perceived visual information, by which elements their attention has been captured, which type of facilities they have perceived as more difficult to ride, and other personal information- e.g. regarding their cycling habits.

Proportion of fixations and fixation time are assumed as a proxy of visual workload. Thus, the relative frequency of fixation has been used to rank those elements that draw cyclist attention. In addition, the combination of multiple data sources, provides high precision and frequency GNSS information related to location, and continuous tracking of speed and heading.

3 RESULT AND DISCUSSION

The system has been evaluated and tested to ensure the accuracy and reliability of the collected data. We collected eye movement and trajectory data as well as a video recording to enable a holistic analysis of riders' behavior during an encounter with a pedestrian or another road user. When investigating eye movement data in real-world traffic situations, we had to define a high number of Areas of Interests (AOIs). Therefore, we use the fov in front of the vehicle as reference image for mapping eye movement data onto AOIs. The visual analysis showed that the explorative analysis with multiple data streams leads to an efficient overview of the collected data.

With the collected data, we want to answer multiple questions:

• Which objects as well as obstacles are focused on most and how distracting are advertisements in rider's fov of the road environment? • What common gaze sequences do riders perform? • What factors affect riding behavior and how rider adjust speed and trajectory to increase comfort and safety on shared-with pedestrian-cycling paths?

4 CONCLUSION

E-scooter riders are vulnerable road users and their safety is a serious issue to be addressed and the study of eye movements, correlated to kinematic parameters, can be a tool to understand visual behavior and to investigate which strategies are adopted by micromobility users. As a result, the proposed system allows safety researchers to select among a wide range of measures to analyze the behavior, workload and comfort of the riders in different road and traffic contexts.

REFERENCES

[1] Ciuffini, M., Asperti, S., Gentili, V., Orsini, R., Refrigeri, L., 6°Rapporto nazionale sulla sharing mobility, https://osservatoriosharingmobility.it/wp-content/uploads/2022/10/6-Rapporto-Nazionale-sharing-mobility.pdf (Accessed on April 15, 2023)

[2] Todd, J., Krauss, D., Zimmermann, J., Dunning, A., Behavior of Electric Scooter Operators in Naturalistic Environments, *WCX SAE World Congress Experience*, April 2019

[3] Kapousizis, G., Ulak, M.B., Geurs, K., Havinga, P.J., A review of state-of-the-art bicycle technologies affecting cycling safety: Level of smartness and technology readiness. *Transport Reviews* (2022), pp.1–23.

[4] Mantuano, A., Bernardi, S., Rupi, F., Cyclist gaze behavior in urban space: An eye-tracking experiment on the bicycle network of Bologna. *Case Studies on Transport Policy* 5, 2 (2016), 408–416.

[5] Schmidt, S., von Stülpnagel, R., Risk Perception and Gaze Behavior during Urban Cycling–A Field Study. In Eye Tracking for Spatial Research, *Proceedings of the 3rd International Workshop. ETH* Zurich, 34–39, 2018.

[6] Chaloupka, C., Risser, R., Füssl, E., Evaluation of technologies that help to identify hazards for cyclists in cities. In: Krsti´c-Furundˇzi´c, A., Djuki´c, A. (Eds.), *Handbook of Research on Urban-Rural Synergy Development Through Housing, Landscape, and Tourism*. IGI Global, Hershey, Pennsylvania, United States, pp. 155–171, 2020. https://doi. org/10.4018/978-1-5225-9932-6.ch008.

[7] Kiefer, P., Giannopoulos, I., Raubal, M., Duchowski, A., Eye tracking for spatial research: cognition, computation, challenges. *Spatial Cogn. Comput.* 17 (1–2), 1–19, 2017.

[8] Pashkevich, A., Burghardt, T. E., Puławska-Obiedowska, S., Sucha, M., Visual attention and speeds of pedestrians, cyclists, and electric scooter riders when using shared road – a field eye tracker experiment. *Case Studies on Transport Policy* 10 (2022) 549–558

Road safety of delivery riders on pedelecs in the Netherlands – An online survey

C. Mons[*,1], **A. Stelling-Kończak**[*,2], **K.G. Kamphuis**[*,3]

*SWOV Institute for Road Safety Research
Henri Faasdreef 312, 2492 JP The Hague, The Netherlands
email: [*,1]celina.mons@swov.nl, [*,2]agnieszka.stelling@swov.nl, [*,3]kas.kamphuis@swov.nl

Keywords: cycling safety, delivery riders, pedelecs, electric bicycles.

1 INTRODUCTION

As in many other countries [1], the number of food and grocery delivery services in the Netherlands has increased rapidly since the COVID-19 pandemic. In 2019, an estimated 20,000 delivery riders on (electric) bicycles and mopeds a day were on the Dutch roads. By the end of 2021 this number had increased to 50,000 [2]. According to Dutch surveys, most food and grocery delivery riders use pedelecs (pedal assisted bicycles) [3, 4], which compared to conventional bicycles make it possible to reach higher speeds with the same physical effort. Also, pedelec riders are vulnerable in traffic since they are not protected by the vehicle. Combined with job-related risk-factors, like time pressure, which has been linked to more aggressive [5] and risky [6] riding behavior, there are growing concerns for road safety. While there have been studies into the road safety of delivery riders, those studies often focus on motorcycle riders and/or are performed in countries with infrastructures that vastly differ from the Dutch infrastructure [6]. The current study aims to gain insight into how riding behavior might differ between delivery riders on pedelecs and non-delivery pedelec riders, and to what extent job-related factors influence the risk of crashes for delivery riders on pedelecs.

2 METHOD

2.1 Online survey

An online survey was conducted among delivery riders on pedelecs and non-delivery pedelec riders in the Netherlands. Respondents were recruited through SWOV's newsletter, advertisements on social media and flyers, which provided the link to the questionnaire. The questionnaire contained questions about demographics, time spent riding a pedelec, helmet use, feelings of time pressure and fatigue, mobile phone use, broken pedelec parts, crash involvement and fines for traffic violations. The 'Cycling Behavior Questionnaire' (CBQ) was used to assess cycling behaviors related to cycling errors, traffic violation and 'positive' behaviors [7, 8]. The questionnaire differed slightly per group in order fit the characteristics of each group. For example, delivery riders were specifically questioned about their behavior while working as a delivery rider, while non-delivery pedelec riders were asked more broadly about their behavior while riding a pedelec.

2.2 Respondents

The questionnaire was completed by 118 delivery riders and 35 non-delivery pedelec riders. The groups were similar in terms of age but not gender. For the delivery riders the age ranged from 16 to 41 years (M = 21.8; SD = 5.6). For non-delivery riders the age ranged from 16 to 45 years (M = 21.4; SD = 5.2). Most delivery riders were male (78.0% male, 18.6% female and 3.4% identified as a different gender). Among non-delivery riders the proportion of males and females was the same (both 48.6%); 2.9% identified as a different gender.

3 PRELIMINARY RESULTS

Preliminary analyses show that delivery riders spend on average more time in traffic than non-delivery pedelec riders. Delivery riders tend to be in traffic in the afternoon and evening, while non-delivery pedelec riders are mainly in traffic during rush hours. Furthermore, delivery riders seem to display more 'positive' riding behaviors than non-delivery pedelec riders. The vast majority of delivery riders was found to wear helmets, while most of non-delivery pedelec riders tend to not wear helmets. When it comes to crash involvements, delivery riders reported more crashes than non-delivery pedelec riders. In further analysis, the groups will be compared on other variables. Additionally it will be investigated which variables are related to crash involvement. The analysis is currently being finalized. Final results will be presented at the conference.

4 IMPLICATIONS

The results of this study can provide insights into possible job-related road safety risk factors for delivery riders and might provide a starting point for policy recommendations to increase the road safety of delivery riders.

REFERENCES

[1] O. Oviedo-Trespalacios, E. Rubie and N. Haworth. "Risky business: Comparing the riding behaviours of food delivery and private bicycle riders." *Accident Analysis & Prevention* 177 (2022), 106820.

[2] C. van Soelen and T. Beijer. "Kopzorgen over groeiend aantal bezorgers: 'We krijgen klachten over verkeersveiligheid'." *RTL Nieuws.* 30 Nov. 2021. Web. 18 Apr. 2023.

[3] M. De Vries. *Jongeren als flitsbezorger, Rapportage onderzoek.* Utrecht: TeamAlert, 2021.

[4] M. De Vries. *Kwantitatieve toetsing maaltijdbezorgers.* Utrecht: TeamAlert, 2021.

[5] H. Dong, S. Zhong, S. Xu, J. Tian and Z. Feng. "The relationships between traffic enforcement, personal norms and aggressive driving behaviors among normal e-bike riders and food delivery e-bike riders." *Transport Policy* 114 (2021), pp. 138-146.

[6] Y. Zheng, Y. Ma, L. Guo, J. Cheng and Y. Zhang. "Crash involvement and risky riding behaviors among delivery riders in China: The role of working conditions." *Transportation Research Record* 2673 (2019), pp. 1011-1022.

[7] A. McKinlay, G. Mitchell, and C. Bertenshaw. "DINED (Delivery-related INjuries in the Emergency Department) part 1: A scoping review of risk factors and injuries affecting food delivery riders." *Emergency Medicine Australasia* 34 (2022), pp. 150-156.

[8] S.A. Useche, L. Montoro, J.M. Tomas and B. Cendales. "Validation of the cycling behavior questionnaire: A tool for measuring cyclists' road behaviors." *Transportation Research Part F: Psychology and Behaviour* 58 (2018), pp. 1021-1030.

[9] S.A. Useche, P. Philippot, T. Ampe, J. Llamazares and B. de Geus. "'Pédaler en toute sécurité': The Cycling Behavior Questionnaire (CBQ) in Belgium – A validation study." *Transportation Research Part F: Psychology and Behaviour* 80 (2021), pp. 260-274.

ReCyCLIST
– a new powerful tool to register and locate bicycle and e-scooter accidents

T. Bjørnskau*, K. Karlsen*, R. Ingebrigtsen*, I. Hesjevoll*, K.V. Weyde*
O. Mjåland#

*Institute of Transport Economics (TØI)
Gaustadalléen 21, N-0873, Oslo, Norway
email: tbj@toi.no

#Hospital of Southern Norway (SSHF)
Eegsveien 100, N-4625, Kristiansand, Norway
email: odd.mjaland@gmail.com

Keywords: bicycle, e-scooter, accidents, injuries, accident location, accident prevention, map, street view.

1 INTRODUCTION

Underreporting of bicycle accidents in the official statistics is a well-known problem [1, 2]. Most bicycle and e-scooter accidents are single accidents, and usually not registered by the police and hence not included in the official statistics. According to data from Oslo Emergency Ward the number of cyclists injured in road traffic accidents is twenty times higher than what is revealed in the official road accident statistics, and e-scooter accidents are even less reported [2, 3].

The problem of underreporting of bicycle accidents is probably increasing due to the successful promotion of active transport and restrictions of car use in the cities, resulting in less crashes with motor vehicles, but possibly more single accidents. One consequence is that the risk factors influencing most bicycle accidents (single accidents) are neglected, i.e., issues related to infrastructure and maintenance. The risk factors being addressed are typically concerned with the risk of being hit by motor vehicles, even if the risk is dramatically reduced. The recent increase of e-scooters, and e-scooter single accidents in our cities, adds importantly to this picture, underlying the need to change both the focus and the data basis for safety efforts for these vulnerable road users in our cities.

Given the vast underreporting of bicycle and e-scooter accidents, it follows that the locations of these accidents are also largely unknown. Hence, we do not know if there are accident black spots, and if so, where they are located. Accordingly, vital information to implement effective countermeasures is lacking.

2 RECYCLIST – A NEW POWERFUL TOOL

The project ReCyCLIST (Recording Cyclist Crashes and Long-term Injury Consequences by new Smart Tools) was launched in 2021 and has developed a new digital accident registration tool that is currently being used in several counties in Norway [4]. Accidents with bicycles, e-scooters and other micro mobility devices are registered at hospitals and emergency wards. The registrations are predominantly carried out by the patients themselves. When coming to the hospital / emergency ward they are informed about the project and asked to register their accident with their mobile phone by scanning a QR-code found on posters and leaflets on the premises. Health personnel can also assist in the registration on their mobile phone or by use of a project iPad.

The QR code gives access to a digital questionnaire with questions about the vehicle, the accident type, and different characteristics of the accident. A new and powerful feature is the possibility to locate the accident site through Google maps and street view.

Registrations started in Agder county in the south of Norway on the 1st of June 2022, and registrations will continue (at least) throughout September 2023. Nearly 300 accidents were registered during the first six months. Officially, ca. 15 bicycle accidents are normally registered in Agder county during this period. Thus, the new tool captures twenty times as many accidents as the official numbers.

2.1 General results

A total of 346 accidents with bicycles, e-scooters and other micro mobility vehicles were registered in Agder county in the period from 1st of June 2022 to 30th of April 2023. Single accidents constitute the majority (81 %) followed by collisions (11 %) and falls due to near misses (8 %). 31 accidents were caused by playing/tricking and omitted from analysis. Thus, there are 315 accidents with bicycles, e-scooter and other micro mobility devices that are the basis for our analyses.

Ordinary bicycles are most often used (48 %), followed by e-bikes (24 %), e-scooters (15 %) and other small vehicles. All age groups are represented, with peaks among children and teenagers (0-12 and 13-17) and adults and elderly (45-65+). Overall, men are victim in 60 % of accidents, and they dominate among ordinary bicycle accidents. However, women have more e-scooter accidents than men, and there are no gender differences for e-bike accidents. There is a clear association between age groups and vehicle types; the middle-aged and elderly have accidents on e-bikes and ordinary bicycles, whereas the young have accidents on e-scooters in addition to ordinary bicycles, cf. figure 1.

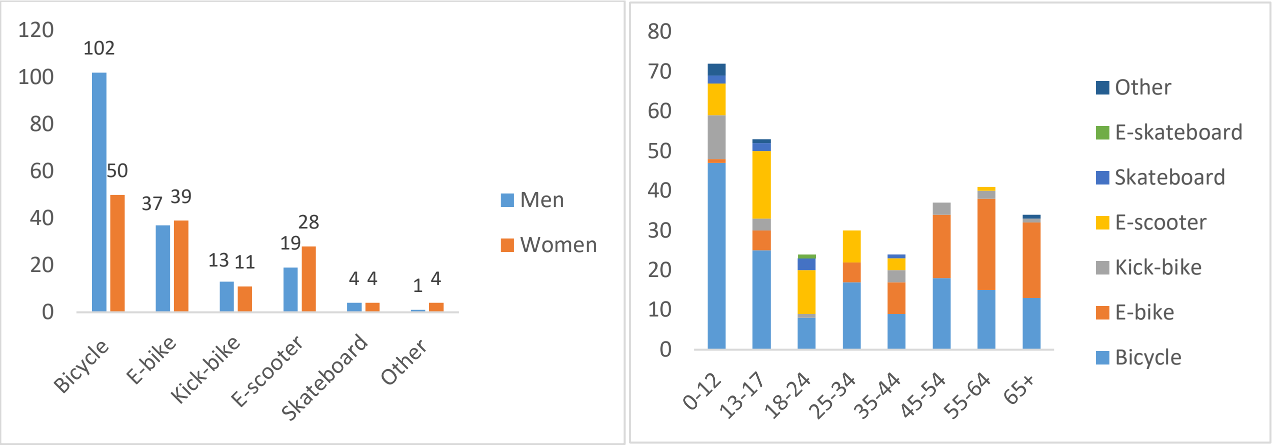


Figure 1: Accidents distributed by vehicle type and gender (left) and vehicle type and age groups (right). Actual numbers, N=315.

2.2 Accident mechanisms

Accident victims were asked several questions about their accident such as surface and infrastructure conditions, e.g., whether they hit potholes, kerbs, stones, or other items, whether there were bike-technical issues leading to the accident etc. We have grouped the answers into three main categories: a) Infrastructure, b) technical issues and c) “own” failure. The last category contains issues like distraction, speed, risky behaviour, drinking and riding etc.

According to the accident victims, one third of the accidents were due to conditions in the infrastructure; seven per cent due to technical failures, 40 per cent were caused by loss of balance, and 19 per because of collisions or falls due to near misses. The accident mechanisms seem to be evenly distributed over age groups, vehicle types and gender. However, e-scooters have more accidents related to the infrastructure than other vehicles and the “young adults” (35-44 years) report more alcohol-related accidents than other age groups. On average 10 % of both men and women say they were influenced by alcohol or drugs. In the age group 35-44 years, 24 % report to be influenced when the accident happened.

2.3 Injuries and consequences

The accident victims were also asked to consent to clinical follow-ups, i.e., to provide information about the injury, the medical follow-up and the course of rehabilitation. 60 % consented. Follow-up results are summarized after three, nine and 12 months. After three months, 9 % of victims still had considerable complaints, i.e., the inability to manage regular activities of daily life without great problems or disabling pain. If the injured cyclist were admitted as a trauma patient, the chance of having ”considerable complaints” at three months was 22%. Diagnosis of head-, neck, spine and complex injuries to knee and shoulders dominated the reasons for “considerable complaints” at three months follow up.

2.4 Accident black spots

A significant novelty of the registration tool is the inclusion of map and street-view functions enabling the identification of possible accident black spots. During the first months of registration several black spots were identified in the city of Kristiansand. One example is Bjørndalssletta in Kristiansand, see figure 2.

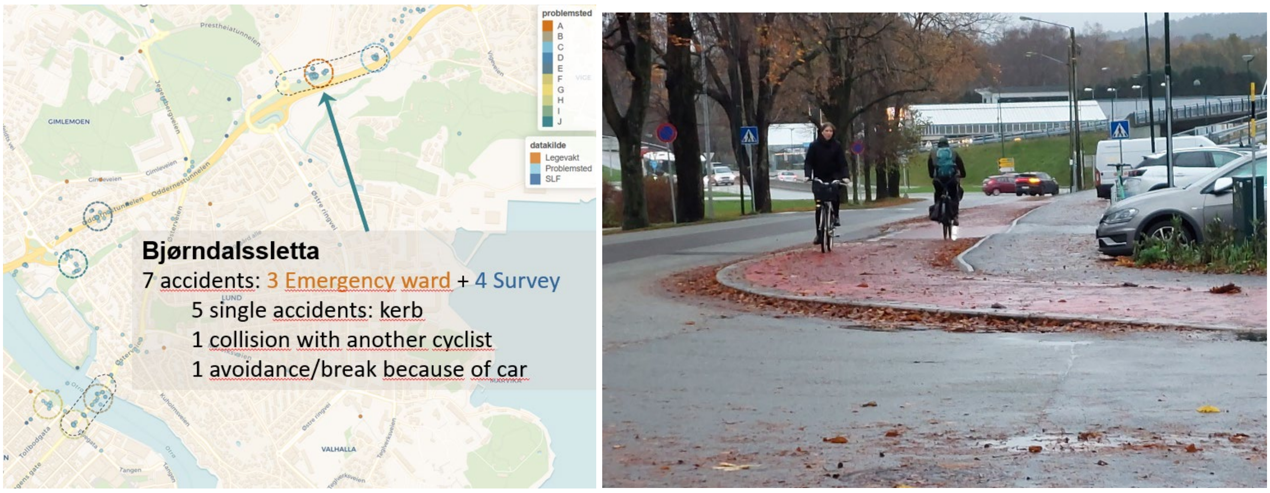


Figure 2: Example of accident black spot in Kristiansand identified by use of Google maps

2.5 Follow-up – countermeasures and evaluations

Based on the registration of accident points, inspections were carried out at the sites to identify accident mechanisms and possible mitigating measures. After the inspections, video analyses were conducted to obtain further information about behaviour and accident mechanisms. Local road authorities will introduce measures that will be evaluated with the help of video surveillance before and after the introduction of counter measures, and if possible, by the development of accident figures at the sites.

REFERENCES

[1] D. Shinar, et al., *Under-reporting bicycle accidents to police in the COST TU1101 international survey: Cross-country comparisons and associated factors.* Accident Analysis & Prevention, 2018. **110**: p. 177-186.

[2] T. Bjørnskau, *Keynote speech II*, International Cycling Safety Conference, Lund, Sweden, 10-12 November 2021.

[3] Norwegian Public Roads Administration, *Injuries on bicycles and e-scooters in Oslo. Results from a registration in 2019/2020.* Norwegian Public Roads Administration, Oslo.

[4] J. Bevan, *Case study: how res-tech can be used to better protect cyclists from injury*. South West Tech Daily 2022; Available from: https://www.swtechdaily.co.uk/article/2022/12/19/case-study-how-res-tech-can-be-used-better-protect-cyclists-injury.

Hitting the Target: What 75% travel means for cyclists

M. Olyslagers*, **S. T. Lucchesi#**

*International Road Assessment Programme
60 Trafalgar Square, London, WC2N 5DS, UK
email: monica.olyslagers@irap.org

#International Road Assessment Programme
60 Trafalgar Square, London, WC2N 5DS, UK
email: shanna.lucchesi@irap.org

Keywords: 75% of travel, safe routes, cyclists routes, star ratings, origin-destination matrix

1 INTRODUCTION

During the United Nations General Assembly of 2018, the UN Member States agreed on 12 Global Road Safety Performance Targets to drive action worldwide to prevent fatalities and severe injuries **Error! Reference source not found.**. Target number 4 establishes that more than 75% of travel on existing roads is on roads that meet technical standards for all road users considering road safety. Since the declaration, two questions have arisen to clarify where countries should direct their investments on existing roads: (i) how to identify if the road meets the technical standards and (i) where 75% of travel is happening.

Different methods can be used to answer question number two. The literature brings examples of road safety audits and inspection procedures for cyclists in the United States [2] and Europe [3]. A globally applicable assessment method is the iRAP Star Ratings. Star Ratings are an objective measure of the likelihood of a road crash occurring and the severity of the outcome in case the crash happens [4]. Scientific road safety evidence guided the development of the method that considers how road attributes influence the most common and severe types of crashes. Therefore, the target of 3 stars or better for cyclists can be used as a metric to analyse and compare safe road standards for cyclists.

On the other hand, five years after the launch of the performance targets, it is still unclear how to establish the 75% of travel parameter. Identifying all the travel happening in a city demands massive data on flows and routes. The grey literature has documented initiatives to identify 75% of vehicle travel maps. As part of the iMOVE projects, telematic data combined with AADT to identify the links with higher Vehicle Kilometers Travelled (VKT) [5]. Alternatively, satellite images have been used to detect vehicle locations and speeds [6]. Nevertheless, these approaches cannot be used for vulnerable road users since their rates make it difficult. The satellite image resolutions and the flying view make it challenging to recognise pedestrians and cyclists in satellite images automatically.

It is worth noting that Target 4 clearly states to consider all road users. However, especially in cities where the modal split is unfavourable to cyclists, calculating the 75% of travel routes considering all trips might bias the investments to continue to be redirected to more prevalent travel modes, like private vehicles. Neglecting the travel demands of other travel modes, like pedestrians and cyclists, can intimidate new users and even deteriorate current travellers' road safety conditions. The lack of safe infrastructure has been documented as a critical barrier for cyclists in studies around the globe [7][8][9][10].

This study aims to identify the 75% of travel routes for cyclists, compare if they differ from the other modes by gender, and determine if cyclists are riding on safe roads. The analyses are built on data collected in the city of São Paulo (RSMP) in Brazil. São Paulo is the second-largest metropolitan region in Latin America, home to 22 million people. The latest origin-destination survey for the Metropolitan region was collected in 2017m and is the primary source of data from this study. The database contains the coordinates of the origin and destination for all the trips, the travel mode and the socioeconomic characteristics of the individuals, to which gender is of particular interest in this analysis.

The cyclists' routes were identified using the OpenRouteService tool [12]on the software QGIS. The Direction service returns the path between two locations based on a selected profile. For this study, it was requested the recommended route (not the faster route) for a regular cyclist (not a mountain bike). The recommended way avoids hills of steep roads.

Route-generated links were ranked by the highest number of passing routes and the links with the 75% of travels per mode were identified and compared with the cyclists' map. The cyclist maps were also compared by gender, highlighting the differences in the origin and destination locations for men and women. Finally, where the star rating results are available for the city of São Paulo, it was checked if the routes meet the target 4 for cyclists.

REFERENCES

[1] UN (2018). Global road safety performance targets. Available at: https://www.who.int/publications/m/item/global-road-safety-performance-targets
[2] Goughnour, E. et al. (2019). Pedestrian and bicyclist road safety audit (RSA) guide and prompt list. Available at: https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa20042.pdf
[3] Makó, E. et al. (2017) Road Safety Audit experiences related to cycling infrastructure. 6th Annual International Cycling Safety Conference
[4] iRAP (2023). iRAP Star Ratings and Investment Plan Manual. Available at: https://irap.org/specifications/
[5] iMOVE (2021). TomTom's 75% of travel mapping: Validation Report. Available at: https://irap.org/75percent/
[6] IRAP and Agilysis (2022) Agilysis' 75% of Travel Mapping: Validation Report. Available at: https://irap.org/75percent/
[7] LEGER, S. J. et al. *"If I had a regular bicycle, I wouldn't be out riding anymore": Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada*. Transportation Research Part A: Policy and Practice, v. 123, p. 240-254, mai. 2019.
[8] YANG, M.; ZACHARIAS, J. *Potential for revival of the bicycle in Beijing.* International Journal of Sustainable Transportation, v. 10, n. 6, p. 517-527, 2 jul. 2016.
[9] FÉLIX, R.; MOURA, F.; CLIFTON, K. J. *Maturing urban cycling: Comparing barriers and motivators to bicycle of cyclists and non-cyclists in Lisbon, Portugal*. Journal of Transport & Health, v. 15, dez. 2019.
[10] ROSSETTI, T. et al. *Modeling safety as a perceptual latent variable to assess cycling infrastructure.* Transportation Research Part A: Policy and Practice, v. 111, p. 252-265, 2018
[11] Metrô SP (2017). OD Pesquisa Origem e Destino 2017. Available at: https://www.metro.sp.gov.br/pesquisa-od/
[12] Openrouteservice (2022). Available at: https://openrouteservice.org

Perception of cyclists while being overtaken by motorized vehicles: A semi-naturalistic field study in urban mixed traffic

F. H. Strelow*, M. Vollrath*

*Department of Traffic and Engineering Psychology
Technische Universität Braunschweig
Gaußstraße 23, 38106 Braunschweig, Germany
email: f.strelow@tu-braunschweig.de,
mark.vollrath@tu-braunschweig.de

Keywords: overtaking distance, drivers' behaviour, cyclist' perception, mental comfort, field study.

1 INTRODUCTION

In mixed traffic, cyclists are particularly vulnerable while sharing the road with motorized vehicles. Overtaking maneuvers by motorized vehicles with insufficient lateral distance can lead to near misses or collisions, causing cyclists to feel unsafe, stressed and uncomfortable. Situations like these can reduce their willingness to use the bicycle as a means of transport [1], [2]. In order to enable safe, comfortable cycling and a high level of cycling participation, it is necessary to consider not only the objective safety conditions but also the subjective perception of safety and well-being of cyclists [3].

Previous studies that addressed subjective perceptions of cyclists during overtaking maneuvers have used different methods such as surveys with videos and photographs [4], [5] or post-ride interviews [6]. First studies investigated subjective perceptions such as the experience of risk or safety during the actual ride (on-ride methods [7]) by having cyclists press corresponding buttons on the handlebar [3], [8], [9].

Despite the importance of understanding cyclists' subjective perceptions during overtaking maneuvers, field studies with a sufficiently large sample of different cyclists have not yet been conducted in Germany. This is especially interesting with regard to the reform of the German road traffic regulations in 2020, according to which motor vehicles have to keep a minimum distance of 1.50 m from cyclists in urban areas (§5 StVo). To date there is a lack of studies in Germany on the extent to which this distance is maintained in urban mixed traffic and how cyclists feel depending on the distance maintained.

The overall aim of the study is to use an on-ride method to conduct a semi-naturalistic field study and investigate to what extent motorized vehicles in urban mixed traffic comply with the legal minimum distance when overtaking cyclists, also depending on the traffic infrastructure, and how cyclists feel depending on overtaking distances. Additionally, the study will examine the impact of other factors on cyclists' perceptions, such as features of the infrastructure, the characteristics of the overtaking motorized vehicle, or attributes of the cyclists themselves.

2 METHOD

2.1 Procedure

The study will be conducted from June to August 2023. Participants (approx. $N = 50$) will ride a bicycle equipped with technical devices along two predefined routes in urban mixed traffic in the city of Brunswick, Germany.

The selected routes mainly include infrastructural sections where cyclists have to share the road with motorized traffic to allow for overtaking maneuvers. These includes cycling on the road (without cycling facilities), on advisory or mandatory cycle lanes or on cycling boulevards. Overall, the selected routes vary in terms of road types, cycling facilities and speed limits.

The participants cycle a total distance of 10.56 km, which is divided into two routes (route A: 4.61 km, route B: 5.95 km). Both routes start and end at the department, allowing for a break in between. Each route takes approximately 20 to 30 minutes to complete. The entire session, including the pre- and post-ride procedure, will take 90 minutes.

In addition to the cycling task, the participants have to complete two other secondary tasks: Within 5.0 seconds after the end of each overtaking maneuver, they have to press a button on the handlebar. Immediately afterwards, they are asked to verbally rate their perceived Mental Comfort [10], [11] on a scale from poor (1 or red) to good (5 or green) as shown in Figure 1. Mental Comfort is a construct that describes a kind of comfort that involves cognitive demands and perceptions such as stress or relaxation. Good Mental Comfort reflects that cyclists feel safe and can cycle stress-free as well as relaxed. In contrast, with poor Mental Comfort, they feel stressed, harassed and unsafe. Overall the rating is made while continuing the cycling task (on-ride) by speaking out loud the corresponding scale value or smiley color. The aim is to encourage participants to assess their experience quickly and intuitively while not distracting them from cycling safely.

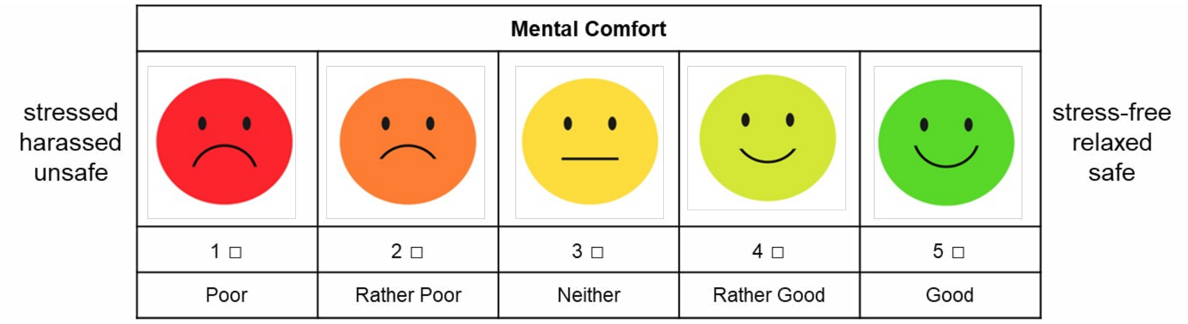


Figure 1: Illustration of the Mental Comfort Scale.

2.2 Material

This study will use a bicycle which is equipped with an OpenBikeSensor (OBS) from the open citizen science project to measure overtaking distances [12]. The OBS consists of a main body attached to the rack connected via a cable to a button and display on the handlebar. The main body contains an ultrasonic sensor that measures the lateral distance to the left and right within 3.00 m, a GPS module to determine the position and an acceleration sensor to measure the cyclists' speed. Overtaking manoeuvres can be confirmed by pressing the button on the handlebar so that they are recorded and marked in the data. A forward-facing video camera is attached to the handlebar to capture the road environment and vehicle type. Additionally, a smartphone for route navigation, a laminated printout of rating scale (Figure 1), and a microphone to record the Mental Comfort rating will also be provided to participants.

After completing cycling, participants fill in questionnaires on socio-demographics, mobility behaviour, and general attitudes towards traffic.

3 RESULTS

In the first step of the analyses, the measured overtaking distances will be analysed with regard to the different infrastructure features in order to assess their influence. The second step focuses on the subjective rating of Mental Comfort and examines to what extent this depends on overtaking distance, but also on infrastructure features. From this, requirements for infrastructure design will be derived in order to promote safe overtaking distances that are also perceived as stress-free and relaxed cycling.

4 CONCLUSION

The purpose of this study is to gather information on the safety of cyclists, both in terms of objective data and their subjective perceptions. Conducting the study in real traffic, using an on-ride method, provides a more realistic insight into the perception of cyclists compared to other methods such as surveys, simulator studies, or post-ride interviews. The findings of this study will improve our understanding of the needs of cyclists, and take a further step forwards creating a safer traffic environment where cyclists feel safe and comfortable.

REFERENCES

[1] Campos Ferreira, M., Dias Costa, P., Abrantes, D., Hora, J., Felício, S., Coimbra, M., & Galvão Dias, T. (2022). Identifying the determinants and understanding their effect on the perception of safety, security, and comfort by pedestrians and cyclists: A systematic review. *Transportation Research Part F: Traffic Psychology and Behaviour*, *91*, 136–163. https://doi.org/10.1016/j.trf.2022.10.004

[2] Sanders, R. L. (2015). Perceived traffic risk for cyclists: The impact of near miss and collision experiences. *Accident Analysis & Prevention*, *75*, 26–34. https://doi.org/10.1016/j.aap.2014.11.004

[3] Beck, B., Perkins, M., Olivier, J., Chong, D., & Johnson, M. (2021). Subjective experiences of bicyclists being passed by motor vehicles: The relationship to motor vehicle passing distance. *Accident Analysis & Prevention*, *155*, 106102. https://doi.org/10.1016/j.aap.2021.106102

[4] Apasnore, P., Ismail, K., & Kassim, A. (2017). Bicycle-vehicle interactions at mid-sections of mixed traffic streets: Examining passing distance and bicycle comfort perception. *Accident Analysis & Prevention*, *106*, 141–148. https://doi.org/10.1016/j.aap.2017.05.003

[5] von Stülpnagel, R., Hologa, R., & Riach, N. (2022). Cars overtaking cyclists on different urban road types – Expectations about passing safety are not aligned with observed passing distances. *Transportation Research Part F: Traffic Psychology and Behaviour*, *89*, 334–346. https://doi.org/10.1016/j.trf.2022.07.005

[6] Llorca, C., Angel-Domenech, A., Agustin-Gomez, F., & Garcia, A. (2017). Motor vehicles overtaking cyclists on two-lane rural roads: Analysis on speed and lateral clearance. *Safety Science*, *92*, 302–310. https://doi.org/10.1016/j.ssci.2015.11.005

[7] Kalra, A., Lim, T., Pearson, L., & Beck, B. (2023). Methods used to capture subjective user experiences in adults while riding bicycles: A scoping review. *Transport Reviews*, *43*(3), 453–477. https://doi.org/10.1080/01441647.2022.2123064

[8] López, G., Pérez-Zuriaga, A. M., Moll, S., & García, A. (2020). Analysis of Overtaking Maneuvers to Cycling Groups on Two-Lane Rural Roads using Objective and Subjective Risk. *Transportation Research Record: Journal of the Transportation Research Board*, *2674*(7), 148–160. https://doi.org/10.1177/0361198120921169

[9] Rasch, A., Moll, S., López, G., García, A., & Dozza, M. (2022). Drivers' and cyclists' safety perceptions in overtaking maneuvers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *84*, 165–176. https://doi.org/10.1016/j.trf.2021.11.014

[10] Berghoefer, F. L., & Vollrath, M. (2022). Cyclists' perception of cycling infrastructure – A Repertory Grid approach. *Transportation Research Part F: Traffic Psychology and Behaviour*, *87*, 249–263. https://doi.org/10.1016/j.trf.2022.04.012

[11] Berghoefer, F. L., & Vollrath, M. (submitted). Prefer what you like? Evaluation and preference of cycling infrastructures in a bicycle simulator. *Journal of Safety Research*.

[12] OpenBikeSensor e.V. (2023). *OpenBikeSensor*. OpenBikeSensor - Passing distance measurement for cyclists - Open Innovation, Open Source, Open Data, Open Science. https://openbikesensor.org/

How is cycling safety affected by micro-level built environment variables? A case study using a deep learning approach

Lurong Xu[*], **Shuli Luo**[#], **Steve O' Hern**[†], **Alexa Delbosc**[‡]

[*]Department of Civil Engineering
Monash University
Clayton VIC 3800 Australia
email: Lurong.Xu@Monash.edu

[#]Department of Civil Engineering
Monash University
Clayton VIC 3800 Australia
email: Shuli.Luo@Monash.edu

[†]Transport Research Centre Verne
Tampere University
FI-33014 Tampere, Finland
email: steve.ohern@tuni.fi

[‡]Monash Institute of Transport Studies
Monash University
Clayton VIC 3800 Australia
email: Alexa.Delbosc@monash.edu

Keywords: street view images, deep learning, cycling safety, built environment.

1 INTRODUCTION

In the field of urban transportation, “bikeability” has become an increasingly important concept as cities throughout the world attempt to promote cycling as a sustainable mode of transportation. Safety is a significant factor in the calculation of bikeability, as safety is essential for encouraging people to cycle [1]. A high level of safety can increase cycling participation and lead to a more bike-friendly environment. Built environment (BE) variables have been found to have a high correlation with cycling safety, and previous research has extensively studied the relationship between these two factors [2, 3]. However, there remain several gaps in the research that require further attention.

One significant issue is the technical limitations that have historically made it challenging to obtain micro-level built environmental variables for large geographic areas [4]. Traditional questionnaires and geographic surveys are time-consuming and require considerable human resources. Another problem arises from limitations in the completeness and openness of cycling infrastructure for large-scale areas, particularly in countries where data acquisition is restricted. Therefore, relevant research can be challenging to conduct.

Furthermore, studies have identified that cycling safety and environmental variables have spatial heterogeneity in regional distribution [5]. Spatial heterogeneity can affect the generalizability of the results of previous studies, and further research is needed to investigate this issue. Additional matters, encompassing the impact of physical disorder defined as the disruption of both residents' lives and public spaces that arises from observable or perceptible visual indications [6], are yet to be examined. Among these concerns are road damage, construction fences' occupancy, littering, and other factors that could potentially compromise cyclists' safety. It is crucial to investigate these phenomena further to gain a better understanding of their implications for cycling safety.

To address the aforementioned limitations and investigate the relationship between BE variables and cycling safety during the evaluation of bikeability, this study proposes a novel framework that utilizes a deep learning approach to extract BE variables for a large geographical area. The findings offer a new approach to explore critical factors that influence cycling safety, which may ultimately promote cycling as a safe and sustainable mode of transportation in urban settings.

2 METHOD

The research area selected for this study is Gusu District, an administrative region of Suzhou City, China. In order to extract micro-level BE variables, street view images were obtained from Baidu map at 100m intervals along the road network. Deep learning models were employed for the extraction process, with an image classification model (Swin Transformer) (https://github.com/microsoft/Swin-Transformer) utilized to extract configurations of cycle lanes and identification of physical disorder. The remaining micro-level BE variables were extracted using a Semantic Segmentation model developed by CSAILVision (https://github.com/CSAILVision/semantic-segmentation-pytorch). At last, there are 8 kinds of micro-level BE variables are extracted, including cycle lanes category, physical disorder degree, relative road width, sky ratio, enclosure, green ratio, presence of waterfront and street lamp, respectively. Factor analysis was then employed to elucidate the associations among different factors. The resulting weighted values were used to generate an objective safety index for all road links in the study area.

3 RESULT & CONCLUSION

The study findings presented herein demonstrate the viability and effectiveness of a novel framework for evaluating cycling safety that utilizes deep learning methods. The model's high level of accuracy performance in both semantic segmentation and image classification tasks to extract BE variables confirms its potential as a valuable tool for assessing the safety of cycling environments. Moreover, the analysis supports prior research indicating a significant correlation between the presence of cycle lanes and cycling safety, which is further confirmed through the use of factor analysis and visualization techniques (see Figure 1). However, the study also reveals that cycling safety is influenced not only by the presence of cycle infrastructures but also by other factors such as physical disorder, enclosure, and road to building ratio, which contribute to spatial heterogeneity.

The study's findings highlight negative associations between cycling safety, physical disorder degree and enclosure extent, indicating that cycling safety is negatively impacted by the presence of physical obstacles and a lack of street visual clearance. Conversely, the study indicates a positive correlation between safety and road to building ratio (relative road width), suggesting that wider roads and more open spaces can improve cycling safety. Based on these results, the study proposes that implementing protected cycle lanes in environments with wider road width, higher street visual clearance, and low enclosure extent is likely to enhance cycling safety.

In conclusion, this novel framework emphasizes its capability to evaluate unsafe locations across an entire city, covering a large geographical area. Moreover, it can provide specific suggestions to promote cycling safety for different cycle lanes with varying built environments. By offering new insights into the relationship between built environment and cycling safety, this study stands out for its unique perspective on identifying the factors contributing to spatial heterogeneity through the application of deep learning. The findings of this study have significant implications for the design of safer cycling infrastructure and urban planning policies, which can help create safer cycling environments in specific cycle lanes.

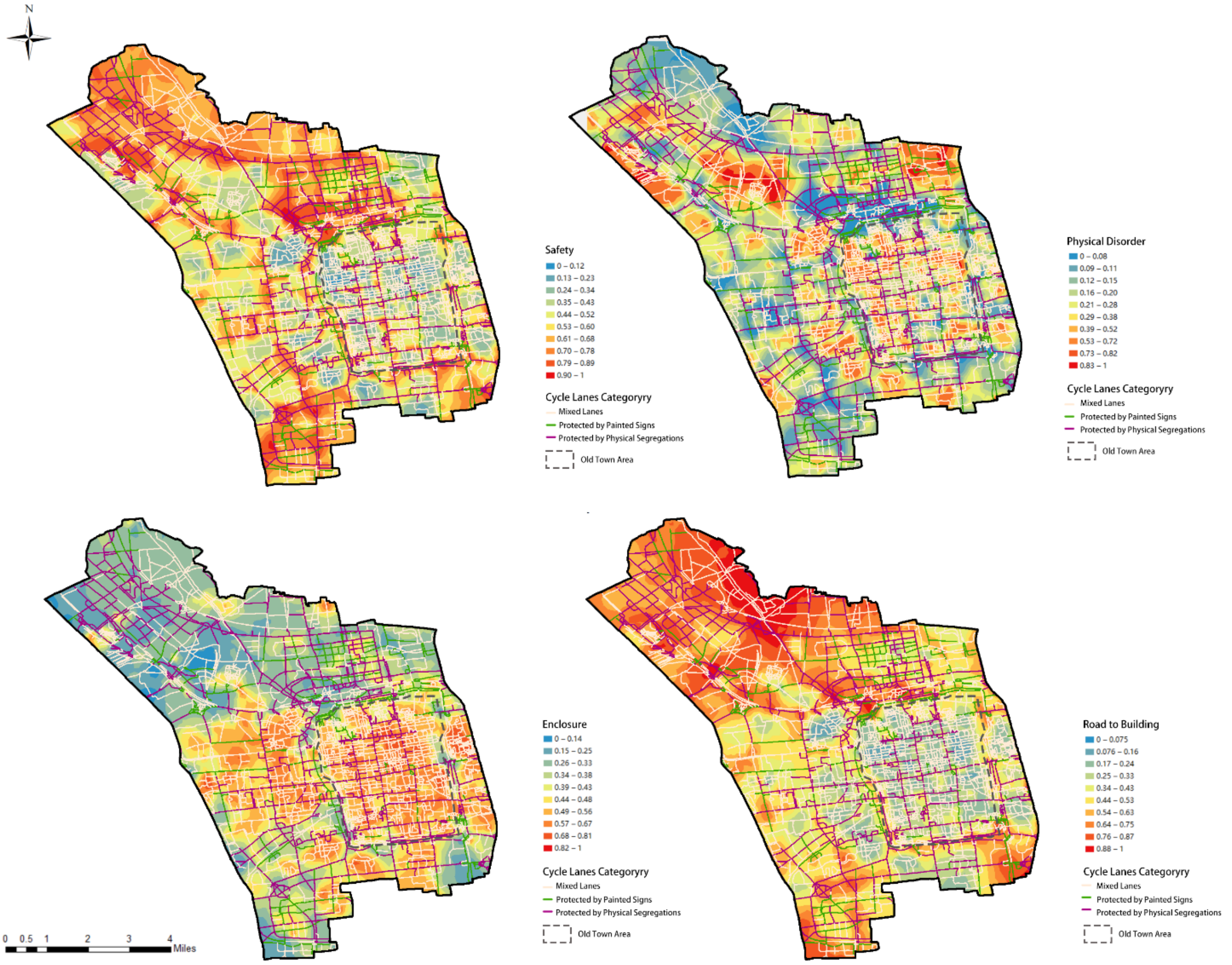


Figure 1: Visualization of Safety and Related BE Variables

REFERENCES

[1] Gu, P., et al., *Using open source data to measure street walkability and bikeability in China: A case of four cities.* Transportation research record, 2018. **2672**(31): p. 63-75.

[2] Osama, A., et al., *Determining if walkability and bikeability indices reflect pedestrian and cyclist safety.* Transportation research record, 2020. **2674**(9): p. 767-775.

[3] Habib, K.N., et al., *Synopsis of bicycle demand in the City of Toronto: Investigating the effects of perception, consciousness and comfortability on the purpose of biking and bike ownership.* Transportation research part A: policy and practice, 2014. **70**: p. 67-80.

[4] Koo, B.W., S. Guhathakurta, and N. Botchwey, *How are neighborhood and street-level walkability factors associated with walking behaviors? a big data approach using street view images.* Environment and Behavior, 2022. **54**(1): p. 211-241.

[5] Pan, Y., et al., *Investigating the impacts of built environment on traffic states incorporating spatial heterogeneity.* Journal of Transport Geography, 2020. **83**: p. 102663.

[6] Chen, J., et al., *Measuring Physical Disorder in Urban Street Spaces: A Large-Scale Analysis Using Street View Images and Deep Learning.* Annals of the American Association of Geographers, 2023. **113**(2): p. 469-487.

Comparison of driving characteristics between e-scooters and e-bikes

Mio Suzuki* **and Katsuhiro Endo**

*Department of Civil Engineering
Tokai University
4-1-1, Kita-kaname, Hiratsuka, Japan
email: mio.suzuki@tsc.u-tokai.ac.jp

Keywords: e-bikes, e-scooters, vibration characteristics, subjective evaluation

1 INTRODUCTION AND OBJECTIVES

E-scooters are treated as motorized bicycles if they have an output of 0.60 kWh or less now. From July 1, 2023, those 16 years and older will be able to ride them without a driver's license or helmet. Currently, social experiments for deregulation of e-scooters are being conducted mainly in Tokyo, and there are several businesses that offer paid rentals. Although efforts are underway to popularize e-scooters in this way, ensuring their safety and creating a comfortable environment for their use are still insufficient. The high number of traffic accidents involving bicycles is a particular problem in Japan. However, the current regulations on e-scooters, other than the speed limit, are not sufficient.

A literature review conducted on the safety of electric kickboards revealed a survey on the intention to use electric kickboards, a study on the road structure based on electric kickboard riding, and a study on riding points related to riding comfort, but no studies were found that mentioned differences among vehicle types. However, there were no studies that mentioned the differences between different types of vehicles. Therefore, this study was conducted with the belief that clarifying the differences in performance and characteristics due to these differences in specifications would be very important basic data for establishing the safety of electric kickboards, which come in a wide variety of models.

Therefore, the purpose of this study is to compare the operability and riding comfort of e-scooters and e-bikes, which are becoming popular under various specifications, and to gain insight into their safety and comfort.

2 METHODOLOGIES

The purpose of this study was to clarify the differences in riding comfort and driving performance between different types of electric kickboards and their use. Eight subjects (7 males and 1 female) were asked to ride along the same route to collect data. The experimental route was set near Takanawa, Minato-ku, Tokyo, because of the large number of vehicles available for rent, and was approximately 2,400 m around the route, which was completed only by turning left, for safety reasons. Data was collected using a triaxial acceleration sensor (using a smartphone) to record vibrations, or by having eight test subjects ride along a predetermined route, and having them rate the ride comfort, operability, and whether they felt scared while riding in a 5-point scale for downhill, flat, and uphill conditions, and to freely describe any points they noticed. The data was collected in two ways. The data collected by these methods were compared by averaging the data from the tri-axial acceleration sensor vibration survey by car model to obtain the variance of each data, and the results of the questionnaire survey were compared by focusing on the 5- point evaluation of the downhill portion, where differences by car model are likely to occur, and averaging this evaluation for each car model.

In this study, three types of e-scooters and one type of e-bike were prepared.

1) Loop: Maximum speed is 15 km/h, but there is no limiter, so the rider can accelerate downhill.

2) Swing: Maximum speed is 15 km/h with a limiter.

3) Movicle: Maximum speed is 30 km/h and has the same specifications as a motorized bicycle.

4) Electric bicycles: Electric power assisted bicycles provide a certain ratio of power to human power up to 24 km/h. They have a limiter and a maximum speed of 15 km/h. They have the same specifications as motorized bicycles.

Figure 1. Exterior of e-scooters and e-bike

3 RESULTS

3.1 Speed and Vibration Characteristics

The speed and vibration data from the triaxial accelerometers are shown in Table 1. On the table, the x-axis means front-back direction, the y-axis means right and left directions, and the z-axis means vertical direction. The differences between the different vehicle types are evident, with both the loop and swing vibration of the special-purpose electric kickboard with limited speed being smaller than the others, and the difference between the two is also smaller than the other. The difference between the two is also small. However, the mobicle, which have a speed similar to that of mopeds, had significantly higher vibration than the others.

3.2 Subjective Ride Quality Evaluation

According to the results of the questionnaire survey on downhill (Table 2), the two special-purpose electric kickboards were generally rated similarly, but there were differences in operability and other aspects of riding. This is thought to be related to the fact that only the swing model brakes at speeds exceeding 15 km/h and is unstable, and that the swing model requires a large kick to move when starting off. In addition, mobicle treated as mopeds received significantly worse ratings than other vehicle types in all three questions on whether they felt scared. From the free descriptions, it is considered that the reason for this is that mobicle have the highest speed and the vehicle stability is poor. Electric bicycles received high ratings in all three questions on starting, despite their high vibration. This is thought to be because many people are used to riding these bicycles, and their large tire diameter makes them stable even with high vibration.

4 CONCLUSIONS

A comparison of electric kickboards with various specifications showed differences in the evaluation of the magnitude of vibration and riding comfort depending on the type of vehicle. In particular, the electric kickboards with a maximum speed limited to 15 km/h had low vibration and were highly rated by riders, while those treated as mopeds had high vibration and poor ratings. This is thought to be due to the tendency for vibration to increase at higher travel speeds and for rider evaluations to worsen. From these results, it can be said that for e-scooters, running at low speeds is the key to ensuring stability, and that speed control is important. On the other hand, it is difficult for the rider of a bicycle to feel the bike wobble, even though the rider is actually wobbling. However, it was found that the two subjects who were accustomed to riding a motorcycle on a regular basis did not feel fear even when riding a vehicle treated as a moped, which travels at a high speed. We plan to conduct more surveys with a larger number of subjects.

Table 1. Speed and vibration characteristics

	Legal Speed Limit [km/h]	**Observed Max. speed [km/h]**	**Observed Ave. of Max speed [km/h]**	**Distribution of acceleration [m/s^2]**		
				x axis	**y axis**	**Z axis**
Luup	15	25.1	20.3	0.642	0.880	0.777
Swing	15	17.4	16.3	0.625	0.780	0.615
Mobicle	30	43.0	34.7	1.032	1.231	0.903
e-bike	-	39.0	26.2	0.991	0.839	0.876

Table 2. Average of subjective evaluation on downhill

	Controllability			**Feeling (Fear)**			**Stability**		
	Starting	**Riding**	**Braking**	**Starting**	**Riding**	**Braking**	**Starting**	**Riding**	**Braking**
Luup	3.64	4.38	4.13	4.38	3.63	4.25	3.88	3.88	3.50
Swing	3.38	3.75	4.25	3.63	3.88	4.13	3.88	3.38	4.13
Mobicle	3.00	4.00	2.75	2.75	2.63	3.13	3.38	3.75	3.13
e-bike	4.25	4.13	3.38	4.38	4.25	3.88	3.88	4.00	3.88

Note: Controllability 5=Excellent, 4=Very Good, 3=Neutral, 2=Fair, 1=Poor
Feeling 5=Excellent (not feel fear), 4=Very Good, 3=Neutral, 2=Fair, 1=Poor (feel fear)
Stability 5=Excellent, 4=Very Good, 3=Neutral, 2=Fair, 1=Poor

REFERENCES

[1] Pilot program of e-scooters without helmet, Metropolitan Police Department, updated December 2, 2022, (Japanese only)
[2] Specification of Electric Kickboards, Ministry of Economy, Trade and Industry, updated November 25, 2022
[3] E-scooters, Nationwide Unification of Rules from July 1, Revised Road Traffic Law Enforced, Sankei Shimbun, January 19, 2023, updated January 19, 2023

Interactions among cyclists riding the wrong way on the bicycle path

C. Leschik[*]**, I. Irizar da Silva**[*]**, K. Gimm**[*]**, M. Junghans**[#]

[*]Institute of Transportation Systems
German Aerospace Center (DLR e. V.)
Lilienthalplatz 7, 38108 Braunschweig, Germany
email: {Claudia.Leschik,Kay.Gimm,
Imanol.IrizarDaSilva}@dlr.de

[#]Institute of Transportation Systems
German Aerospace Center (DLR e. V.)
Rutherfordstraße 2, 12489 Berlin, Germany
email: Marek.Junghans@dlr.de

Keywords: bicycle-bicycle interaction, wrong-way cycling, traffic safety, trajectory data.

1 INTRODUCTION

If not exceptionally signalled, riding in the opposite direction on the bicycle path is a criminal offence (§ 2 para. 4 StVO) in Germany, regardless of hindering or endangering other cyclists (and pedestrians). Unfortunately, no official statistics are kept of such situations for Germany, although they often lead to critical encounter situations or accidents. According to traffic accident statistics in Braunschweig 2021 [1], illegal riding in the opposite direction is the second leading cause in 13% of accidents involving cyclists. Among the causes of road accidents with injuries caused by cyclists, illegal riding in the wrong direction of travel accounts for 9%. Currently, only observation studies shed some more light on such situations. Some of them show that the proportion of irregular use of the bicycle path in the wrong direction of travel varies widely. In case of separate bicycle paths, 20% of 39,000 observed cyclists use the wrong way, with values scattering between 8% and 50% for each study area [2]. This study also shows that in 5% of the cases cyclists adopt the pedestrian walkway to overtake other cyclists or to avoid oncoming wrong-way cyclists. In [3] 16% of 2,549 observed cyclists took the wrong way due to time savings and convenience. However, the analysis of cyclists' interactions with wrong-way cyclists could help to identify and understand behavioural patterns of cyclists and help to improve traffic safety and conduct realistic simulation studies. In addition, the obtained results can be used to gain knowledge about road usage. In this paper, we will analyse the interaction between cyclists on the bicycle path with cyclists riding the wrong way.

2 METHOD

The observation took place at the AIM Research Intersection in Braunschweig, Germany. This large-scale research facility records trajectory data with 20 fps with 14 stereo-cameras at a traffic signal-controlled crossing with bicycle paths. The trajectory data contains information about GNSS-based timestamp, location (UTM), velocity, acceleration, road user type (e.g., pedestrian, bicycle, car) and size of each detected road user. A total of 121 hours of video material were analysed (48 hours in February 2022, 73 hours in October 2022), with interactions occurring most frequently between 6 a.m. and 6 p.m. No interactions between cyclists and cyclists took the wrong way were found after 8 p.m. and up to 6 a.m. The examined intersection has a separate footpath and bicycle path (see figure 1). It is only permitted to ride on the bicycle path in the direction of travel. This bicycle path is around 1.50m wide, which makes it difficult for two cyclists riding next to each other or to overtake. Therefore, most cyclists take the footpath. The field of vision of the sensor system ("area of interest") is approx. 25m long and straight. For this analysis, cyclists were detected and the direction of travel determined. Subsequently, interactions between cyclists and cyclists who rode in the wrong direction were identified and analysed. In addition to determining the Euclidean distances between the object centres of the interacting couples, and other metrics, such as TTC, were computed. Assuming that the bicycles maintain their direction and velocity when passing each other, data gaps were interpolated linearly.

Figure 1: left: Satellite image of AIM Research Intersection (black: area of interest for this analysis); middle: trajectory sample of an interacting bicycle couple in UTM 32U (red: wrong-way cyclists; green: cyclists in the direction of travel); right: video image for this situation

3 RESULTS AND DISCUSSION

In the data set, 117 interacting couples were identified, in which a cyclist drove in the direction of travel and a cyclist took the wrong direction at the same time in the area of interest (see figure 1, middle and right). The interacting couples' trajectories that were too short or broken were not used, thus 77 interacting pairs remained for analysis. The average Euclidean distance d between cyclists during interaction was approximately 2.14m. In 27 cases d was even less than 2m. The smallest d was approximately d_{min}=0.68m.

Table 1: Scenarios of 77 interacting cyclist pairs with speed: $|v|$, and mean of minimum distance between the cyclists during interaction: $d_{min,mean}$ and type "straight" for keeping their lane during they passed each other or type "crossing" for first changed lanes

No.	Cyclist^{c}	Wrong-way cyclist^{wwc}	Type	Number of cases	$d_{\text{min,mean}}$ [m]	$\lvert v \rvert$ [m/s]
1.1	bicycle path	footpath	straight	57 (74.0%)	2.25 ± 0.06	4.99 ± 0.19^{C} 4.10 ± 0.18^{WWC}
1.2			crossing	10 (13.0%)	2.13 ± 0.08	5.26 ± 0.44^{C} 4.55 ± 0.35^{WWC}
2.1	bicycle path	bicycle path	straight	4 (5.2%)	1.33 ± 0.32	5.44 ± 0.55^{C} 4.91 ± 0.43^{WWC}
2.2			crossing	3 (3.9%)	1.57 ± 0.07	5.12 ± 0.11^{C} 4.76 ± 0.64^{WWC}
3.1	Footpath	bicycle path	straight	2 (2.6%)	2.55 ± 0.39	6.82 ± 0.57^{C} 4.51 ± 0.77^{WWC}
3.2			crossing	1 (1.3%)	0.68 ± 0.00	5.29 ± 0.00^{C} 4.22 ± 0.00^{WWC}

On average, there were 11.0% wrong-way cyclists (n = 7,598). The proportion of wrong-way cyclists was with more than 20% the largest between 6 and 7 a.m. Normal driving and wrong-way riding cyclists do not always meet in the same way. The wrong-way cyclists most often drove on the footpath and did not have an observable influence on the cyclist on the bicycle path. Table 1 shows a comparison of the different scenarios of the cyclists interacting with wrong-way cyclists. Particularly, column $d_{\text{min,mean}}$ quantifies the minimum distance during interaction; in column |*v*| the speeds of both, the normal driving cyclists (notation “C”) and the wrong-way traveling cyclists (notation “WWC”) are shown during interaction.

Cyclists and wrong-way cyclists can ride on the bicycle path or footpath. It appeared that in 70 cases the cyclist or the wrong-way cyclists rode on the bicycle path, and in seven cases both adopted the bicycle path at the same time. There were no examples found where both rode on the footpath. Within the area of interest, it occurred that the cyclist and the wrong-way cyclist first changed lanes before they passed each other (see Table 1 “crossing”). Otherwise both cyclists kept their lane during the oncoming interaction (see Table 1 “straight”). In each situation the speed of the WWC was lower than C. Perhaps C slowed down deliberately. The reason for this could be to ride more safely, because of the awareness that he/she was riding in the wrong direction. In 3 of 9 of the “crossing” cases it appeared that WWC had already driven on the footpath before the curve. In 6 cases, the WWC was already on the bicycle path. In the remaining 5 “crossing” cases, the WWC was not detected until the lane change. WWCs switched from the bicycle path to the footpath approx. 14.4m ± 3.7m before the interaction. When riding on the cycle path at the same time, small distances were measured.

4 CONCLUSIONS & FUTURE PROSPECTS

The analysis shows that the interaction of cyclists, while one was traveling in the wrong direction on the bicycle path, differed from each other and can be clustered. Mostly, the wrong-way cyclists and normal riding cyclists rode already separately on footpaths and bicycle paths before the start of the area of interest. A reason for this can be that wrong-way cyclists were aware of that someone was approaching, and—since the bicycle path is very narrow—they avoided riding on the bicycle path. This indicates that wrong-way cyclists had lower speeds than “normal” cyclists. In some cases, wrong-way riders switched to the footpath within the study area or continued to ride on the cycle path. Further analyses of the trajectories could provide information about when cyclists avoid or keep their path and, if necessary, at what distance a speed is maintained or adjusted.

We expect that riding behaviour and specifically bicycle-bicycle interactions differ depending on type and width of bicycle lane as well as of the bicycle type and the drivers themselves. Further investigations should be carried out to compare riding behaviour on other infrastructure and among different bicycles types and rider types. In the future, additional data of crossing cyclists will be collected and analysed applying further suitable metrics of traffic conflict technique in order to determine behavioural and kinematic patterns of interacting cyclists for developing reliable tactical and operational cycling models for safety simulation purposes. Also, it may be possible to determine that wrong-way cyclists switch to the footpath at similar distances.

REFERENCES

[1] Polizeiinspektion Braunschweig, *Polizeiliche Verkehrsunfallstatistik 2021*. 18.04.2023. https://cache.pressmailing.net/content/e9c85f39-e7ae-4701-a269-fc9cb131e6f6/VU-Statistik2021.pdf

[2] D. Alrutz, W. Bohle, H. Müller, H. Prahlow, U. Hacke & G. Lohmann, *Unfallrisiko und Regelakzeptanz von Fahrradfahrern*, 2009.

[3] A. K. Huemer & M. Vollrath, *Cycling in Braunschweig: Characteristic crashed, crash risks, risk behaviour, and motivation for infringements of traffic regulations*, In Presentation at the 5th International Conference on Applied Human Factors and Ergonomics (AHFE 2014), Krakow, 2014.

Bicyclists' attitudes and perceptions towards self-driving cars:
A mixed methods approach

E. Hollauf*, C. Luger-Bazinger, V. Hornung-Prähauser

Salzburg Research Forschungsgesellschaft mbH,
Jakob-Haringer-Straße 5/3, 5020, Salzburg, Austria
email: *eva.hollauf@salzburgresearch.at

Keywords: bicyclists, autonomous vehicles, trust, perceived safety, affinity for technology.

1 INTRODUCTION

In recent years, the development of autonomous vehicles (AVs) has become a central focus of research and development and is expected to significantly impact road traffic in the future. While research on AVs has largely concentrated on the technology itself and the direct users of AVs, such as passengers in self-driving cars, the role of bicyclists who interact with AVs in traffic has not been explored in depth. As vulnerable road users, the needs, and expectations of bicyclists [1] must be considered when developing emerging technologies like AVs, especially if the number of bicyclists is expected to increase in the coming years [2] [3]. To ensure the safe and successful integration of AVs into future traffic, it is crucial to design a secure interaction between bicyclists and AVs that considers both subjective and objective safety measures, and to involve bicyclists in the development process. A key determinant of the successful adoption of AVs is the acceptance of this new technology by other road users, especially vulnerable road users (VRUs), such as bicyclists.

Perceived safety and trust are the key factors that determine the acceptance of autonomous vehicles [4] [5]. People feel safe when they perceive a decrease in danger and an increase in comfort when interacting with technology [6]. While the objective safety of AVs can be improved through engineering, the perceived or subjective safety of these vehicles is critical to their adoption and use [7]. This is important not only for those actively using AVs, but also for those who share the road with AVs, such as bicyclists. the development of AVs must prioritize the establishment of trust as a prerequisite for their acceptance, as previous research on the acceptance of automated systems has shown [8]. Moreover, the perceived traffic safety is important even for those who are not actively using AVs, as it is linked to their fear of accidents [9].

2 MATERIAL AND METHODS

In literature, perceived safety and trust have been discussed as important factors in the subsequent acceptance of Avs. We want to examine how these factors are influenced by other variables, particularly cyclists' affinity for technology. To gain new insights into these perceptions and attitudes of cyclists towards automated vehicles, we used a mixed methods explanatory sequential approach: An initial quantitative online survey (N=889) is followed by a qualitative data collection and analysis (N=19) to interpret the survey findings.

The online survey was shared with various online bicycling communities in Germany and Austria (02-03/2021). The survey included questions about socio-demographic factors, bicycling behavior, experiences in traffic, attitudes towards automated cars, and affinity for technology. Additionally, an open-ended question asked participants what they would wish for from a self-driving car. The Affinity for Technology Interaction (ATI) scale was used to assess participants' technological affinity.

The survey results were further explored in focus group discussions with lead users from the bicycling communities (04/2021). The focus group method was used to interpret survey results and explore attitudes and behaviors towards AVs. Participants were selected based on their affinity for technology score and discussed attitudes and perceptions towards AVs from a bicyclist's perspective and focused on the information they would like to receive from AVs and in what form.

3 RESULTS

3.1 Survey

The survey was completed by 889 participants (67% male and 33% female; mean age 43.2 years). 58% of participants lived in cities with over 500,000 inhabitants and all reported riding their bicycles in traffic at least occasionally. To measure attitudes towards self-driving cars, two items were developed using a 5-point Likert scale, one focusing on trust in self-driving cars (*As a bicyclist, I would trust self-driving cars*., mean = 3.35, 1= strongly disagree, 5 = strongly agree), the other one focuses on perceived safety (*As a bicyclist, I would consider self-driving cars as safe,* mean = 3.41, 1= strongly disagree, 5 = strongly agree). The Affinity for Technology Interaction (ATI) scale was used to measure affinity for technology, consisting of four items on a 6-point Likert scale. The Cronbach alpha was high ($\alpha = .85$) and a summability score was calculated for better internal consistency (summability = .59). Results showed that men had a higher affinity for technology than women ($t = 10.49$, $p < .001$). Multiple regression was used to explore the predictors of trust and perceived safety in self-driving cars, with ATI score, gender, and age as predictors and trust and perceived safety as dependent variables. The results showed that the ATI score was the strongest predictor of trust in self-driving cars, with men having more trust than women, and trust decreasing with age. Similarly, for perceived safety of self-driving cars, age was the strongest predictor, with men feeling safer than women. Participants were also asked whether they would like to know if they encountered an AV in traffic and whether they would like to know what the AV does next, with women showing a greater desire to know if they encountered an AV. Participants were asked an open question on what they would wish for in a self-driving car from their perspective as a cyclist, with many wishing for reliable technology, followed by signals of the car and it abiding by traffic rules.

Table 1: Results from multiple regressions on trust and perceived safety as dependent variables and gender, age and ATI score as independent variables [10]

Trust	***B***	***SE***	***β***	***p***
Gender	-0.20	0.09	-0.08	< .05
Age	-0.01	0.00	-0.13	< .001
ATI	0.15	0.03	0.14	< .001
R Squared = 0.05 (N = 889)				
Perceived Safety	***B***	***SE***	***β***	***p***
Gender	-0.25	0.09	-0.10	< .001
Age	-0.01	0.00	-0.14	< .001
ATI	0.13	0.01	0.13	< .001
R Squared = 0.06 (N=889)				

3.2 Focus groups

In the more in-depth focus group discussions, it was found that participants felt safer when they were informed about the status and intentions of the autonomous vehicle (AV) they were interacting with. To convey this information to bicyclists, it is suggested that the AV should communicate that it is autonomous, follows traffic rules and has detected the bicyclist. This could be done through eHMI (external human machine interface), which recreates the eye contact that is exchanged between drivers and bicyclists in traditional traffic. Warning signals should also be used in certain situations, such as approaching intersections with high traffic volumes, to alert bicyclists if they have not been detected or if there is a potential danger. However, it was also noted that too many or poorly interpreted warnings could cause overstimulation or make bicyclists feel insecure. Some participants expressed concerns that sudden warning signals might startle bicyclists, leading to increased feelings of insecurity or recklessness.

The study also revealed that trust in the AV is strengthened when it communicates its status (autonomous or non-autonomous), intentions, compliance with traffic rules, and correct detection of bicyclists to the rider. While participants assumed that technical errors would not occur in advanced autonomous vehicles, they still desired eHMI to convey this information. However, it was noted that participants did not imagine putting all their trust in a technical tool alone. The suggestion to use eHMI to communicate the status and intention of the AV was well received by the focus group participants, while 46% of survey respondents preferred a warning signal on the bike itself.

4 CONCLUSION

For AVs to be accepted in traffic, it is important to consider the needs of bicyclists. In our mixed-method study, we examined the trust and perceived safety of AVs among bicyclists, as well as their attitudes towards eHMIs and the factors that influence their acceptance of AVs. We used both quantitative survey results and qualitative data from focus groups to investigate these factors. Our study found that gender, age, and affinity for technology were significant predictors of both trust and perceived safety regarding Avs, which relates to other findings from survey studies [11]. The flawless functioning of AVs and clear communication of their intentions to bicyclists were deemed crucial factors for successful interaction between AVs and bicyclists.

Affinity for technology was also a significant predictor for both trust and perceived safety, with higher affinity for technology leading to higher values in the dependent variables. This factor was not previously explored and can be considered as a strong factor in influencing the trust and perceived safety, as well as acceptance of automated vehicles in future studies. Furthermore, the qualitative findings show that using eHMIs to facilitate communication between bicyclists and AVs was a promising approach.

The insights obtained from our study can serve as valuable guidance for the development of eHMIs that promote effective communication between bicyclists and AVs, and contribute to better understand the key factors that influence people's perception of AVs and their acceptance as a viable mode of transportation in future traffic.

REFERENCES

[1] B. Botello, R. Buehler, S. Hankey, A. Mondschein, Z. Jiang (2019). Planning for walking and cycling in an autonomous-vehicle future. *Transp. Res. Interdiscip. Perspect.* 1, 100012. doi: 10.1016/J.TRIP.2019.100012

[2] P. Penmetsa, E.K. Adanu, D. Wood, T. Wang, S.L. Jones (2019). Perceptions and expectations of autonomous vehicles – A snapshot of vulnerable road user opinion. Technol. Forecast. Soc. Change 143, 9–13. doi: 10.1016/J.TECHFORE.2019.02.010

[3] S. Pettigrew, J.D. Nelson, R. Norman (2020). Autonomous vehicles and cycling: Policy implications and management issues. Transp. Res. Interdiscip. Perspect. 7, 100188. doi: 10.1016/J.TRIP.2020.100188.

[4] M. Kyriakidis, R. Happee, J.C.F. De Winter (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. Transp. Res. Part F Traffic Psychol. Behav. 32, 127–140. doi: 10.1016/J.TRF.2015.04.

[5] S. Stegmüller, M. Werner, M. Kern (2019). Akzeptanzstudie “Robocab”. Autonome Mobilitätskonzepte aus Sicht der Nutzer. Available at: http://publica.fraunhofer.de/documents/N-531897.html.

[6] C. Bartneck, T. Kanda, O. Mubin, A. Al Mahmud (2009). Does the Design of a Robot Influence Its Animacy and Perceived Intelligence? Int. J. Soc. Robot. 2009 12 1, 195–204. doi: 10.1007/S12369-009-0013-7.

[7] J.G. Lee, K.J. Kim, S. Lee, D.H. Shin (2015). Can Autonomous Vehicles Be Safe and Trustworthy? Effects of Appearance and Autonomy of Unmanned Driving Systems. Int. J. Hum. Comput. Interact. 31, 682–691. doi: 10.1080/10447318.2015.1070547.

[8] A.O. Salonen (2018). Passenger’s subjective traffic safety, in-vehicle security and emergency management in the driverless shuttle bus in Finland. Transp. Policy 61, 106–110. doi: 10.1016/J.TRANPOL.2017.10.011.

[9] R. Parasuraman, V. Riley (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. Human Factors, 39(2), 230–253. https://doi.org/10.1518/001872097778543886

[10] C. Luger-Bazinger, E. Hollauf, H. Atasayar, C. Zankl, V. Hornung-Prähauser (submitted). Perceptions and attitudes of bicyclists towards self-driving cars: A mixed methods approach. Frontiers in Future Transportation.

What turns a bicycle street into a street for cyclists? A multimodal study on subjective safety of infrastructure measures on bicycle streets using an approach in virtual reality.

M. Schwarzkopf[*]**, A. Dettmann**[*]**, M. Kreußlein, J. Trezl**[*]**, A. C. Bullinger**[*]

[*] Chair of Ergonomics and Innovation Management
Chemnitz University of Technology,
Institute of Mechanical Engineering
D-09125 Chemnitz, Germany
email: marc.schwarzkopf@mb.tu-chemnitz.de

Keywords: cyclist perception, subjective safety, validity, virtual reality, extended reality infrastructure

1 INTRODUCTION

In Germany, a bicycle street is a designated street for bicycle and E-Scooter traffic. According to a survey by the German Federal Ministry of Transport and Digital Infrastructure [1], 39 percent of respondents listed "more bicycle routes" as the most urgent demand for the government. Hence, bicycle streets need to become an important element in bicycle traffic planning to increase the safety and attractiveness of cycling in Germany [1]. To accomplish this, cars and other vehicles are allowed but with speed restrictions and special rules to increase the attractiveness and safety of cycling and create advantages over motor vehicle traffic.

To implement bicycle streets are a set of technical regulations are used. These design rules are based on the analysis of objective safety. Often, they do not consider the subjective safety of cyclists. This can result in infrastructure that is objectively safe but does not feel subjectively safe for cycling, which can have a negative affect on the frequency of bike usage [2,3,4,5,6]. Here, three shortcomings in the existing research stand out: previous work rarely examines the influence of specific infrastructure characteristics of bicycle streets (lane width, lane markings, etc.) on subjective safety, there is limited information on whether bicycle streets that allow car traffic under special rules actually increase perceived safety, and studies evaluating the subjective safety of cycling infrastructure typically only include people who actually cycle, ignoring those who avoid cycling due to perceived safety concerns.

To address these shortcomings, our study focuses on analyzing the influence of infrastructure features (implemented and potential) and special traffic rules (implemented and potential) on subjective safety while cycling along a bicycle route with allowed car traffic in the city of Chemnitz, Germany. The goal was to involve both people who cycle and those who typically do not cycle due to safety concerns.

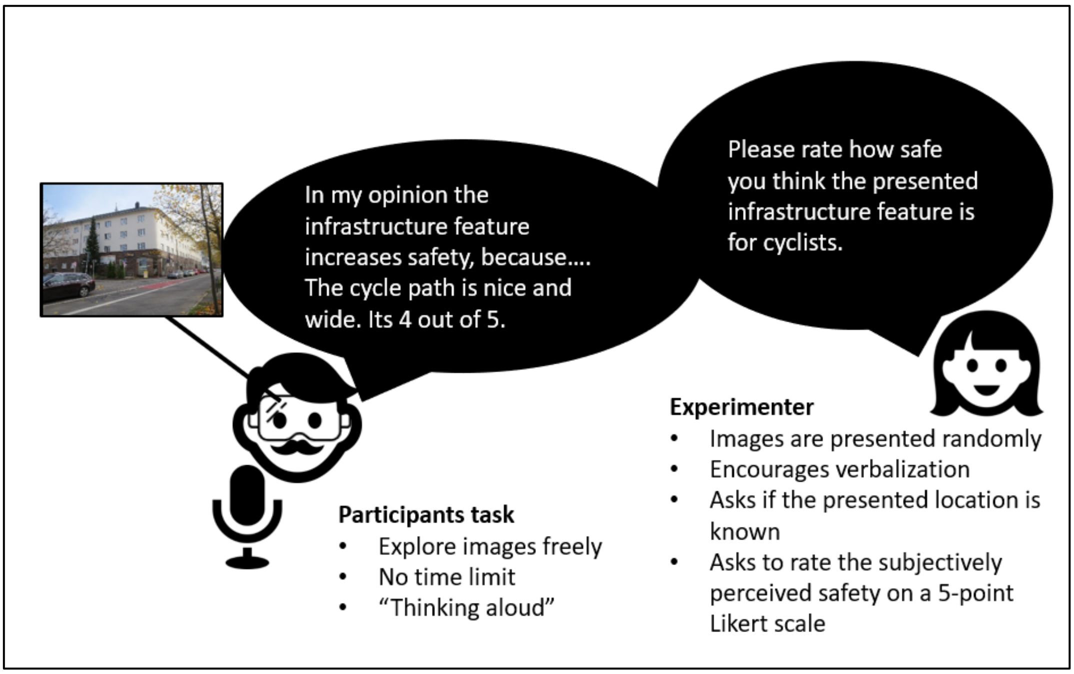
2 METHOD

A two-staged experimental design was chosen for this purpose. In the first phase of the study, 18 factors were derived from literature which have an impact on the subjective safety of cyclists. The scale of subjective safety from the Bicycle Climate Test of the German Cyclist's Association (ADFC) was used to measure subjective safety [8]. The infrastructure elements were queried via photo examples from exemplary best-practice bicycle routes. A sample of *N* = 182 students was surveyed using an online questionnaire.

Only individuals who engaged in moderate to frequent cycling participated in the initial trial, while those who seldom or never cycled did not participate. For this reason, a second phase was added to explicitly include the evaluation of people who do not currently use bicycles but would like to use them more frequently (people with moderate to frequent cycling also participated in the second phase as well). This part also evaluated the influence of specific infrastructure features for bicycle streets with allowed car traffic on subjective safety while cycling.

3 MATERIAL

Here, stereoscopic 360° recordings of infrastructure features of the bicycle street were created and presented through a self-programmed app that runs on stand-alone virtual reality (VR) headsets. The methodological structure of the second stage is presented in Figure 1.



In my opinion the infrastructure feature increases safety, because.... The cycle path is nice and wide. Its 4 out of 5.

Please rate how safe you think the presented infrastructure feature is for cyclists.

Participants task
- Explore images freely
- No time limit
- “Thinking aloud”

Experimenter
- Images are presented randomly
- Encourages verbalization
- Asks if the presented location is known
- Asks to rate the subjectively perceived safety on a 5-point Likert scale

Figure 1: Outline of the methodological structure of the assessment of the subjective safety perception of cycling infrastructure via Virtual Reality

The advantage of this app is that the presented images in VR allow viewers to better immerse themselves in the infrastructure measure shown, and thus an evaluation can be made independently of the use of the respective infrastructure measure [8]. $N = 35$ people will participate in this experiment, and the questionnaires used corresponded to those used in phase I except in phase II only implemented infrastructure features are evaluated.

4 RESULTS

For the first phase it was found that the subjective safety of cycling on the bicycle route was rated better than cycling in general in the city of Chemnitz. The difference can be described as a large effect ($d = -2.4$) and exceeded expectations. Furthermore, it was not confirmed that there is no difference in subjective safety between experienced and inexperienced/part-time cyclists. The highest predictors were the maximum speed of 30 km/h ($\beta = -0.27$) and a wider road width ($\beta = 0.25$) for the criterion of subjective safety. The model demonstrated a medium to high level of goodness of fit ($R^2corr = .32$; $f^2 = .47$).

The second phase of this study is still in progress and will be finished in June.

5 SUMMARY

The presented studies provide insight into which infrastructure measures increase the subjective safety of bicycle streets with car traffic. The results can be used to select safety-promoting infrastructure elements in infrastructure planning or to implement them into existing infrastructure measures and regulations. Furthermore, the study applies an evaluation method in VR to make infrastructure measures and elements evaluable, regardless of whether they are familiar to the participants. The utilization of this virtual reality method has the potential to simplify and streamline future studies on cycling safety, making them more cost-effective and efficient. This approach can supplement or even replace on-site surveys depending on the specific research context, allowing for greater flexibility and adaptability in the research process.

REFERENCES

[1] Bundesministerium für Verkehr und digitale Infrastruktur, Fahrrad-Monitor Deutschland 2021. Ergebnisse einer repräsentativen Online-Befragung, Bundesministerium für Verkehr und digitale Infrastruktur, Berlin, 2021

[2] D. Horton, *Fahrradstraßen – Leitfaden für die Praxis*, Deutsches Institut für Urbanistik, Berlin, 2021.

[3] A. Hull and C. O´Holleran, “Bicycle infrastructure: can good design encourage cycling?”, *Urban, Planning and Transport Research* 2 (2014), pp. 369-406.

[4] C. Skorna, D. Treutlein, S. Westermoreland, C. M. Loock, J. F. Paefgen, S. von Watzdorf, L. Ackermann and A. Bereuter, *Baloise Group-Sicherheitsstudie 2010: Gefahren und Risikofaktoren beim Fahrradfahren in der Schweiz*, Baloise Group, 2010.

[5] J. Y. Wang, L. Mirza, A. K. Cheung and S. Moradi, „Understanding factors influencing choices of cyclists and potential cyclists: A case study at the University of Auckland”, *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice* 23 (2014), pp. 37-51.

[6] T. Klein, S. Hummel, T. Leven, J. Gerlach, T. Stein and S. Bührmann, *Fahrradstraßen – Leitfaden für die Praxis*, Deutsches Institut für Urbanistik, Berlin, 2021.

[7] Allgemeiner deutscher Fahrradclub (ADFC). Ergebnistabelle – ADFC-Fahrradklima-Test 2020. https://www.adfc.de/fileadmin/user_upload/Im-Alltag/Fahrradklimatest/FKT_2020/ADFC-Fahrradklima-Test_2020_Ergebnistabelle_Gesamt_A3.pdf

[8] M. Schwarzkopf, A. Dettmann, J. Trezl and A. Bullinger, “Do you bike virtually safe? An exploarative VR study assessing the safety of bicycle infrastructure”, in D. de Waard, S.H. Fairclough, K.A. Brookhuis, D. Manzey, L. Onnasch, A. Naumann, R. Wiczorek, F. Di Nocera, S. Röttger and A. Toffetti (Eds.), *Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2022 Annual Conference: Enhancing Safety Critical Performance*, Torino, Italy, 2022.

Cyclists’ Gaze Patterns and Driver Detection when Encountering Manual and Driverless Vehicles: A Field Study

S. H. Berge*, J. C. F. de Winter#, D. Dodou#, N. Reddy*, Y. Dong*, N. Raju*, A. P. Afghari†, E. Papadimitriou†, H. Farah*

*Faculty of Civil Engineering and Geosciences
Delft University of Technology
Stevinweg 1, 2628 CN, Delft, The Netherlands
email: S.H.Berge@tudelft.nl, N.Reddy@tudelft.nl, Y.Dong-4@tudelft.nl, S.S.N.Raju@tudelft.nl, H.Farah@tudelft.nl

#Faculty of Mechanical, Maritime and Materials Engineering
Delft University of Technology
Mekelweg 2, 2628 CN, Delft, The Netherlands
email: D.Dodou@tudelft.nl, J.C.F.deWinter@tudelft.nl

†Faculty of Technology, Policy and Management
Delft University of Technology
Jaffalaan 5, 2628 BX Delft, The Netherlands
email: A.P.Afghari-1@tudelft.nl, E.Papadimitriou@tudelft.nl

Keywords: cycling, eye-tracking, automated driving systems

1 INTRODUCTION

Research on cyclists’ gaze behaviour when interacting with conventional vehicles has shown that cyclists tend to look towards drivers in ambiguous situations such as uncontrolled intersections, bottlenecks, and during parking [1]. With the introduction of automated driving systems, the interaction between cyclists and vehicles might become increasingly complex as a human driver might not occupy the driver's seat. It has been proposed that vehicle motion cues may suffice in such interactions [2][3]. However, research on cyclists’ gaze towards vehicles and detecting driver presence or absence is currently limited. In this field study, we investigate how cyclists interact with manual and driverless vehicles by analysing cyclists’ gaze dynamics. We aim to identify the areas of focus for cyclists during interactions with approaching vehicles and their ability to detect the presence of a driver. This study will contribute to understanding cyclists’ interactions with driverless vehicles and the potential role of interpersonal communication.

2 METHODS

We examined cyclists’ gaze patterns using eye-tracking glasses in a Wizard-of-Oz field experiment. In a Wizard-of-Oz experiment, a hidden *ghost driver* controls the vehicle, creating the illusion that the participant is interacting with a driverless vehicle. Thirty-seven participants (23 males and 14 females) cycled a predetermined 530-metre route around a building at Delft University of Technology in the Netherlands while wearing Tobii Pro 3 eye-tracking glasses (see Figure 1).

Figure 1: The cyclist participant is cycling straight with the vehicle approaching from their left-hand side. The driver is wearing a seat suit to imitate a driverless vehicle.

Participants cycled the route four times first without instructions, encountering a vehicle with a concealed *ghost driver* in two out of four trials. In a second session, the participants were briefly interviewed and then instructed to cycle the same route four more times. During each of these rounds, they had to read two letters on a sign approximately 5 seconds before passing the vehicle and then indicate whether they could detect a driver in the vehicle or not. After this session, the participants were interviewed a second time.

Data was gathered through eye-tracking glasses, as well as via interviews. Instead of manual annotation, computer vision methods were employed for automatic gaze behaviour identification. The vehicle was identified using a pre-trained YOLO model for each video frame. The driver's location was then estimated by taking a distance of 65% in width and 20% in height, calculated from the top left of the bounding box. The visual angle between the estimated driver position and the gaze point was calculated for each frame. A threshold angle of 4 degrees was applied [4]. When the angle falls below the threshold value, it can be stated that the cyclist was looking at the vehicle (driver), see Figure 2.

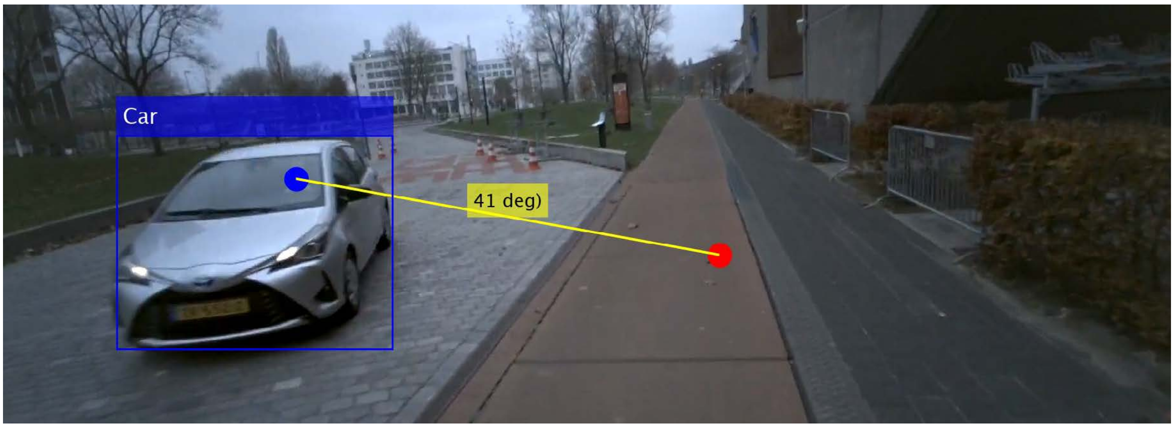


Figure 2: Still frame from the video recorded by the eye-tracking glasses. The red circle indicates the participant's gaze point, and the blue box is the area-of-interest surrounding the vehicle. The angular distance indicates whether the participant glances at the vehicle. The threshold for looking at the vehicle was set to 4 degrees.

Due to the eye-tracker's imperfect accuracy, it is not unequivocally determinable whether the cyclist was looking at the driver or another aspect of the vehicle, particularly from a distance where the bounding box around the vehicle is small. We will define other target points, such as the centre of the front bumper and bounding box, to make probabilistic inferences about the cyclist's gaze location on the vehicle.

3 RESULTS AND DISCUSSION

The experiment is complete, and the analysis is ongoing. Preliminary results indicate that the automatic gaze behaviour identification method is effective. The analysis of one participant's results showed a brief sampling of the vehicle, alternating with looking at other locations, such as the bicycle path (see Figure 3), indicated by an angle larger than 4 degrees. As the car passes, the angular distance typically increases due to its lateral position in the participant's field of view (see Figure 2).

Although these findings pertain to only one individual, the findings revealed differences between the uninstructed Session 1 and the instructed Session 2, with longer vehicle observation in Session 2, possibly to determine the presence of a driver as requested. Specifically, the participant sampled the vehicle in 21.9% in Session 2 compared to 15.3% in Session 1. In Session 2, the cyclist correctly detected whether the driver was absent or present in 4 out of 4 interactions.

4 CONCLUSION

The results may provide insight into whether cyclists look at vehicles and, if they do look at vehicles, whether they can detect the presence of a driver behind the wheel. In turn, these findings may inform the development of automated vehicles, such as whether external human-machine interfaces (eHMIs) can compensate for any lack of interpersonal communication.

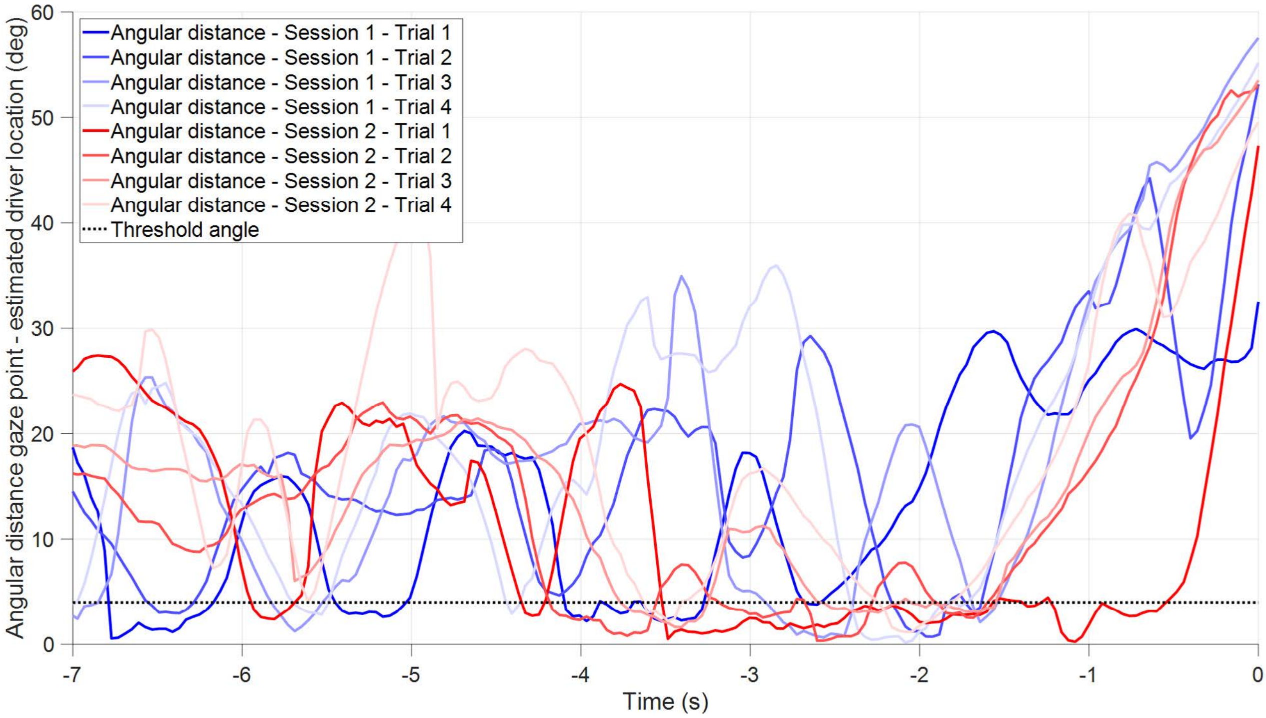


Figure 3: Angular distance between the participant's gaze point and the estimated position of the driver. Angular degrees of ≤ 4 indicate the participant was glancing at the vehicle (driver). t = 0 s is the moment the vehicle disappeared from the image (i.e., the moment the cyclist passed the vehicle)

ACKNOWLEDGMENT

The authors would like to acknowledge the seed funding received from the TU Delft Safety and Security Institute for the GAZETOAV project, which facilitated carrying out the field test of this study, and the Outdoor Mobility Digital Twin for providing access to the trajectory data recorded from their cameras.

REFERENCES

[1] A. Al-Taie, Y. Abdrabou, S. A. Macdonald, F. Pollick, and S. A. Brewster, "Keep it Real: Investigating Driver-Cyclist Interaction in Real-World Traffic", in *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, Hamburg, Germany, 23-28 April 2023, ACM, 2023, pp. 1–15. doi: 10.1145/3544548.3581049.

[2] D. Moore, R. Currano, G. E. Strack, and D. Sirkin, "The Case for Implicit External Human-Machine Interfaces for Autonomous Vehicles" *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery,* Utrecht, Netherlands, 21 September 2019, Association for Computer Machinery, New York, USA, 2019, pp. 295–307. doi:10.1145/3342197.3345320

[3] S. H. Berge, M. Hagenzieker, H. Farah, and J. De Winter, 'Do cyclists need HMIs in future automated traffic? An interview study', *Transportation Research Part F: Traffic Psychology and Behavior* 84 (2022), pp. 33–52. doi: 10.1016/j.trf.2021.11.013.

[4] V. Onkhar, P. Bazilinskyy, J. C. J. Stapel, D. Dodou, D. Gavrila, and J. de Winter, 'Towards the detection of driver–pedestrian eye contact', *Pervasive and Mobile Computing* 76 (2021), p. 1-14. doi: 10.1016/j.pmcj.2021.101455.

Share the road – International experiences with recommendations and laws on lateral distance to cyclists

Anne Eriksson, Søren Underlien Jensen

Danish Road Directorate
Carsten Niebuhrs Gade 43
DK-1577 København V, Denmark
email: agke@vd.dk

Trafitec
Transformervej 18
DK-2860 Søborg, Denmark
email: suj@trafitec.dk

Keywords: share the road, cycling, evaluation.

1 INTRODUCTION

In Denmark, cyclist advocacy groups have asked for a law regulating minimum lateral distance for cars that are overtaking cyclists. It has been referred to as the "Mallorca-rule" as such a law is in power in Spain and also in several other countries. A "borgerforslag" (citizens' proposal to the Danish Parliament) was raised but didn't get the necessary public backup in order to be presented to Parliament.

However, the topic was also raised by the Transport Minister in 2021, so the Danish Road Directorate launched an investigation to gain knowledge from different experiences with law and other measures regarding lateral distance for cars when overtaking cyclists. This abstract contains a brief presentation of the findings.

2 INVESTIGATION FRAME WORK

A screening of the Road Traffic laws in 31 European countries as well as USA, Australia, Canada and New Zealand was carried out to see if the countries had laws defining a fixed overtaking distance. A number of questions was subsequently sent to the 14 European countries that had a law or similar on lateral distance when overtaking a cyclist.

The questions related mainly to experiences with and evaluation of enforcement and compliance.

Also, a literature study was carried out to collect experiences from different evaluations and investigations carried out on the broader subject of car driver behavior when overtaking cyclists.

The investigation was carried out by Trafitec, a private consultant. The work was initiated in August 2022 and final report was handed in in November.

3 FINDINGS

The investigation showed interesting results that were useful for us in Denmark and could be interesting for other decision makers and law makers.

3.1 Survey

The aim when introducing a law that defines a lateral distance for cars overtaking cyclists is of course to improve the safety for the more vulnerable road user; the cyclist. The group "cyclists" also includes e-bikes, mopeds and e-scooters, vehicles that travel at relatively low speed on the road together with motorized vehicles unless there is a separate infrastructure, like a path. When they share the same wearing course as the motorized vehicles they are more at risk of being hit from behind. On rural roads with high speeds this often has a serious outcome for the cyclist. A Danish analysis based on 25 fatal accidents of this type showed that the major part of the accidents had taken place on roads with no cycle infrastructure or very narrow edge lanes not fit for cycling.

But will a law change driver behavior and reduce the risk for cyclists? The investigation showed that although many countries had laws, there are challenges:

- Not all drivers are aware of the law
- The information about the law is seldom included in driving school curriculum
- The Traffic Police does not enforce the law due to lack of measuring equipment that can be used in court

The investigation also shows that the law text varies:

- In some countries the law demands different distance on rural and urban roads
- Some countries also have regulatory or information signs about the distance
- Ina some countries the law only applies when there is no separate cycle infrastructure

3.2 Literature study

A literature study was also carried out as a part of the investigation. The study found several investigations that pointed in the direction that a law on lateral distance when overtaking doesn’t have a significant effect in it self but has to be supported by enforcement and/or information. The study also referred to several conditions that had an effect on the actual overtaking distance. Here are a few of them:

- The average overtaking distance increases when the road width increases
- The average overtaking distance decreases when oncoming traffic increases
- The cyclists’ gender, clothes, speed, helmet use only has little effect on the overtaking distance

Some studies indicate that car drivers with negative impressions of cyclists tend to overtake with less distance.

REFERENCES

[1] Road Directorate, Trafitec, https://www.vejdirektoratet.dk/udgivelse/erfaringsopsamling-om-minimumsafstand-ved-overhaling, 2022

Assessing Micromobility Safety on Horizontal Curves of Bike Lanes: A Video Motion Analysis Methodology

M. H. Sabbaghian[*], **D. Llopis-Castelló**[*], **A. García**[*]

[*]Highway Engineering Research Group, Universitat Politècnica de València, Camí de Vera, s/n, 46022, Valencia, Spain

emails: mhossab@upv.es, dallocas@upv.es, agarciag@tra.upv.es

Keywords: Micromobility, Road Safety, Horizontal Curve, Bike Lane, Users Behaviour, Motion Analysis

1 OBJECTIVE

Geometric characteristics of a bike-lane can affect safety for Micromobility (MM) users. Besides, MM users' behavior is still understudied [1]. In critical segments like sharp horizontal curves with restricted sight distance, risky behavior patterns of users such as lane violation, lane transgressing, and speeding, could lead to serious safety concerns. The objective of this study is to propose a naturalistic data-driven methodology to identify surrogate safety measures that can be used to assess safety on isolated horizontal curves. The proposed procedures can be applied to any curve case study with a larger sample size to draw conclusions about any objective factor that may affect safety of users of horizontal curve of a bike lane.

2 METHODOLOGY

This study proposes a naturalistic data-driven approach to observe surrogate safety measures of speed and trajectory of MM users on bike lanes, using motion-analysis. An isolated sharp curve with critical geometry (small radius and sharp deflection angle) is selected for an initial analysis. This case study was selected from an available total sample dataset of 30 isolated curves, which were collected during fall 2022 in the city of Valencia, Spain. The data were collected using a set of Garmin VIRB Elite cameras and tripods (6 meters height). The dataset is labeled, segmentized, and undistorted using some scripts programmed in Python.

The selected simple circular curve has a deflection angle of 89.02 degrees, and a radius of 6.280 meters. Three sections or points on the centerline of the curve were defined to trace lateral position and speed of MM users. These points of interest correspond with Point of Curvature (PC), Midpoint (MP), and Point of Tangency (PT), that will be used to shape and calculate effective trajectory curves and their corresponding effective radius from real trajectory of users. Direction of movement on the curve were also divided to Left-Turn (LT) and Right-Turn (RT) movements.

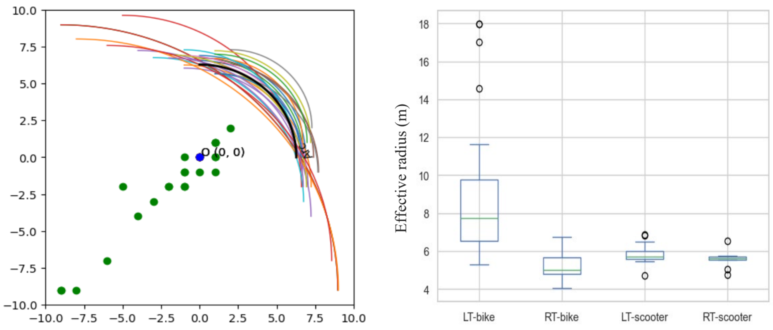
Four regions of interest were defined to assess displacement of the riders: on the center line (CL), within the lane (LN), on the opposite lane (OPL), and outside the bike lane (OTL). For the speed analysis, the average speed of each user along the horizontal curve was estimated from the observed speeds at the points of interest. In order to identify risky patterns of the users, the lateral position coordinates (x, y) and speed of each user type (cyclists and e-scooterists) were tracked by using the software Kinovea, after calibration of the griding system using references measured on the field. In total, the speed and displacement of 74 users (50 cyclists and 24 e-scooterist) were extracted, that were utilized to obtain effective radius, displacement heatmap, and speed patterns. The reliability of Kinovea to evaluate motion patterns is confirmed in previous studies [2] [3].

3 RESULTS

In this section, effective trajectory arcs and correlated displacement of bike users on Left-Turn (LT) direction are presented so as to prove the usefulness of the proposed methodology. Additionally, a comparison between both travel directions –Left-Turn and Right-Turn– is included to illustrate the differences of effective radius among different directions and user types.

3.1 Effective Radius

The effective trajectory arcs and their centers for the LT movement of bike users are illustrated in Figure 1a. The black arc and blue center are representative of the actual curve and the colored arcs with their corresponding green centers are demonstrating the effective curve for 25 bike users in that direction. Figure 1b shows a box and whisker plot for both travel directions and type of user. Regarding this, a great dispersion of the effective radius was observed for LT movement. It can be explained by bikelane-side conditions, especially on bike lanes located on the sidewalk, that could impact the behavior of MM users. In this case study, for RT movement, due to the presence of vegetation on the left side of first tangent, users were tending not to violate their lanes, as it could leave them with no space to maneuver in case of encounter maneuvers. Accordingly, cyclists exhibit larger lateral acceleration, role angles, and steering angles comparing to e-scooters [4]. This can explain why e-scooterists had similar patterns regardless of their travel direction.

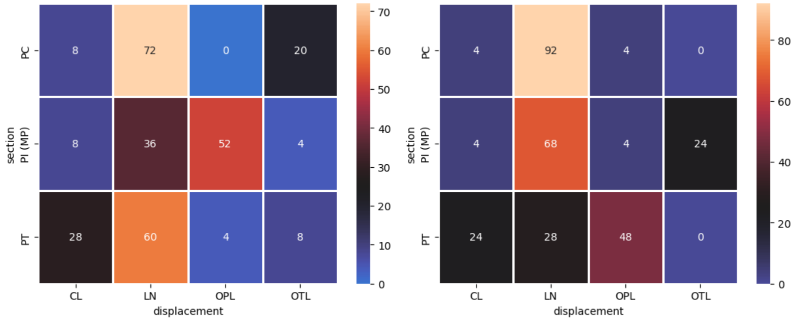


(a) (b)

Figure 1: Effective radius: (a) Cyclists' path and (b) effective radius box and whisker plot

3.2 Lateral Displacement

A heat map is developed from the observed displacement of the MM users with respect to the centerline at each point of interest –PC, MP, and PT– (Figure 2). The resulted displacements were then grouped in four regions of interest: on the center line (CL), within the lane (LN), on the opposite lane (OPL), and outside the bike lane (OTL). To this regard, the highest displacement to the opposite lane in LT direction for bike users was identified at MP (Figure 2a). Nearly 52% of the users violated their dedicated lane as they moved towards the middle of the curve, perhaps to maintain their speed or to avoid pedestrians crossing or walking in the proximity of the bike lane. Nevertheless, in RT direction, the cluster of lateral violation were evident on the PT section (Figure 2b). This could be due to bike lane-side environment and other factors like the presence of pedestrians. Comparatively, for the scooters, a similar pattern was observed with 50% displacement on PT for RT movements, and 83% displacement on MP for the LT movements.



(a) (b)

Figure 2: Lateral displacement for cyclist: (a) LT movement and (b) RT movement

3.3 Speed Analysis

The speed of the users at the points of interest was estimated using tracking capability in Kinovea. The speed data were then used to calculate the 85th and 50th percentile speeds as well as maximum and minimum speed (see Table 1).

Table 1: MM users' speeds expressed in km/h

User	Dir*	Vav	Vmin	Vmax	V85	V50
bike	LT	21	10	33	25	21
bike	RT	20	11	32	26	19
e-scooter	LT	26	9	42	31	24
e-scooter	RT	19	9	32	26	18

The 85th percentile speed, considered as operating speed, was around 25 km/h except of e-scooterists travelling in LT direction. It could lead to an increased severity of potential collisions as this speed is greater that the limit speed. Additionally, an ANOVA test was carried out to determine if there are statistically significant differences between users' speeds. Accordingly, except between e-scooter riders on LT and RT directions, there was no statistically significant difference found. This shows that in terms of speed most users – cyclists and e-scooterists – on this case study followed a similar speed pattern.

4 CONCLUSIONS

The initial results of the case study have stressed out a high risk for head-on and side-angle crashes throughout the arc and exiting tangent. This is due to the fact that a high rate of lane violation pattern was evident inside the arc segment, that in case of mishandling or low sight, could potentially increase the likelihood of conflicts with the users on the opposite lane. The 85th percentile speed results are also illustrative of reduced handling capability for the users who violate their lane and try to avoid potential frontal conflicts. As cyclists do not show statistically significant differences in terms of speed, their behavior is not influenced by the direction of the curve, that is, their maneuverability is higher than that for e-scooterists. The differences in speed for e-scooterists traveling in opposite directions is evident. This could indicate that in right turn movements they feel more confident because they may even move into the lane for the opposite travel direction. However, their confidence seems to be reduced when taking left-hand turns. In this case study, this fact could be influenced by the proximity of the edge of the sidewalk.

REFERENCES

[1] P. Vansteenkiste, G. Cardon, E. D'Hondt, R. Philippaerts, and M. Lenoir, "The visual control of bicycle steering: The effects of speed and path width," *Accid. Anal. Prev.*, vol. 51, pp. 222–227, Mar. 2013, doi: 10.1016/j.aap.2012.11.025.
[2] D. de Waard, F. Westerhuis, and B. Lewis-Evans, "More screen operation than calling: The results of observing cyclists' behaviour while using mobile phones," *Accid. Anal. Prev.*, vol. 76, pp. 42–48, Mar. 2015, doi: 10.1016/j.aap.2015.01.004.
[3] S. Moll, G. López, and A. García, "Analysis of the Influence of Sport Cyclists on Narrow Two-Lane Rural Roads Using Instrumented Bicycles and Microsimulation," *Sustainability*, vol. 13, no. 3, Art. no. 3, Jan. 2021, doi: 10.3390/su13031235.
[4] M. Dozza, A. Violin, and A. Rasch, "A data-driven framework for the safe integration of micro-mobility into the transport system: Comparing bicycles and e-scooters in field trials," *J. Safety Res.*, vol. 81, pp. 67–77, Jun. 2022, doi: 10.1016/j.jsr.2022.01.007.

Understanding Perception of Cycling Safety through Pairwise Image Comparisons

Miguel Costa*,†, Felix Wilhelm Siebert#, Carlos Lima Azevedo#, Manuel Marques†, Filipe Moura*

* Civil Eng. Research and Innovation for Sustainability
Instituto Superior Técnico, Universidade de Lisboa
Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
email: mncosta@isr.tecnico.ulisboa.pt
fmoura@tecnico.ulisboa.pt

†Institute for Systems and Robotics
Instituto Superior Técnico, Universidade de Lisboa
Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
email: manuel@isr.tecnico.ulisboa.pt

Department of Technology, Management, and Economics
Technical University of Denmark
Kgs. Lyngby, 2800, Denmark
email: felix@dtu.dk
climaz@dtu.dk

Keywords: Perception of Cycling Safety, Pairwise Comparisons, Subjective Safety Score, Berlin (Germany).

1 INTRODUCTION

Cycling is critical for cities to transition to more sustainable transport modes. Cycling provides numerous benefits, including short- and long-term health benefits [1]. Yet, safety concerns remain the critical deterrent to cycling [2]-[4]. If cyclists perceive an environment as unsafe, they will prefer other means of transportation.

The perception of cycling safety relates to how individuals subjectively experience cycling accident risk. Current research shows that infrastructure layout, fear of traffic, and distracted cycling influence this perception [5]. Most research focuses on surveys, in-loco, and post-riding interviews to compare factors influencing perceptions [6]. However, these are not scalable due to their inherent high cost (human, time, and money) while providing only a snapshot of the current panorama and cannot be easily redeployed.

In this work, we present a novel approach for analyzing how the built environment and cycling contexts impact cyclists' perception of safety using pairwise comparisons of real-world images. Unlike traditional surveys, pairwise comparisons are straightforward to set up, well suited for non-experts participants, and generally lead to lower measurement error than direct ratings [7]. We create a perceived score for each environment, which we then model to understand and map what built environment characteristics matter the most for individuals' perceptions.

2 METHODOLOGY

2.1 Pairwise Comparisons of Cycling Environments

Inspired by MIT Media Lab's Place Pulse project [8], we use real-world images to survey users about their perceptions of cycling risk. We begin by downloading road environment pictures of Berlin, Germany, from Mapillary (https://www.mapillary.com/), capturing a wide range of infrastructure layouts, urban features, etc. Using an online website, we repeatedly present respondents with two road environment pictures and ask them to select the one they perceive as safer for cycling, as shown in Figure 1. More, we collect data on respondents' cycling profiles (e.g., how they assess standard cycling environments).

2.2 Perception of Risk Scores

While using pairwise comparisons to acquire data on risk perception is straightforward and fast to deploy, it requires more complex methods to attribute a perception of safety score for each image. To convert our image comparisons to a quantitative measurement, we solve a convex optimization problem [9]:

Which environment is SAFER to cycle in?

(Use the buttons bellow to choose which one you find safer)

Figure 1: Pairwise comparison of two road environments in Berlin.

$$
\begin{aligned}
&\min_{x,t} 1^T t + \lambda \sum_{n}^{N_{ties}} |b_n^T x| \\
&s.t. \qquad 1^T x = 0 \\
&\qquad\quad \varepsilon - b_n^T x \ \le t_n \\
&\qquad t_n \ge 0, n = 1, \dots, N
\end{aligned}
\tag{1}
$$

where x is a vector with images perception scores, b_n is a vector depicting each comparison n (taking value 1 for the image that "won" the comparison and -1 for the "losing" one), ε is an error term to be tolerated, λ a "ties" weight, and t_n an additional variable product of linearizing the program. This convex problem accounts for "ties" (images with the same perceived risk) and penalizes scores that violate comparisons. Ultimately, we get a perceived safety score x_i for image i (with higher scores perceived as safer).

2.3 Support Vector Regression

Finally, after quantifying each environment's perceived cycling risk, we fit a ν-SVR [10] to understand what urban characteristics matter most for individuals' perceptions. We extract an extra set of data from each image's location to accomplish this. First, using each image's geographic coordinates, we pull data from OpenStreetMaps about urban features (e.g., the existence of buildings, urban furniture, and type of infrastructure) and urban metrics (e.g., closeness and betweenness). Second, we process the shown images to extract what objects exist in the image [11] (e.g., sidewalk, road, traffic light, cars, trucks, vegetation).

3 RESULTS

In total, and for this work, we focus on a subset of 6759 comparisons from 231 respondents (3.02 average comparisons per image). Regarding cycling typology, 52% of respondents were classified as *Interested but Concerned,* 38% as *Confident and Enthused*, 4% as *Strong and Fearless*, and 6% as *No Way, No How* [12].

Figures 2 and 3 show the perceived cycling risk score for Berlin's environments. Environments scoring lower perceived safety (Figure 2, left and middle) contain a partly visible car close to the camera's viewpoint, indicating potential danger. Conversely, the perceived safer image shows a cycle lane with ample vegetation.

Figure 2: Perceived cycling safety scores for three of Berlin's environments.

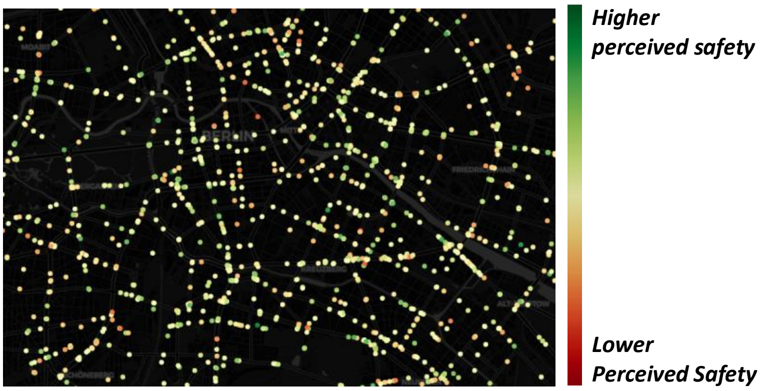


Figure 3: Perceived cycling safety scores in Berlin.

To understand what environmental features contribute to a higher or lower sense of risk, we fit a SVR using urban context data and the estimated perceived scores. We achieve a $R^2 = 0.89$, showcasing its low error. A mix of urban characteristics seems highly important when predicting perceived safety, including presence of cycleways and sidewalks, traffic lights, cycling betweenness, and residential and commercial land use.

4 CONCLUSIONS

This work explores a new framework to assess cyclists' perceived safety using pairwise comparisons of real-world environments. Results highlight this framework's potential to understand people's perceptions. We quantify these safety perceptions and establish a subjective safety score, which we then use to understand what characteristics impact cyclists' perceptions. We map these scores and locate areas of Berlin where there is an increase in safety concerns. This has real-life impact, e.g., cycling promotion interventions can use this knowledge to better target individuals' needs, thereby improving the effectiveness of such interventions. Furthermore, this approach facilitates the continuous assessment of evolving cycling environments. In the future, we plan on using the same method to study individuals' perceptions in other cities. We intend to compare the obtained results and test if there is a shared layer of subjectivity across cities.

REFERENCES

[1] T. Götschi, J. Garrard, B. Giles-Corti, "Cycling as a part of daily life: a review of health perspectives," *Transp Reviews*, 36.1, 2016, 45-71.
[2] R. Félix, F. Moura, K. J. Clifton, "Maturing urban cycling: Comparing barriers and motivators to bicycle of cyclists and non-cyclists in Lisbon, Portugal." *Journal of Transport & Health*, 2019
[3] A. R. Lawson, V. Pakrashi, B. Ghosh, W. Y. Szeto, "Perception of safety of cyclists in Dublin City." *Accident Anal Prev,* 50, 2013, 499-511.
[4] R. Aldred, and S. Crosweller, "Investigating the rates and impacts of near misses and related incidents among UK cyclists," *Journal of Transport & Health*, 2.3, 2015, 379-393.
[5] E. Heinen, B. Van Wee, K. Maat, "Commuting by bicycle: an overview of the literature," *Transp Reviews*, 2010.
[6] R. L. Sanders, "Perceived traffic risk for cyclists: The impact of near miss and collision experiences." *Accident Anal Prev* 75, 2015, 26-34.
[7] M. Perez-Ortiz, R. K. Mantiuk, "A practical guide and software for analysing pairwise comparison experiments," *arXiv preprint arXiv:1712.03686,* 2017.
[8] N. Naik, J. Philipoom, R. Raskar, C. A. Hidalgo, "Streetscore-Predicting the Perceived safety of one million streetscapes," *CVPR Workshop on Web-scale Vision and Social Media*, 2014.
[9] G. Costa, "City-SAFE: Estimating Urban Safety Perception," *MSc Thesis, Instituto Superior Técnico*, 2019.
[10] A. J. Smola, B. Schölkopf, "A tutorial on support vector regression," *Stats Comp*, 14, 2004, 199-222.
[11] Y. Yuan, X. Chen, J. Wang, "Object-contextual representations for semantic segmentation." *ECCV 2020, Glasgow, UK, Proceedings, Part VI 16, Springer International Publishing*, 2020.
[12] J. Dill, N. McNeil. "Four types of cyclists? Examination of typology for better understanding of bicycling behavior and potential." *Transportation Research Record* 2387.1, 2013, 129-138.

Shared E-Scooter Crashes and Probe Data Exposure: A Case Study for Nashville, Tennessee

Sameer Aryal[*], **Nitesh Raj Shah**[#], **Christopher R. Cherry**[†]

[*]Graduate Research Assistant in Civil and
Environmental Engineering
University of Tennessee, Knoxville
851 Neyland Drive, 37996, Knoxville, TN, USA
email: saryal2@vols.utk.edu

[#]Postdoctoral Research Engineer
University of North Carolina Highway Safety Research
Center
130 Mason Farm Rd. 27514, Chapel Hill, NC, USA
email: shah@hsrc.unc.edu

[†]Faculty of Civil and Environmental Engineering
University of Tennessee, Knoxville
321 John D. Tickle Building, 851 Neyland Drive, 37996, Knoxville, TN, USA
email: cherry@utk.edu

Keywords: Shared E-scooter, Micromobility, Riding risk, Trip Volume, Transportation safety

1 INTRODUCTION

The use of shared e-scooters has grown rapidly in recent years, making it a popular micromobility option in the US. However, concerns about the safety of this mode of transportation have arisen after several crashes involving e-scooters. In 2019, Nashville banned all electric scooters following a rider's death due to a crash involving an e-scooter and a car. Several studies have examined the relationship between e-scooter usage, accidents, and injuries, all with similar findings after accounting for exposure. The first notable study in Austin showed that during the early stages of the pilot program, there were 2.0 emergency department visits per 10,000 e-scooter trips [1]. Another study over 17 months estimated a slightly higher rate of 2.1 emergency department visits per 10,000 trips, which remained relatively consistent over time [2]. In this study, about 10% of injuries were due to collisions with cars, which suggests an injury rate of approximately 0.2 car-related visits per 10,000 e-scooter trips. Another study focusing solely on car crashes reported a similar rate of 0.26 car-related crashes per 10,000 scooter trips [3].

Furthermore, both studies found that the risk of accidents or injuries at night is roughly twice as high as during the day. Despite these incidents, many micromobility operators and safety researchers have argued that shared micromobility, including e-scooters, can contribute to safer city streets. To address these concerns, researchers have examined the relationship between e-scooter use and crashes.

Investigating patterns of shared e-scooter crashes and identifying factors contributing to these incidents is crucial for enhancing e-scooter safety. This study focuses on the most severe crash types, e-scooter crashes with vehicles. It analyzes an exposure measure, e-scooter vehicle miles traveled, against traffic levels and street type to understand the patterns of shared e-scooter crashes. The goal is to identify high-crash networks (total crashes on corridors) and high-risk networks (disproportionately high crashes controlling for e-scooter exposure).

2 DATA SET

To conduct our study, we utilized two distinct data sets: the Tennessee Integrated Traffic Analysis Network (TITAN) police database, which provided records of motor-vehicle-involved e-scooter crashes in Nashville, Tennessee, between September 2018 and January 2022. E-scooter crashes in that data set are relatively well-coded, and researchers reviewed narrative summaries of all potential e-scooter crashes, ultimately identifying 82 geocoded crashes. The Shared Urban Mobility Device (SUMD) dataset offered link-level information on e-scooter usage in Nashville between September 2018 and February 2020. For the remainder of our study, we obtained e-scooter trip data from Populus Technologies, INC, which curates e-scooter data for Nashville. By combining these two data sets, we were able to establish a comprehensive overview of e-scooter usage patterns and associated crashes in Nashville, Tennessee, and draw meaningful conclusions about the safety implications of shared e-scooter use in this urban setting.

3 METHODS

In this study, we explore statistical differences in the crash rate (crashes per 100,000 e-scooter miles traveled) for different street types with the e-scooter trips as the exposure variable. To analyze the data, we will employ various statistical methods, including negative binomial regression, to model the relationship between the dependent and independent variables. We will conduct statistical tests to determine if there are significant differences in the crash rate for different street types with varying levels of vehicle and e-scooter trip volume.

To further understand the relationship between e-scooter crashes and urban infrastructure, we will conduct a similar analysis using the Census Tracts. Each census tract will be cataloged based on its street density and intersection density, and then use a negative binomial model to explore the statistical difference in crash rates. This analysis will help us determine if the street and intersection density impact the crash rate and the vehicle miles traveled for e-scooters.

In addition to negative binomial regression, we will utilize other statistical techniques, such as clustering and classification, to identify patterns and trends in the data. By identifying the underlying factors contributing to e-scooter crashes, we can develop strategies for reducing the number of accidents and improving public safety. Our study aims to understand better the complex relationship between e-scooter crashes and urban infrastructure. By analyzing data from multiple sources and utilizing various statistical methods, we hope to gain insights into the factors contributing to these accidents and ultimately improve the safety of urban streets for e-scooter riders and the general public.

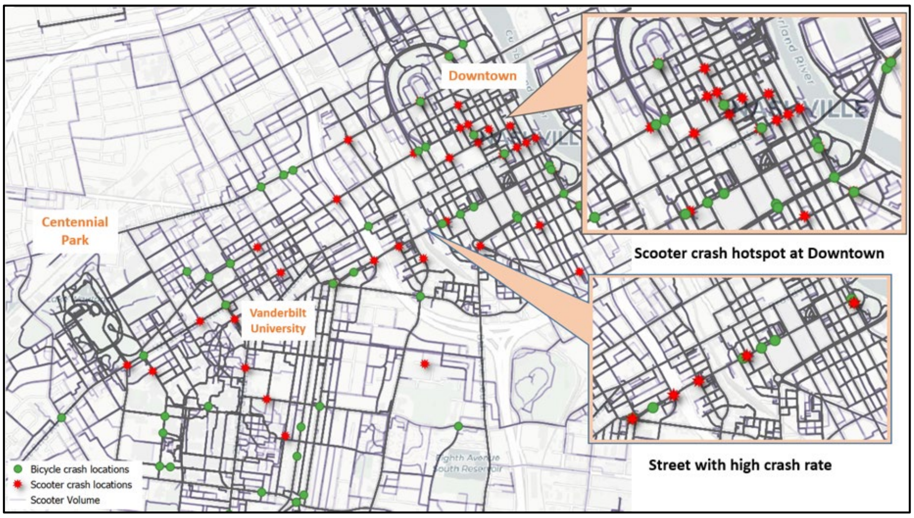


Figure 1: Locations of crashes involving e-scooters and bicycles on streets in Nashville and the volume of e-scooters on those streets.

4 CONCLUSIONS

This research comprehensively analyzes e-scooter crashes in different street types, considering the e-scooter miles traveled in each street section as an exposure metric. We also examine specific street sections to understand crash patterns in high-risk environments better. Our study sheds light on the complex interplay between e-scooter usage, vehicle use, and crashes, highlighting the importance of targeted interventions to improve road safety for all individuals.

REFERENCES

1. Hayden, S. and R. Spillar, *Dockless electric Scooter-Related injuries study.* Austin Public Health, 2019.
2. Williams, C., et al., *Incidence of emergency department visits for electric rental scooters using detailed ridership data.* Western journal of emergency medicine, 2022. **23**(2): p. 174.
3. Shah, N.R. and C.R. Cherry, *The Chance of Getting Struck by a Car on an e-Scooter is Twice as High at Night.* Findings, 2022.
4. Azimian, A. and J. Jiao, *Modeling factors contributing to dockless e-scooter injury accidents in Austin, Texas.* Traffic injury prevention, 2022. **23**(2): p. 107-111.

Safe and Risky Behaviours of Group Cyclists

O. M. Heeremans*, E. M. Rubie*, O. Oviedo-Trespalacios#

* Centre for Accident Research and Road Safety - Queensland
Queensland University of Technology (QUT)
130 Victoria Park Road, Kelvin Grove 4059, Australia
email: olaf.heeremans@qut.edu.au

#Department of Values, Technology and Innovation
Faculty of Technology, Policy and Innovation
Delft University of Technology
Mekelweg 5, 2628 CC Delft, Netherlands
email: ooviedot@gmail.com

Keywords: peloton, group cycling, team behaviour.

1 INTRODUCTION

Cycling in a peloton or group is popular in many countries, including low cycling countries such as Australia. The literature shows that there are many potential benefits to riding in a group such as heightened personal security, easy wayfinding, increased visibility for motor vehicles controllers, and social enjoyment (Heeremans et al., 2022). Despite these benefits and popularity, the road safety aspects of group riding are not well researched (Fraser & Meuleners 2020).

In low cycling countries, the main safety challenge that cyclists face is sharing space with motor vehicles (Fishman et al., 2012). Group cyclists share that safety challenge with individual cyclists, however, group cyclists also face unique challenges due to riding closely to each other, the larger space taken up on roadways, potentially higher speeds, and social norms that could increase risky behaviours (Heeremans et al., 2022). The aim of this paper is to increase understanding of the unique safety challenges faced by group cyclists, what behaviours group cyclists perform in response to these safety challenges, how group cyclists learn these safety behaviours and to increase knowledge of the unique road safety attributes of group cycling.

2 THEORETICAL FRAMEWORK

When studying groups, examination of individual behaviours alone does not allow an understanding of group behaviours as decisions are made as a unit and solutions to group problems are group solutions, not individual ones (Cooke, 2015). This current study therefore applies a Human Factors lens and uses a teamwork theory, the model of team effectiveness to increase understanding of the interconnectedness of the riders. The model of team effectiveness includes eight teamwork factors: leadership (direct and coordinate the team), mutual performance monitoring (monitoring team-mate performance), backup behaviour (anticipate needs of team-mates), adaptability (adjust behaviour to conditions), team orientation (team goals over individual goals), shared mental models (shared understanding), mutual trust (trust that team-mates perform their roles and protect each other), and closed-loop communication (communication that is acknowledged) (Salas et al., 2005).

3 METHOD

The qualitative study explained in this paper uses a deductive exploratory approach through in-depth semi structured interviews of experienced amateur sports group cyclists about group cycling. Interview questions were created using the eight factors of the model of team effectiveness. The data was analysed using a thematic analysis methodology underpinned by an understanding of human factors and teamwork.

The research captures the experience of twelve Australian based sports cyclists. Participants were recruited and interviewed in person. Female participants were purposively recruited as previous research suggest that females may be more likely to ride in groups than alone in a low cycling country (Beecham & Wood 2014). Due to the use of the model of team effectiveness as the theoretical framework, semi-structured interviews were chosen to allow space for unanticipated views and ideas while addressing the main areas of interest with all participants. Pre-prepared questions covered the features and experience of riding in groups, safety benefits and challenges and what can be done to make group cycling safer. Interviews were audio recorded and orthographically transcribed. As the model of team effectiveness was the theoretical framework, Thematic Analysis was used to understand participant's experience. As themes were pre-determined, coding of sub themes was conducted.

4 RESULTS

4.1 Shared mental models

One of the main motivations for riding with others was a perceived increase in safety. Every participant stated they were safer riding in a group. When asked details about why they felt safer important sub codes were found: participants did not just think they were more visible in a group but felt that the group made it impossible for them be ignored, that the group had a presence and that traffic as a whole respected them, even if individual motor vehicle controllers may become angry.

All participants understood the need for shared language and the importance of the informal rules that govern group safety behaviours. Different participants learned the 'rules' in different ways. Female participants were more likely to have learned how to group ride through more formal ways such as through a bicycle club, reading about group cycling or seeking assistance from experienced riders they knew to help them learn before they started group riding. The males were more likely to "just turn up" and start riding in a group, but they were often grateful that other riders had gone out of their way to help them learn.

4.2 Back-up behaviours

Nearly all participants also mentioned back up behaviours: if there was an incident, or even a flat tyre at least some in the group would stop and help, you were never left on your own in a dangerous situation. Female participants were more likely to mention heightened security. They were more likely to feel safe riding at night or in isolated places with a group.

4.3 Mutual trust

Participants talked about the importance of trusting their fellow riders, when riding so close to each other it is important that each group member rides in a safe manner. Indeed a number of the participants talked about what they did when they found themselves behind a rider who's safety behaviours were less than optimal, such as shifting themselves behind a safer rider or even leaving the group if they felt safety behaviours were not acceptable.

4.4 Adaptability

Many participants described how the group worked with traffic such as moving to a single file formation when the group thinks it is safer to do so. Circumstances participants mentioned included when the road narrowed or sight distance was compromised by the road configuration.

5 DISCUSSION

The study explained in this paper explored the experiences of amateur sports group cyclists and their views of the safety challenges and benefits of riding in groups and related safe and risky behaviours. The Model of Team Effectiveness was found to be a useful theoretical framework as found previously by Heeremans et al., (2022) to categorise group cycling safety behaviours and explore the unique challenges and benefits of group cycling. The safety focus and informal team structure of group cyclists revealed by these interviews may inform transport system improvements that in turn increase cyclist safety.

6 CONCLUSION

As found previously by Aldred and Jungnickel (2012), the participants in this study held a large store of knowledge that they use to ensure they are safe when riding in groups. The participants took safety very seriously. Indeed, a feeling of increased safety was a main motivator for riding in a group. This study makes a unique contribution to literature as group cycling and the unique safety challenges and safety behaviours have received little prior attention. Given that the rules that govern group cycling are informal, and they are learned in different ways, the knowledge created by this paper could help inform interventions to ensure that group cyclists learn the correct behaviours, but it might also be that cyclists who do not ride in groups may benefit from group riding to decrease crash risk when riders find themselves in 'accidental groups'.

REFERENCES

[1] O. Heeremans, E. Rubie, M. King and O. Oviedo-Trespalacios, "Group cycling behaviours: A systematic review", *Transportation Research Part F: Traffic Psychology and Behaviour* 91 (2022), pp. 26-44.
[2] M.L. Fraser, L.B. Meuleners, "Characteristics of unsafe events involving a motor vehicle for group riders in Western Australia: A naturalistic study", *Transportation Research Part F: Traffic Psychology and Behaviour*, 74 (2020), pp. 40-51.
[3] Fishman, E., Washington, S., & Haworth, N. "Understanding the fear of bicycle riding in Australia". *Journal of the Australasian College of Road Safety*, 23(3) (2012).
[4] N.J. Cooke, "Team Cognition as Interaction", *Current Directions in Psychological Science*., 24 (6) (2015), pp. 415-419.
[5] E. Salas, D.E. Sims, C.S. Burke, "Is there a "Big Five" in Teamwork?", *Small Group Research*, 36 (5) (2005), pp. 555-599.
[6] R. Beecham, J. Wood, "Characterising group-cycling journeys using interactive graphics", *Transportation Research Part C: Emerging Technologies*, 47 (2014), pp. 194-206.
[7] Aldred, R., & Jungnickel, K. "Constructing Mobile Places between 'Leisure' and 'Transport': A Case Study of Two Group Cycle Rides". *Sociology*, 46(3) (2012), 523–539.

Evaluation of the trial of smart bicycle lights

H. Alavi*, D. Young#, H. Reddan#, J. Johnson#, N. Haworth†

* HA Consulting
Victoria St, Brunswick Victoria 3056, Australia
email: hafez.alavi@haconsulting.com.au

Transport Accident Commission (TAC)
Brougham St, Geelong 3220, Australia
email: David_Young@tac.vic.gov.au,
Helen_Reddan@tac.vic.gov.au;
Jake_Johnson@tac.vic.gov.au

†Centre for Accident Research and Road Safety - Queensland
Queensland University of Technology (QUT)
130 Victoria Park Road, Kelvin Grove 4059, Australia
email: n.haworth@qut.edu.au

Keywords: bicycle lighting, visibility, template, final symposium paper, formatting instructions.

1 INTRODUCTION

The role of active travel is becoming more prominent and crucial as the adverse consequences of a chiefly vehicle-based transport system manifest themselves. From serious road trauma, social life disruptions and negative impacts on the lives of children, the elderly and other more vulnerable community members to climate and environment degradation and societal costs due to noise, pollution and public health deterioration, active travel is shown to offer an effective, democratic, and sustainable solution. Cycling and the provision of safe, convenient bicycle infrastructure and technology play a crucial part in this emerging picture. Technology is playing a more and more defining and definitive role in cycling mobility and cyclist safety. Therefore, there is a need to investigate innovative methods and technologies to improve cyclist safety and mobility.

In 2021, the Transport Accident Commission (TAC) launched the Light Insights Trial (LiT) to investigate the role and potentials of innovative bicycle light technology to increase cycling and enhance cyclist safety in Victoria, Australia. LiT was a 12-month trial which enlist a diverse group of 800 cyclists to use a See.Sense smart bicycle light (described in [1] and shown in Figure 1) The technology gathers data such as crash events, near miss incidents, abrupt acceleration and deceleration, swerving, road conditions, average speeds, dwell time and rider feedback. The light operates in tandem with a smartphone app, which transmits data, while additional safety features include a brighter flash in high-risk situations, such as intersections, and when riders brake. The trial participants (the triallists) were offered vouchers to contribute to their purchase of See.Sense bicycle light products, and a variety of products were purchased by the triallists. The cyclists recorded their data via the See.Sense app, providing a baseline of cyclist data and increased understanding of cycling behaviour. The trial aimed to inform policy and strategy and increase awareness of cycling as an alternative safe mode. An overview of the trial is provided in Figure 2.

TAC offered road safety expertise and partial funding and led the trial's delivery and evaluation. See.Sense provided industry expertise and technology support, Deakin University was the research partner and partial funder, and the iMOVE Cooperative Research Centre provided partial funding. Painted Dog conducted behavioural research and qualitative stakeholder interviews. Bicycle Network Victoria, the Amy Gillett Foundation, and Aus Cycling advocated for the trial and promoted it to their members and databases. The researchers, local governments, and other stakeholders were regularly invited to attend the trial's events, including webinars.

Figure 1: The See.Sense smart bicycle light

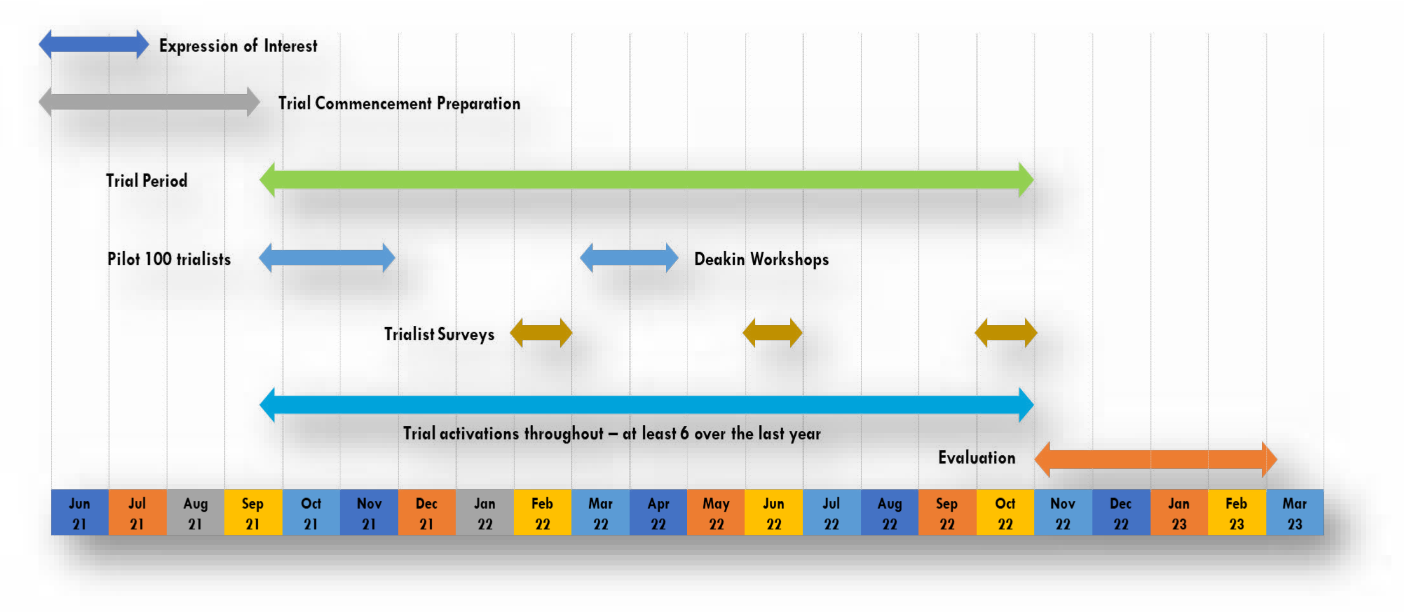


Figure 2: An overview of the Trial

2 EVALUATION METHOD

The evaluation comprised a) literature/document review, b) social and transport research findings review, c) in-depth interviews with some subject matter experts (SMEs) and technical experts, and d) technical workshopping of future options with TAC and some SMEs.

During the literature and document review phase, trial inception, planning, implementation and reporting/presentation document were collected from TAC and other online sources. These documents were used in conjunction with ongoing project meetings with TAC (and in-depth interviews and the trial engagement events such as stakeholder webinars) to build a clear picture of LiT's background, objectives, logic map, key stakeholders, and the schedule of key trial events. TAC engaged Painted Dog Research to understand perceptions from both trialists and stakeholders with regards to a) the extent to which LiT's objectives were understood and met, and b) how these social research findings could inform the decision-making process about the future of the trial.

Deakin University carried out several research activities to:

1. develop a data storage and management system suitable for the LiT trial
2. examine approaches for data analysis to consider individual privacy and security while still providing specific road safety insights
3. develop methods for data analysis as well as a reporting tool for effective communication of information and insights derived from the collected data.

3 RESULTS

3.1 Social research findings

Some results of the June online survey of trialists' perceptions showed that:

- ~60% male, 75% 30-60 yo, ~90% ride at least once a week, 50% prefer dedicated bike lanes, +70% record often or always
- Key barriers to recording: forgetting to, Bluetooth connection, multiple bikes, difficulty using the app
- Motivation to continue: contribute to better cycling safety and planning, safer riding and their commitments to the trial
- 80% are satisfied with the experience – light quality and duration
- +90% are enthusiastic to remain a contributing member
- ~60% said contributing to safer cycling is their main purpose of the trial.

The qualitative surveys of the perceptions and expectations of some key stakeholders revealed and overall positive perception of the trial in terms of its safety impact, increase in cycling, new technology assessment and robustness of the trial (operation, trialist numbers and methodology).

3.2 Cycling data collected

LiT was able to build a cyclist-specific dataset that could be potentially used to inform future strategies, investments, policies, and planning/design. The dataset includes data on the purpose of cycling trips, demographic characteristics of cyclists, type of bicycle, safety and mobility indicators, and the time, length, origin-destination and routes of the captured cycling trips. The trial data could also inform policy and strategy areas such as speed management, cycling promotion, bicycle infrastructure mandates, geofencing, and policies related to bicycle type and e-bikes.

4 CONCLUSIONS

The evaluation of the LiT found that the trial successfully established a network of committed and activated cyclists and served as a new stakeholder engagement avenue to reach out to the cycling community. The trial also provided valuable insights into cyclist demographics, riding behaviour, attitudes towards safety, technology, and road infrastructure, and cyclist crashes.

REFERENCES

[1] See.Sense website. https://seesense.cc/blogs/hub/everything-you-need-to-know-about-connected-bike-lights

Implicit Communication between Cyclists and Turning Automated Vehicles – A Low-Level Simulator Study

A. M. Harkin*, A. Mangold*, K. A. Harkin*, T. Petzoldt*

* Chair of Traffic and Transportation Psychology
University of Technology Dresden
Hettnerstr. 1-3, 01069, Dresden, Germany
email: anna_marie.harkin@tu-dresden.de

Keywords: Automated vehicle, cyclist, implicit communication, turning maneuver, low-level simulator.

1 INTRODUCTION

The integration of automated vehicles (AVs) into mixed traffic necessitates human-machine interaction. Vulnerable road users such as pedestrians and cyclists may not be able to communicate explicitly via gestures or eye contact, because there is no attentive driver anymore. This communication gap can be relevant in the context of cycling, which is simultaneously viewed as safety-critical [1] and promoted as a sustainable and healthy mode of mobility [2]. The potential disruption of established communication forms could not only raise safety concerns but also diminish the utilization of cycling as a mode of transportation. Hence, research into the communication processes between cyclists and AVs or manually-driven vehicles (MV) is needed to ensure objectively and subjectively safe interactions. In the context of pedestrian-AV interaction implicit communication, e.g., behavior such as slowing down before a pedestrian crossing, is considered an important determinant in interaction evaluation [e.g., 3–5]. However, research on cyclists remains limited and sometimes contradicting. For example, findings on the influence of automation status on cyclists' interaction evaluation are mixed. While results of a photo experiment [6] and VR study [7] revealed that the automated driving status of the interacting vehicle had little effect on the cyclist's behavior, another video-based study showed that cyclists tended to slow down when encountering AVs [8]. Results of the rare studies that look at implicit communication (e.g. driving dynamics or gap distances) between AVs and cyclists are consistent with findings in pedestrian studies. Implicit communication plays a crucial role in cyclists' decision-making processes [e.g., 7, 9]. However, such communication, especially via driving dynamics, can be ambiguous. For instance, vehicle turning implies deceleration, even if the vehicle does not come to a halt for a cyclist. Recently, research has shown that from a pedestrian's static perspective, a correct assessment of the vehicle/driver's intention is possible, even when the vehicle/driver only decelerates to make an appropriate turn [3]. This study aims to address the question of whether such assessments are also feasible for cyclists driving on a street. Specifically, the study explores the effects of automation status and driving dynamics of a left-turning vehicle on the perceived safety, intention to continue cycling, and brake anticipation of cyclists proceeding straight ahead. To accomplish this, a low-level simulator experiment was conducted.

2 METHOD

49 participants were recruited, but five were excluded for riding a bicycle less than once a week and two could not complete the experiment due to technical problems. Therefore, a total of 42 people participated (23 female, 19 male) aged between 18 and 73 years (*M* = 33.79, *SD* = 15.69). Participants were seated on a bicycle and watched videos, that were displayed on a large screen (102x198 cm) using a projector (EPSON EB-1795F). The videos depicted a vehicle approaching an intersection and intending to turn left into a road, while the cyclist was heading straight across this road (Figure 1). The interacting vehicle was either an AV (without a driver and indicated by a cyan-colored LED band) or an MV and approached the intersection with different driving dynamics. The driving dynamics (Figure 2) were derived from natural driving behavior (according to [10]) and were classified into three categories: active yielding, passive yielding, and no yielding.

These dynamics differ in the time advantage or disadvantage that the vehicle has compared to the cyclist when reaching the potential collision point. While passive yielding exhibits a continuous deceleration, active yielding shows a more pronounced but later braking, and no yielding proceeds through the intersection ahead of the bicycle. Additionally, a fourth variant was included in which a collision occurred (collision), resulting in a total of eight different videos (2x4 within-subjects design), which were presented twice. Following each video, participants were asked to rate their experience in terms of their perceived safety and intention to continue cycling. The video stopped automatically 0.5 s before the cyclists would reach a conflict point. Additionally, they could stop the video by pressing the right brake lever (braking time). The time at which the participants touched the brake lever (brake anticipation time) was recorded.

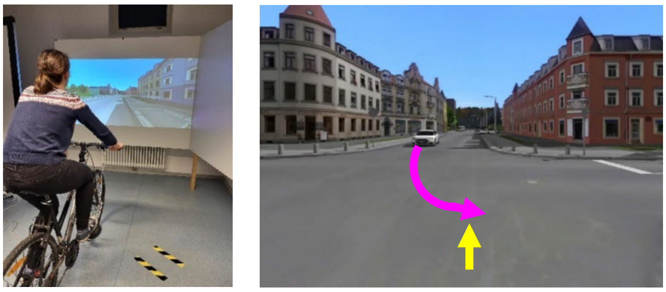


Figure 1: Study set-up (left) and screenshot from one of the videos (right)

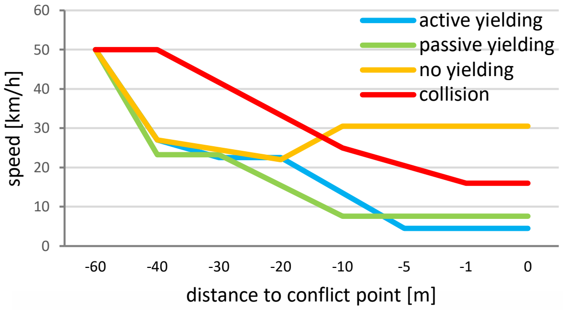


Figure 2: Speed profiles of the different driving dynamics.

3 RESULTS

The dependent variables were analyzed using general estimation equations (GEEs). The odds ratio (OR) was used to describe the influence of the independent variables and control variables (gender, trial order) on the odds of perceiving the situation as safer and anticipating the need to brake. Main effects of driving dynamics were revealed (Figure 3 and Figure 4). People perceived passive yielding as safer compared to all other types of driving dynamics. While active yielding was perceived as safer than collision, there was no difference from no yielding. Still, no yielding was perceived as safer than collision. Given that some participants did not exhibit any brake anticipation (BA) in some of the trials, the study investigated the occurrence of reaching for the brake at all. GEE analysis revealed that the BA occurrence was lower for passive yielding than for any other driving dynamic. Additionally, participants showed a lower BA occurrence when confronted with active yielding than collision. The automation status did not affect perceived safety (*p* = .163) or BA occurrence (*p* = .560). There were no interaction effects between the automation status and driving dynamics.

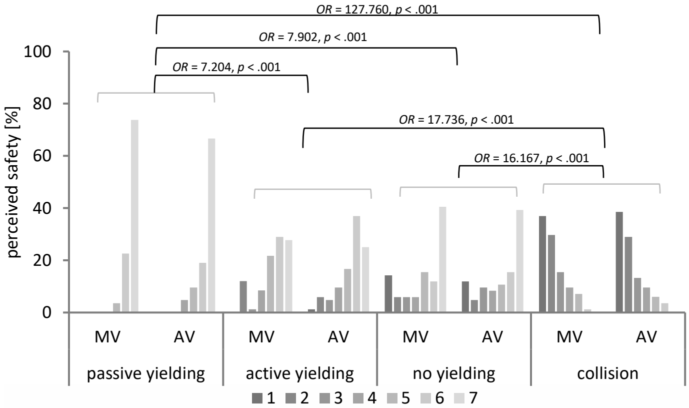


Figure 3: Perceived safety (question "How safe would you feel if you would continue cycling at this moment?", answers on a 7-point Likert scale from 1 (not safe) to 7 (safe)), separated by automation status, and driving dynamics.

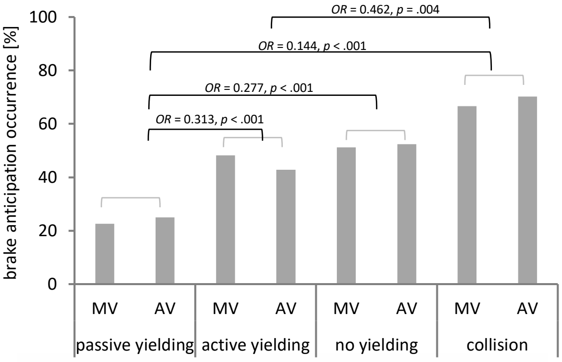


Figure 1: Brake anticipation occurrence, separated by automation status, and driving dynamics.

4 DISCUSSION AND CONCLUSION

The results indicate that cyclists base their decisions to cross an intersection on the driving dynamics of the oncoming turning vehicle. Although all four driving dynamics include deceleration, either for turning or stopping, participants were able to assess them accurately. In particular, continuous and early braking (passive yielding) lead to a higher perceived safety, which was reflected in a lower BA occurrence. It appeared to be irrelevant whether the vehicle brakes more pronouncedly but later (active yielding) or accelerates to cross the intersection ahead of the cyclist (no yielding). No yielding was perceived as safer than the collision dynamic, but participants still anticipated braking at the same rate. This is likely because the objective safety of the no yielding dynamic is recognized later. The automation status appears to not influence the participants' evaluations or behavior. Further investigation of the data is needed to find out how the results are affected by braking time or if there are any observable effects on brake anticipation time.

In conclusion, driving dynamics derived from real human behavior are a good starting point to model AV behavior. It is especially worth considering more complex movement patterns of vehicles, as in the present case. Even differences between decelerating to turn and decelerating to stop can influence the assessment of cyclists´ safety and their behavior.

5 REFERENCES

[1] European Commission, *Road safety in the European Union, trends, statistics and main challenges*. Luxembourg: Publications Office of the European Union, 2018. [Online]. Available: https://road-safety.transport.ec.europa.eu/system/files/2021-07/vademecum_2018.pdf

[2] OECD/International Transport Forum, *Cycling, Health and Safety*: OECD Publishing/ITF, 2013. [Online]. Available: http://dx.doi.org/10.1787/9789282105955-en

[3] A. M. Harkin, K. A. Harkin, and T. Petzoldt, *What to Rely on - Implicit Communication between Pedestrians and Turning Automated Vehicles*, unpublished.

[4] C. Ackermann, M. Beggiato, L.-F. Bluhm, A. Löw, and J. F. Krems, “Deceleration parameters and their applicability as informal communication signal between pedestrians and automated vehicles,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 62, pp. 757–768, 2019, doi: 10.1016/j.trf.2019.03.006.

[5] X. Kong, S. Das, Y. Zhang, and X. Xiao, “Lessons learned from pedestrian-driver communication and yielding patterns,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 79, pp. 35–48, 2021, doi: 10.1016/j.trf.2021.03.011.

[6] M. P. Hagenzieker *et al.,* “Interactions between cyclists and automated vehicles: Results of a photo experiment *,” *Journal of Transportation Safety & Security*, vol. 12, no. 1, pp. 94–115, 2020, doi: 10.1080/19439962.2019.1591556.

[7] J. P. Nuñez Velasco, A. de Vries, H. Farah, B. van Arem, and M. P. Hagenzieker, “Cyclists’ Crossing Intentions When Interacting with Automated Vehicles: A Virtual Reality Study,” *Information*, vol. 12, no. 1, p. 7, 2021, doi: 10.3390/info12010007.

[8] W. Vlakveld, S. van der Kint, and M. P. Hagenzieker, “Cyclists’ intentions to yield for automated cars at intersections when they have right of way: Results of an experiment using high-quality video animations,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 71, pp. 288–307, 2020, doi: 10.1016/j.trf.2020.04.012.

[9] P. Bazilinskyy, D. Dodou, Y. B. Eisma, W. Vlakveld, and J. de Winter, “Blinded windows and empty driver seats: The effects of automated vehicle characteristics on cyclists’ decision-making,” *IET Intelligent Transport Systems*, vol. 17, no. 1, pp. 72–84, 2023, doi: 10.1049/itr2.12235.

[10] M. Zhang, M. Dotzauer, and C. Schießl, “Analysis of Implicit Communication of Motorists and Cyclists in Intersection Using Video and Trajectory Data,” *Frontiers in psychology*, vol. 13, p. 864488, 2022, doi: 10.3389/fpsyg.2022.864488.

Keep Me Safe - Evaluating the Safety Perception of Different Bicycle Facilities

Tanja Stoll[*], **Désirée Hagmann**[#], **Markus Hackenfort**[†]

[*]Human Factors Psychology
ZHAW
Pfingstweidstrasse 96, 8005, Zurich, Switzerland
email: tanja.stoll@zhaw.ch

[#] Human Factors Psychology
ZHAW
Pfingstweidstrasse 96, 8005, Zurich, Switzerland
email: Desiree.hagmann@zhaw.ch

[†]Human Factors Psychology
ZHAW
Pfingstweidstrasse 96, 8005, Zurich, Switzerland
email: Markus.hackenfort@zhaw.ch

Keywords: traffic safety, bicycle lane, safety perception

1 INTRODUCTION

Bicycle traffic represents a central aspect of inner-city traffic of the present and future. Less air and noise pollution and less traffic congestions compared to car use are some of the benefits [1,2]. Therefore, the traffic safety of cyclists is becoming a more critical issue in traffic planning. In general, bicycle facilities can be separated into different groups: (1) bicycle paths, which are exclusive for bicycles and pedestrians; (2) bicycle tracks – adjacent to roadways – that are physically separated from vehicular traffic and exclusively for bicycle use; and (3) bicycle lanes, which are on-road space intended for bicycle use and indicated by painted marking [3]. While bicycle paths are often described as the gold standard for safety, they could pose a challenge to city road authorities because of the limited available space. Regarding bicycle tracks and lanes, mainly at conflictive road sections, the discussion arises about whether a structural separation between the bicyclists and the vehicular traffic improves traffic safety as well as the safety perception compared to a design which separates the groups by painted marking.

Therefore, the question of safety perception was investigated on a street in Zurich (Switzerland) with a high level of conflict for cyclists by implementing three different forms of bicycle facilities which either separated the bicycles from vehicular traffic physically or by painted marking.

2 METHODS

Bicyclists were surveyed before as well as after each implemented modification regarding their general safety perception as well as their safety perception at the road in question. Furthermore, it was determined whether demographic factors influence the safety perception.

The survey periods were between May and July 2022.

2.1 Setting

Figure 1 shows the original bike lane (Fig. 1.1) and the three different modifications that were implemented. Vehicles entering the parking lot of a shopping mall must cross the bike lane, thus constituting a point of conflict. Bicycles have the right of way but are overlooked by some drivers.

In a fist modification the implication of solid yellow lines was showing drivers where it is forbidden to enter the bike lane (Fig. 1.2). In a second modification round speed bumps were added (Fig. 1.3) and finally, a structural separation with guide beacons makes it impossible for cars to enter the bike lane without impacting the guide beacons.

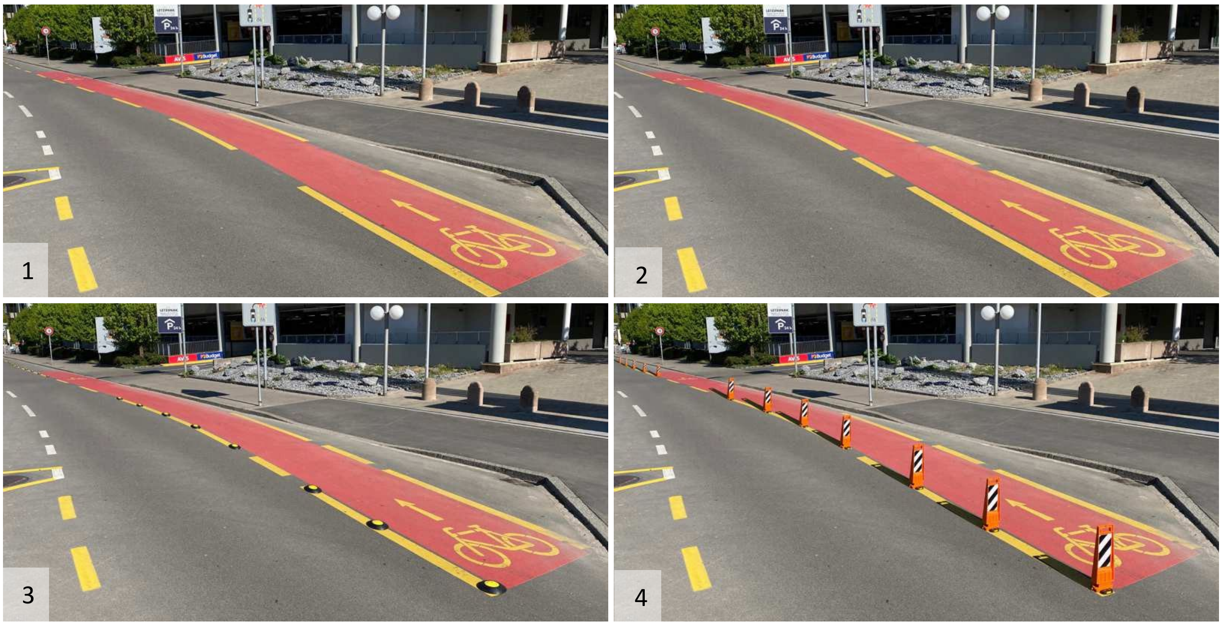


Figure 1: The (1) original colored bicycle lane was supplemented by (2) a protective lane, (3) individual round speed bumps that allows to ride over them, and (4) a structural separation with guide beacons that do not allow cyclists and cars to ride over them.

2.2 Participants

Table 1 shows the demographics of the interviewed bicyclists. Both drivers of traditional and e-bikes were interviewed. Every interview took about three minutes.

Table 1: Sample of interviewed bicyclists

Trial	***n***	**who rides daily**	**E-Bike usage**
Colored bike lane	96 (35% f, 64% m, 1% n.s.)	75%	31%
Protective lane	124 (33% f, 67% m)	73%	28%
Round speed bumps	112 (45% f, 55% m)	68%	31%
Structural separation	117 (32% f, 62% m, 6% n. s.)	76%	22%

F= female; m = male; n.s. = not specified

2.3 Procedure

Since bicyclists were interviewed spontaneously, the interview was kept as short as possible. First, participants were asked about their demographics before they were asked about the frequency of bicycle usage, if they were using an e-bike or a traditional bicycle, their general safety perception as a bicyclist in Zurich, their familiarity with this specific crossing and if they experienced a conflict there before. Finally, they were asked about their safety perception of the current and of the other three modifications on a six-point Likert scale. To better assess the modifications that currently were not in place, pictures were presented to the participants.

3 RESULTS

A one-way ANOVA was carried out to investigate if the safety perception is different between the original design and the three modifications. Significant differences were found regarding the safety perception between the implemented measures (F (2, 440) = 3.861, p < .001). Post-hoc test revealed a significant difference between the original design (M = 4.68) and individual speed bumps (M = 5.18; p = . 013).

In addition, a linear regression was calculated to investigate if the safety perception was influenced by demographics and other factors (see Table 2). Female gender, high general safety and fewer perceived conflicts were associated with higher safety perception. Age, frequency of bike usage, e-bike usage as well as familiarity with the study area showed no significant influence (see Table 2).

Table 2: Sample of interviewed bicyclists

Coefficients							
				Wald Test			
	Estimation	Standard error	*z*	Wald-Statistic	df	*p*	
Intercept	-2.376	0.855	-2.780	7.727	1	0.005	**
Gender	-0.478	0.229	-2.083	4.339	1	0.037	*
Age	0.110	0.156	0.709	0.503	1	0.478	
Frequency of bike usage	-0.166	0.177	-0.936	0.876	1	0.349	
E-bike Usage	-0.204	0.245	-0.832	0.692	1	0.406	
General Safety Perception in Zurich	0.566	0.105	5.389	29.046	1	< .001	***
Familiarity with the study area	-0.132	0.248	-0.530	0.281	1	0.596	
Perceived conflicts	-1.076	0.267	-4.027	16.219	1	< .001	***
Presented modification	0.287	0.102	2.827	7.991	1	0.005	**

4 DISCUSSION

At the investigated point of conflict, regarding safety perception round speed bumps were preferred over the structural separation or markings on the streets. In the future we want to link the perceived safety of bicyclist with the statistics of near misses and accidents.

REFERENCES

[1] L. Ming Wen and C. Rissel "Inverse associations between cycling to work, public transport, and overweight and obesity: Findings from a population based study in Australia", Preventive Medicine 46 (2008), pp. 29-32

[2] C. Morrison, J. Thompson, M. C. Kondo and Ben Beck," On-road bicycle lane types, roadway characteristics, and risks for bicycle crashes", Accident Analysis & Prevention 123 (2019), pp. 123

[3] J.P. Schepers, P.A. Kroeze , W. Sweers and, J.C. Wüst "Road factors and bicycle–motor vehicle crashes at unsignalized priority intersections", Accident Analysis & Prevention 43 (2011) pp. 853-861

How does an Electrically Propelled Bicycle Trailer influence the driving properties of a Bicycle-Trailer-Combination? – Simulation and Driving Experiments

B. Bourauel[*], P. Seiniger[#], J.Gail[%]

[*]Division of Automotive Engineering
Federal Highway Research Institute of Germany (BASt)
Brüderstraße 53, 51427, Bergisch Gladbach, Germany
email: bourauel@bast.de

[#]Division of Automotive Engineering
Federal Highway Research Institute of Germany (BASt)
Brüderstraße 53, 51427, Bergisch Gladbach, Germany
email: seiniger@bast.de

[%]Division of Automotive Engineering
Federal Highway Research Institute of Germany (BASt)
Brüderstraße 53, 51427, Bergisch Gladbach, Germany
email: gail@bast.de

Keywords: electrically propelled bicycle trailer, electrification, vehicle dynamics, bicycle safety, active safety.

1 INTRODUCTION

Due to the growth of the mobility of cyclists in the last years there are a lot of new technologies in the cycling industry. On the market there are multiple manufacturers who sell bicycles with an integrated electric motor (Pedelecs and E-Bikes), and in the sector of micro mobility e.g. scooters have been electrified. A new idea is not to electrify the bicycle itself, but a trailer that can be attached to the bike by using a normal coupling device. This technology of electrically propelled bicycle trailers has the advantage that the bicyclist can decide by his own to ride a normal bike, if desired with an electrified trailer to carry heavy loads or without a trailer.

Electrically propelled bicycle trailers raise some new questions with regard to vehicle safety because of the possible influence of the additional engine in the trailer to the driving properties of the bicycle-trailer-combination. In this project the goal was to find performance requirements for electrically propelled bike trailers regarding the active vehicle safety of the bicycle-trailer-combination. This aspect has been investigated with theoretical investigations, simulations and driving experiments. To limit the scope of this project only electrically propelled bicycle trailers with a power of up to 250 W and maximum support speed until 25 km/h (in line with German pedelec definitions) have been taken into account.

2 TECHNICAL AND THEORETICAL BASICS

An electrically propelled bike trailer introduces a second driven axle to the combination of bicycle and trailer. So, the most safety critical situation is assumed to be a pushing force from the engine of the electrified trailer that causes an unstable state of the bike-trailer-combination. Yaw and roll rates, the slip angle speed and yaw and roll angles were identified as stability-relevant parameters [1][2].

In general, there are two different types of electrically propelled bike trailers: Those that only overcome their own driving resistances, so that there is no pushing force from the trailer onto the bike ("Pulled Trailers"), and those that propel with more power than is needed to overcome their own driving resistance, so that there is a pushing force that acts from the trailer on to the bike ("Pushing Trailers").

In addition to the control strategy of the motor of the propelled trailer, the following bicycle-trailer-specific parameters are considered in this research project: a high or low drawbar (different leverage in combination with the pushing force), type of coupling, single- or multi-track trailers [3].

3 SIMULATION

A simulation offers the possibility to test safety-critical scenarios, such as what effect a push force caused by the engine of the electrically propelled bike trailer would have on the vehicle dynamics behavior of the combination. Test scenarios were created using the simulation software MotorcycleMaker from IPG in which different push forces (representing different masses of trailers and power of electric engines) and articulation angles between bicycle and bike trailer were introduced (s. Figure 3-1). Also, a braking scenario with a simultaneous push force was investigated.

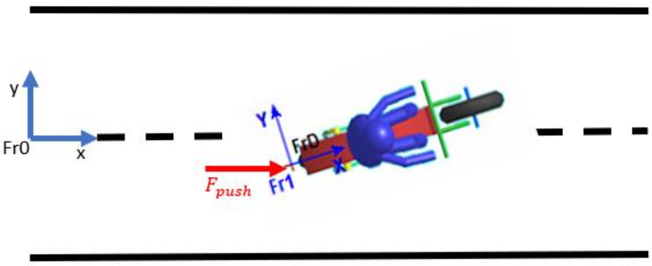


Figure 3-1: Push force model in simulation that represents the force of the engine of the bike trailer.

The simulation results show that a braking scenario with a pushing trailer is the most critical. In order to ensure the safety of the bicyclist in this case, this condition has to be avoided, e.g. by functional safety requirements.

4 DRIVING EXPERIMENTS

Driving experiments were executed with an exemplary electrically propelled two-track, two-axle bicycle trailer. The trailer has a pedal sensor that confirms the bicycle rider is pedaling to ensure there is only support in this case [4]. Movement data of both trailer and bicycle was measured with an Inertial Measurement Unit (IMU), and the trailer brake status with a displacement sensor (s. Figure 4-1).

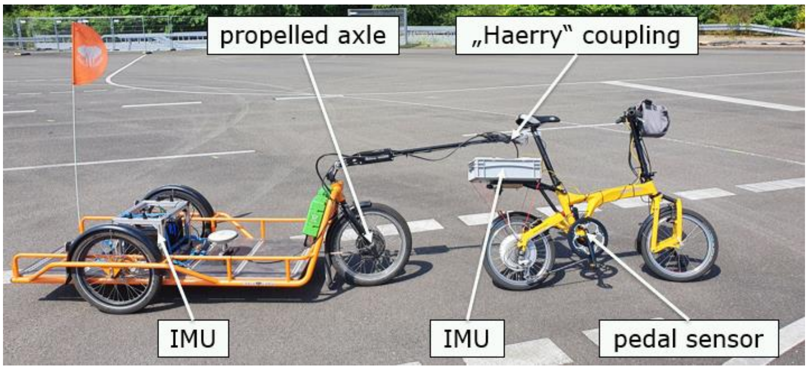


Figure 4-1: Test bicycle with electrically propelled bike trailer equipped with measurement tools.

To compare the vehicle dynamic behavior driving tests were carried out with the trailer engine on and off. Both conditions therefore could be directly compared. Test cases were a lane change maneuver, a stationary constant radius cornering and a braking.

The results (e.g. the yaw rate of bike and trailer in Figure 4-2) do not show any significant change in the vehicle dynamic data, regardless whether the trailer was propelled or non-propelled.

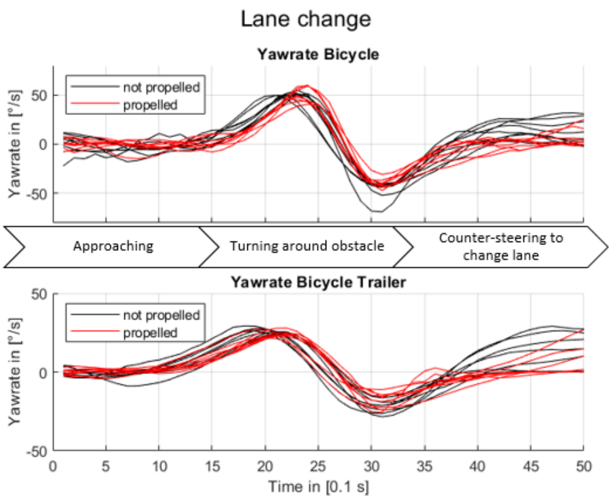


Figure 4-2: Yaw rate in a lane change maneuver. Red: electrically propelled bike trailer. Black: normal bike trailer.

5 CONCLUSIONS

This project analyzed how an electrically propelled bicycle trailer influences the driving behavior of a bicycle-trailer-combination. Theoretical investigations and simulations suggest that critical situations could occur if the trailer actively pushed the towing bicycle, so this condition should be avoided, e.g. by requiring functional safety for those trailers. In driving experiments, an exemplary electrically propelled bike trailer was tested in several scenarios which represented the most critical cases in reality (max. speed with drive support 25 km/h). The results do not show any significant difference with the trailer engine on or off. It is thus assumed that propelled trailers have no negative influence on the driving dynamics of bicycle-trailer-combinations as long as the trailer is not pushing the bicycle.

REFERENCES

[1] P. Seiniger, O. Bartels and M. Bierbach, „Active safety of self-propelled trailers: Proposal for safety requirements“, in *Proceedings of the 27th ESV INTERNATIONCAL CONFERENCE*, Yokohama, Japan, 03-06 April 2023.

[2] P. Seiniger, *Erkennbarkeit und Vermeidbarkeit von ungebremsten Motorrad-Kurvenunfällen*, VDI Verlag, Darmstadt, 2009

[3] DIN EN 15918:2011+A2:2017, *Cycles- Cycle trailers- Safety requirements and test methods; German version*, Beuth-Verlag, Berlin, 2017.

[4] CARLA CARGO Engineering GmbH, *Technical data sheet – eCARLA 03-2023*, 2023, Published online: https://www.carlacargo.de/site/assets/files/2259/2023-datasheet_carla_ecarla_en.pdf

Development of a new zone-based cycling safety metric to determine the crash risk associated with work trips

Mehrnaz Asadi[a,1], **M. Baran Ulak**[a,2], **Karst T. Geurs**[a,3], **Wendy Weijermars**[b]

[a] University of Twente, Department of Civil Engineering, Faculty of Engineering Technology, P.O. Box 217, 7500 AE Enschede, The Netherlands; emails: [1] m.asadi@utwente.nl, [2] m.b.ulak@utwente.nl, [3] k.t.geurs@utwente.nl

[b] SWOV Institute for Road Safety Research, P.O. Box 93113, 2509 AC The Hague, The Netherlands
emails: wendy.weijermars@swov.nl

Keywords: cycling safety, trip-based crash risk, commute trip crash risk, areal level crash risk.

1 INTRODUCTION

Cycling is a healthy, green, and low-cost mode of transport and numerous policies and initiatives are employed for promoting cycling in the Netherlands. Despite various individual and societal advantages of prevalent bicycle use, the increasing number of fatal and severe injury crashes involving cyclists has raised concerns over safety of cyclists. In this regard, past studies have investigated effective environmental and traffic factors on cycling safety. In evaluating the relationships between cycling safety and probable effective factors, accounting for a reliable risk measure is critical.

Exposure and the number of incidences are two important factors in crash risk measurement. Unlike vehicular crash analysis, a common limitation in analyzing cycling crash risk is the availability of extensive bicycle counts as the exposure variable [1]. In the past studies, bicycle counts, bicycle trips, and bicycle-kilometer-traveled are some proxies used as exposure variable (e.g., [1-3]). In this regard, Ding, Sze [1] revealed that application of trip-based exposure variable (expressed in bicycle-kilometer-traveled) resulted in outperformance of cycling safety models. Moreover, new machine learning methods used for prediction of number of crashes [4, 5] have enhanced crash risk estimations. Despite the new ideas developed in cycling safety analysis, past studies have failed to address how cyclists as "travelers" are exposed to traffic crashes along their trips from an origin to a desired destination. Thus, this paper suggests a methodological approach to introduce a trip-based risk index to estimate crash risk associated with specific trip purposes at specific locations. We applied this approach to estimate a trip-based index for crash risk indicating the cost associated with work trips by bicycle in the municipality of Utrecht. This city is known as the best-bicycle-city in the world in 2022 with a 51% cyclists population. This study is focused on postcode-level 5 (PC5) zones in Utrecht and a 5 km buffer area. Various databases including road and cycling network, zonal socioeconomic and demographic chacrteristics, crash data, and Dutch national travel behavior data were used in the analysis.

2 METHODOLOGICAL APPROACH

This paper uses a 4-steps modeling approach coupled with a route choice model and safety model to develop a trip-based crash risk index estimating the potential crash risk associated with work trips between different origins and destinations. The mothodology consists of five main steps as follows.

1) Configuration of OD trip distribution matrix: First, the PC5 zones were assigned as origins and destinations based on landuse and demographic characteristics of the zones. The trip distribution matrix was then generated based on the density of population and number of jobs in the zones.

2) Route choice set generation: We generated choice sets for the OD pairs by minimization of six different impedance factors including *(actual) travel distance*, *travel time*, *number of crossings*, and *perceived* *travel distances.* We considered the perceived travel distances based on three scenarios in which the road types of mixed traffic, suggested cycling road and separated cycling lanes/paths were differently weighted.

3) Assignment of trips on generated routes: The probability of choosing each route among others in the generated route choice set was calculated based on a path-size route choice model for cyclists. This model was developed by Ton, Cats [6] in the municipality of Amsterdam. Then, Eq. 1 was used to calculate share of potential work trips between ODs made by bicycle on each route (W^r); where,$_iT_{ij}$ is the potential number of work trips between zones i and j; and P^r is the probability of selection of route r between the O$_i$ and Dj. We also took the share of bicycle use in making trips to/from work into account. According to data from Travel Survey in the Netherlands, this share was about 21.85% in the Province of Utrecht.

$$W_{ij}^{r} = T_{ij} \times P_{ij}^{r} \times 21.85\% \tag{1}$$

4) Safety modeling: In this study we included two types of sever and slight injury crashes in the analysis. We used the national crash data in the Netherlands to develop a safety model indicating the relationships between traffic, road network, and other environmental characteristics on crash frequency. To alleviate the problem of extenssive number of zeros in the crash data a resampling method [7] was also applied. Then the number of crashes were predicted based on this model developed by a machine learning method (XGBoost).

5) Trip-based crash risk analysis on routes and in zones: In the last step, an index for trip-based crash risk assessment on the routes was developed that includes share of work trips made on the routes, number and cost of crashes of each type, as well as total exposure on routes (Eq. 2). The total exposure on route was estimated for 4 hours (during peak-hour traffic), during the working days in 4 years. The crash cost for severe injury crashes was considered equal to 1 million Euro (value of the Statistical Severe Injury (SSVI) in the Netherlands [8]) and the cost of slight injury crashes was considered equal to 5,000 Euro [9]. Finally, total value of crash risk costs for all potentail trips originating from each zone was calculated based on the summation of crash risk costs on the routes originated from each zone to all possible destinations.

$$Potential\ Crash\ risk\ Cost_{ij}^{r} = W_{ij}^{r} \times \frac{\sum_{t=1}^{T} (No.\ Crash_{ij}^{t} \times Crash\ Cost^{t})}{Total\ exposure_{ij}} \tag{2}$$

3 RESULTS AND CONCLUSIONS

The insights gained from this study may be of assistance estimation of an index for crash risk imposed to travelers by accounting for route, mode, purpose, and time of the travel. Figure 1 depicts the histogram of such crash risk associated with work trips by bicycle on the routes. Figure 2 illustrates an example of generated cycling routes between zones 3438L and 3513A representing the results of estimated crash risk cost per year associated with work trips by bicycle between these zones. The routes are shown in different colors from red (the riskiest route) to dark green (the safest route). As this Figure shows, the route with smallest number of crossings which was the most probable route to be chosen by the cyclists. Whilst, the route with shortest distance found to be the safest route among others. This result could be due to small exposure value on this route.

Figure 3 shows the estimated injury crash risk cost associated with work trips in the PC5 zones. This figure shows that zones located in the center and Eastern areas of the city were safer. This result can be related to slower motor vehicle traffic because of traffic congestions during the peak hours in these areas. Additionally, presence of high density of jobs and short distance between the locations in the city center zones results in more attraction of more bicycle trips in these areas leads to presence of a large number of bicycles on roads in these zones. A result of that would be drivers pay more attention to cyclists, specifically on the mixed traffic roads and suggested cycling lanes. In contrast, the zones located in the Northwest and Northeast were less safe compared with other areas. This result can be explained by the high population density of the active population, as well as the high density of residential areas resulting in increased production of the work trips.

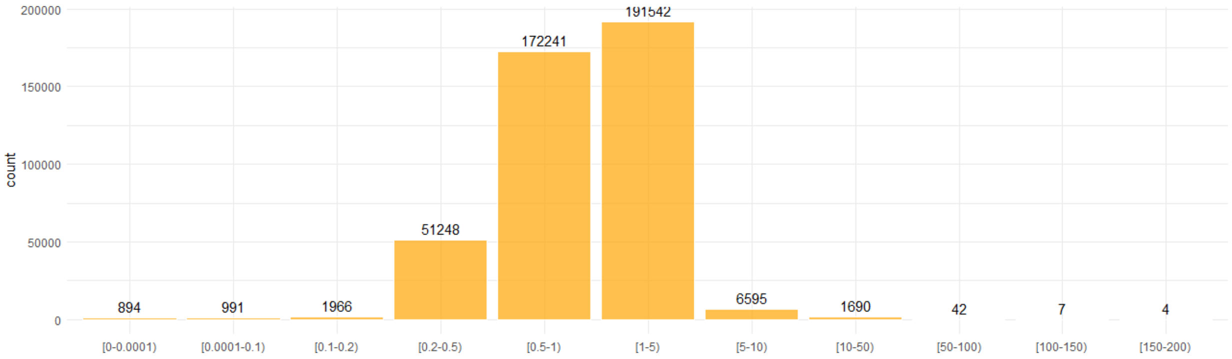


Figure 1 trip-based crash risk costs on routes

Figure 2 Alternative routes created between PC5 zones: 3438L – 3513A

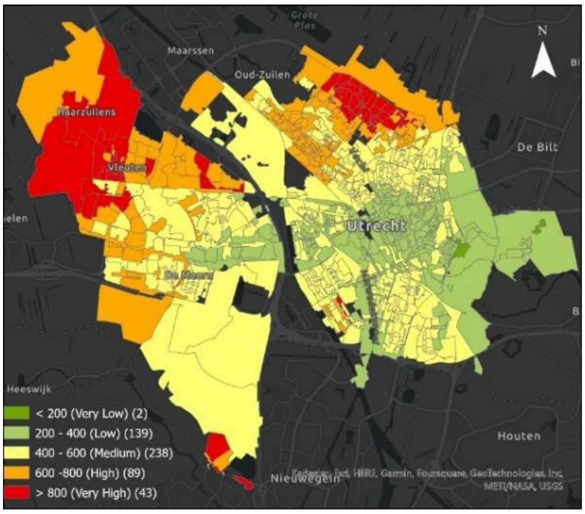


Figure 3 Total yearly average potential cost of crash risks associated with work trips by bicycle (€ per Origin)

REFERENCES

1. Ding, H., et al., *Role of exposure in bicycle safety analysis: Effect of cycle path choice.* Accident Analysis & Prevention, 2021. **153**: p. 106014.
2. Uijtdewilligen, T., et al., *How does hourly variation in exposure to cyclists and motorised vehicles affect cyclist safety? A case study from a Dutch cycling capital.* Safety Science, 2022. **Volume 152**.
3. Asadi, M., et al., *A comprehensive analysis of the relationships between the built environment and traffic safety in the Dutch urban areas.* Accident Analysis & Prevention, 2022. **172**: p. 106683.
4. Abdel-Aty, M.A. and H.T. Abdelwahab, *Predicting injury severity levels in traffic crashes: a modeling comparison.* Journal of transportation engineering, 2004. **130**(2): p. 204-210.
5. Tang, J., et al., *Statistical and machine-learning methods for clearance time prediction of road incidents: A methodology review.* Analytic Methods in Accident Research, 2020. **27**: p. 100123.
6. Ton, D., et al., *How do people cycle in amsterdam, netherlands?: Estimating cyclists' route choice determinants with gps data from an urban area.* Transportation research record, 2017. **2662**(1): p. 75-82.
7. Morris, C. and J.J. Yang, *Effectiveness of resampling methods in coping with imbalanced crash data: Crash type analysis and predictive modeling.* Accident Analysis and Prevention, 2021. **159**: p. 106240.
8. Schoeters, A., et al., *Monetary valuation of the prevention of road fatalities and serious road injuries; Results of the VALOR project*. 2021, VIAS institute: Brussels. p. 125.
9. Wijnen, W., *Maatschappelijke kosten van verkeersongevallen in Nederland: actualisatie 2020*, W2economics, Editor. 2022.

Analysis of High School Students' Safety Behavior Change through Workshops with Exploratory Learning by Using Naturalistic Cycling Data

Fumiya ISHIGAMORI*, **Nagahiro YOSHIDA#**, **Yuto KITAMURA†**

*Graduate School of Engineering
Osaka Metropolitan University
3-3-138 Sugimoto, Osaka 558-8585, Japan
e-mail: si22186c@st.omu.ac.jp

#Graduate School of Engineering
Osaka Metropolitan University
3-3-138 Sugimoto, Osaka 558-8585, Japan
e-mail: yoshida-na@omu.ac.jp

† Graduate School of Engineering
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8654, Japan
email: yuto@p.u-tokyo.ac.jp

Keywords: Road Safety Education, Workshop, Naturalistic Cycling, Behaviour Modification

1 INTRODUCTION

Road Safety Education (RSE) is one of the key elements of safety programs and plays an important role in leading safety behavior. As an educational intervention method, there are studies that have examined the effects of education using the Theory of Planned Behavior (TPB) [1][2] and changes in knowledge and actual behavior [3][4], and based on these findings, correct understanding of RSE and more effective teaching and learning opportunities are needed. As a method to understand the actual cycling behavior, naturalistic cycling data has been used to understand users' behavior and evaluate their safety [5][6], but there are few examples of its use to verify educational or learning effects [7].

The purpose of this study was to demonstrate the impact of workshop-style RSE focusing on the process of changing cycling behavior through exploratory learning. The Model of Behavior Modification (MBM) developed by the Advisory Group to the Norwegian Council for Road Safety was adopted in the workshop (WS) design and the factors affecting behavioral change was examined based on the Exploratory Teaching and Learning Model (ETLM) that utilizes naturalistic cycling data [8].

2 METHOD

The RSE program was implemented in a mid-mountainous area where cycling to school was not expected to be popular due to issues such as school consolidation and poor public transportation service. The main objective of the project including the program was to improve the local road environment and school commuting issues by providing electrically power assisted bicycles (EPACs), safety education and community learning opportunities, and monitoring methods to high school students who were beginning to commute by bicycle. During the implementation of this program, three WSs on road safety and pre- and post-WS observation surveys were conducted.

2.1 Naturalistic Cycling Data

A naturalistic cycling observation was conducted to collect cycling data and behaviors of high school students during their commute to and from school. The equipment used on the EPACs was a 360-degree camera, a heart rate monitor, a cadence sensor, and a speed sensor. The bicycle was fitted with a 360-degree camera and a cycling computer with GPS that can be connected wirelessly to cadence and speed sensors and subjects were asked to wear a wireless wrist heart rate monitor. A total of 16 subjects were surveyed, and data was recorded for a total distance traveled of 959 km and 51.6 hours in the three phases shown in Table 1. Clip videos identifying desirable or undesirable cycling and risk taking or avoidance behaviors were extracted from these behavioral records and used to share specific videos among students during the three WS.

2.2 Structure of the WS and Intervention Effectiveness Analysis Method

Based on the MBM, road safety WSs were conducted to allow comparison of different contents as shown in table 2. In WS-1, one group (Group B) was shown only dangerous videos and asked to discuss undesirable behaviors, while the other group (Group A) was shown both dangerous and safe videos and was asked to discuss desirable behaviors to avoid any dangers. In WS-2, multiple videos produced by a certain organization were provided to the three groups, so that students could acquire safety knowledge and hazard prediction skills together. In WS-3, the same contents with different behavioral videos as in WS-1 were provided. The WS utilized “Engage” and “Explore” in the ETLM to encourage spontaneous behavior change in students.

In order to evaluate the subjective effects of the WS intervention, questionnaire surveys were conducted before and after the WS with respect to WS-1. The surveys included 11 questions on self-evaluation of usual behavior, 4 questions on confidence in behavior, 5 questions on sense of responsibility, and 1 question on intention to change behavior. In WS-2, a questionnaire survey including 12 questions on self-evaluation of cycling behavior was conducted after the workshop. In WS-3, the questionnaire surveys were administered before and after the workshop. The surveys included the following questions: 4 questions on normative awareness, 3 questions on behavioral confidence, 2 questions on sense of confidence, 3 questions on sense of responsibility, 2 questions on motivation to learn, 1 question on intention to change behavior. Common responses before and after the WS were compared using a t-test assuming equal variances, and where there significant differences, then the questions were scored and a multiple regression analysis was conducted to identify the factors that contributed to the change.

For the comparison of cycling behavior, changes in the frequency of safe or dangerous behaviors were compared by counting six specific behaviors: driving while wearing earphones (days), ignorance of a stop sign (times), failure frequency on making a two-stage right turn (times), riding time on sidewalk (seconds), number of times checking for safety (times), and predicting and avoiding dangerous behavior toward cars (times)). For the log data, before-and-after comparisons by t-test assuming equal variances were also performed.

Table 1: Summary of Naturalistic Behavioral Observation Surveys.

Phase	**Before WS-1**	**After WS-1**	**Before WS-3**
Observation Date	Nov.-Dec. 2021	Jan.-Jun. 2022	Jun. 2022-Jan. 2023
Subjects (Gender)	4 boys / 2 girls	5 boys / 4 girls	5 boys / 2 girls
Total Trips	60 trips	81 trips	70 trips
Total Distance	210 km	287 km	462 km
Total Minutes	628 min.	975 min.	1,491 min

Table 2: WS Structure and Intervention Effectiveness Analysis Methods

	WS-1	**WS-2**	**WS-3**
Date	Dec. 21, 2021	Aug. 31, 2022	Jan. 23, 2023
Number of students	Group A: 6, Group B: 6	Group A: 6, Group B: 6, and Group C: 5	Group A: 7, Group B: 6
Contents of WS	Group A: desirable + undesirable clips Group B: Only desirable clips	Hazard prediction (all groups)	Group A: Only desirable clips Group B: Only undesirable clips
Specific elements in the ETML	Engagement	Engagement and Exploration	Engagement and Exploration
Focus elements in the MBM	Group A: Knowledge, Insight, Motivation, and Engagement Group B: Only Knowledge	Stimulate Knowledge and Insight	Group A: Knowledge, Insight, Motivation, and Engagement Group B: Only Knowledge

3 RESULTS

After the WS-1, there was a decrease in subjective self-evaluation ($p<0.05$) and an increase in the frequency of hazard avoidance behavior in the group (Group A) that was encouraged to change by showing both dangerous and safe behaviors. Analysis of actual behavior also showed that a 17% decrease in failure of stop behaviors at unsignalized intersections, a decrease in average speed for all six students($p<0.01$), and a decrease in heart rate for four students ($p<0.01$), which suggested that most students gained the ability to utilize the EPAC without excessive fatigue. In addition, WS-3 increased "motivation" and "sense of responsibility" in the MBM in subjective evaluations ($p<0.05$) and increased the intention to change behavior ($p<0.01$) to "want to change my current behavior".

4 CONCLUSIONS

These results suggested that ETML using students' naturalistic cycling data stimulates “Motivation” and “Commitment” in the MBM, then these factors lead to transformation of desirable cycling behaviors to avoid hazards. In terms of contents in WS, it was shown that "showing undesirable and desirable behaviors" was more effective in the voluntary transformation of desirable cycling behaviors.

In the future, more detailed analysis on educational intervention, factors affecting behaviors, and behavioral change mechanism related with information provision.

5. ACKNOWLEDGEMENT

This research is part of the 2205B project in the International Association of Traffic and Safety Sciences (IATSS) "Measures to Solve Transportation Problems and Educational Effect on High School Commuting in a Mid-Mountainous Area". The authors would like to sincerely appreciate all those involved in the research.

REFERENCES

[1] Sandra Mandic, Charlotte Flaherty, Jennifer S. Mindell, Enrique García Bengoechea. “Adolescents' perceptions of long-term effects of cycle skills training”. Journal of Road Safety Vol. 33, Issue 4 (2022):5-20.

[2] Vilius Floreskul, Kristina Zardeckait e-Matulaitiene, Aukse˙ Endriulaitiene, Laura Seibokaite. “Effectiveness of pre-driver education programme for high school students Application of Theory of Planned Behaviour on road risk taking behavior”. Journal of Behavior, Health & Social Issues Vol. 8 (2017):8-16.

[3] Jonathan Hooshmand, G. Hotz, V. Neilson, L. Chandler. “BikeSafe: Evaluating a bicycle safety program for middle school aged children”. Accident Analysis and Prevention Vol. 66 (2014):182-186.

[4] Karen McLaughlin, A. Glang. “The Effectiveness of a Bicycle Safety Program for Improving Safety-Related Knowledge and Behavior in Young Elementary Students”. Journal of Pediatric Psychology Vol. 35, Issue 4 (2010):343-353.

[5] Katja Schleinitz, Tibor Petzoldt, Luise Franke-Bartholdt, J. Krems, T. Gehlert. “The German Naturalistic Cycling Study – Comparing cycling speed of riders of different e-bikes and conventional bicycles”. Safety Science Vol. 92 (2017):290-297.

[6] P. Huertas-Leyva, M. Dozza, N. Baldanzini. “Investigating cycling kinematics and braking maneuvers in the real world e-bikes make cyclists move faster, brake harder, and experience new conflicts”. Transportation Research Part F Vol. 54 (2018):211–222.

[7] J. Hatfield, M. Dozza, D.A. Patton,P. Maharaj, S. Boufous, T. Eveston. “On the use of naturalistic methods to examine safety-relevant behaviours amongst children and evaluate a cycling education program”. Accident Analysis and Prevention Vol. 108 (2017):91–99.

[8] Torkel Bjørnskau, Nils Petter Gregersen, Anders Isnes, Tori Grytli, Bård Morten Johansen and Kristin Eli Strømme. “The Norwegian Council for Road Safety's model for behaviour modification”. Norway: (2017).

Analysis of cyclists' safety on "bicycle streets" in four large Dutch municipalities: A crash and conflict study

M. J. M. Odijk#*1, M. Nabavi Niaki#2, M. B. Ulak*3, K. T. Geurs*4

#SWOV Institute for Road Safety Research
Henri Faasdreef 312, 2492 JP,
The Hague, The Netherlands

*Department of Civil Engineering
Faculty of Engineering Technology
University of Twente
Drienerlolaan 5, 7255 NB, Enschede, Netherlands

Contact: 1masha99@live.nl; 2matin.nabavi.niaki@swov.nl; 3m.b.ulak@utwente.nl; 4k.t.geurs@utwente.nl

Keywords: bicycle street, safety, crash cost rate, Tobit regression, conflicts

BACKGROUND AND AIM

Starting in the 2000s, a new type of bicycle infrastructure, the *fietsstraat* (bicycle street) emerged, and has been implemented throughout in the Netherlands. A bicycle street is a street on which a minimum of two functions are combined; a flow function for bicycle traffic, and an exchange function for motor vehicle traffic. Therefore on bicycle streets, cyclists are given priority and motorized vehicles are expected to adjust their behavior. This sharing of road space, where motor vehicles are subordinate to bicycles, makes bicycle streets interesting for transportation planners as they are more space efficient. However, mixed traffic conditions are often associated with increased crash risk for non-motorized modes [1]. A handful of studies have addressed the topic of bicycle street safety [2, 3, 4, 5]. Common findings from these conflict and perceived safety studies are that motor vehicle intensities, the road width (incl. rabat strip width), and speed are significant predictors for dangerous encounters and perceived safety. These studies provide a basis for understanding traffic safety on bicycle streets. However, little is known about how the traffic safety on bicycle streets compared with other facilities in terms of crash occurrence and risk for cyclists, and the effects of traffic volumes and design on user behavior and crash rates on bicycle streets. This scarcity of research, in combination with increasing implementation of bicycle streets, is problematic, especially in times of increasing bicycle crash numbers in the Netherlands [6]. The aim of this study is to provide insight into the safety of bicycle streets, using historic crash data as well as the near crash events (i.e., conflicts).

METHODS

The study area consists of the four largest municipalities in the Netherlands, namely Amsterdam, Rotterdam, The Hague, and Utrecht. In addition to being the largest, a high number of bicycle streets is located in these municipalities. The safety evaluation is covered at two levels: 1) a road segment based crash cost rate analysis using historic crash data distinguishing property damage only, light injury, and severe injury/fatal crashes; and 2) a supporting conflict study at selected bicycle streets. Analyzing safety in terms of both crashes and conflicts allows for a more complete understanding of the safety of bicycle streets.

Crash cost rate analysis

First, BRON registered crashes [7] were mapped in GIS and linked to bicycle facility they are located on. Cyclist and vehicle traffic volumes estimated from a traffic model are used to calculate crash cost rate. Then, a model is developed to 1) test the average rates for significant statistical differences, and 2) develop Tobit regression models to quantify the relationships between crash cost rate on different bicycle facilities and various traffic and environmental variables. Two types of regression models were developed: 1) a model for each time period with all bicycle facility links, and 2) separate models for each bicycle facility per time period.

The crash cost rate was estimated for four time periods (average, rush, non-rush, and weekend) based on the sum of observed crash severities, the exposure at the time interval BC_{iT}, the link length L_i, and the relative severity of the crash W_j based on social costs related to the severity level SC_j (Equation 1 and 2) [8].

$$CR_{iT} = \frac{\sum_{n=1}^{j} C_j \times W_j}{y_i \times L_i \times BC_{iT}} \times 10^6 \tag{1}$$

$$W_j = \frac{SC_{fatal}}{SC_j} \times 10^3 \tag{2}$$

Applying conventional models to censored data results in biased and inconsistent parameter estimates. Therefore, the Tobit regression model is used to overcome the zero-inflated data, since it can model segment-based crash data with zero crash segments (i.e. censored at zero), and a crash probability is still modelled [9].

The limited number of bicycle streets leads to an imbalanced dataset for the analysis. Imbalanced datasets suffer from internal model biases where the majority overpowers the minority [10], and it can be difficult to model the effects of the minority classes. To overcome this issue the minority group (bicycle streets) is over-sampled using ADASYN (Adaptive Synthetic Sampling Approach for Imbalanced Learning).

Conflict study

In the second level, a conflict study on a selection of four bicycle streets was performed to support the crash based study, by providing in-depth understanding of how and why crashes on bicycle streets occur. In the conflict study event characteristics (severity, interaction type, road users, evasive action, design) of safe and conflicting interactions are collected on four bicycle streets that vary in traffic volumes and road profile. On each bicycle street video data was collected between 7:00-11:00 and 14:00-19:00 on a weekday, covering both rush and non-rush hours. The interactions were given a severity score following Table 1, where the red line notates the threshold between a safe interaction between road users (above) and a conflict (below).

Table 1 Conflict severity level on bicycle streets [11]

Level	*Overtaking & oncoming traffic*	*Car-behind-bicycle*
1	No hinder of each other, safe situation.	At a comfortable distance.
2	Adjusted behaviour (“make space”), but safe situation.	Close to the cyclist (bothersome).
3	Bothersome (high speed, at small distance), not comfortable, but through adjusted behaviour the probability of a collision is small.	Hard breaking, close to cyclist (dangerous).
4	Very bothersome, breaking or evasive manoeuvre is necessary to prevent collision.	
5	Very dangerous (physical contact), in some cases leading to a crash.	

RESULTS

The two sample z-tests on the average crash cost rates showed that bicycle paths are significantly safer for cyclists than bicycle streets, bicycle lanes, and regular residential roads, on average, and during rush and non-rush hours. This is in line with the general perception that separating bicycle and motor vehicle traffic benefits cyclists’ safety. Due to the small bicycle street sample, no significant differences were found between the crash rates during different periods on bicycle streets.

The regression dataset was resampled for the minority class *bicycle street* with majority class *bicycle path*. The neighborhood size (K=20) and balance level (β=0.05) were selected such that changes in variable averages are minimal, and the model performance (significance of coefficients) is optimal. Figure 1 shows the standardized regression coefficients of the four Tobit regression models developed for each time period. The bicycle facility type is modelled as a categorical variable, meaning that each dummy variable is compared with the reference group: bicycle street. Thus, these models show that for each time period the crash cost rate on bicycle streets is significantly higher than on any other bicycle facility, when controlling for traffic and environmental variables. Motor vehicle volumes are positively related to crash cost rates on bicycle facilities. However, on bicycle streets specifically the findings, both in the crash and conflict part, are unreliable due to data limitations.

On the other hand, both parts produced similar results on the effects of bicycle volumes on crash and conflict rates. Namely, increased bicycle volumes are related to increased crash and conflict rates on bicycle streets. The conflict study also showed that duo-cyclists are exposed to the highest conflict rates, and are strongly disadvantaged on narrow and/or high volume bicycle streets. Also, the results suggest that bicycle streets with very low motor vehicle volumes do not properly facilitate interactions with motor vehicles, as they are primarily designed to facilitate interactions between cyclists.

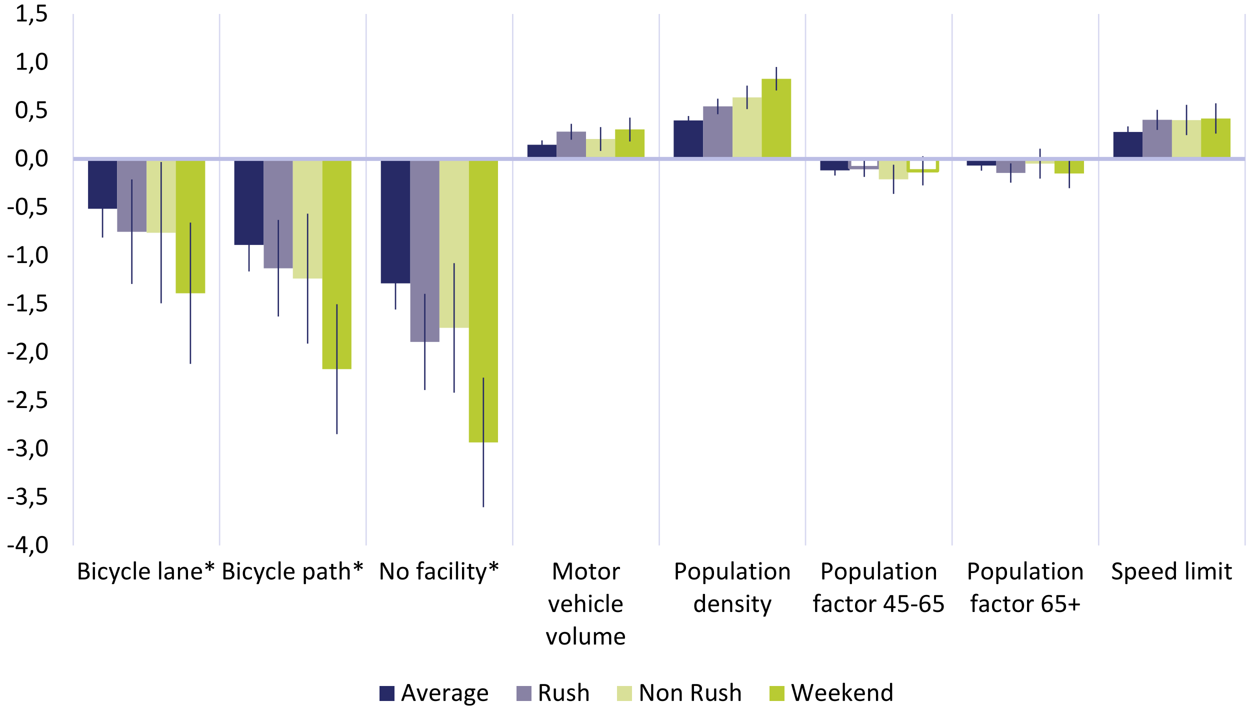


*Figure 1 Standardized regression coefficient of Tobit regression models, for each time period. Error bars show CI at 95%, and significant coefficients $p < 0.05$ filled bars, *categorical variables are modelled against the reference group: Bicycle street*

CONCLUSIONS

The aim of this study is to provide insight into the safety of bicycle streets, through a comparison of crash cost rates on bicycle streets and other bicycle facilities, and a conflict study on bicycle streets to more specifically address the characteristics of, and related factors to unsafe interactions. The main finding of this study is that crash cost rates for cyclists are higher on bicycle streets than on other bicycle facilities such as lanes and tracks, and on regular residential roads, while controlling for traffic and environmental variables. To conclude, this study adds to the knowledge gap on bicycle street safety by comparing objective safety levels to other bicycle facilities and analyzing the “how” and “why” of unsafe events. It should be noted that these results are subject to some limitations in the crash and traffic volume data. However, the high average crash cost rates, and the regression model outcomes both show lower safety levels on bicycle streets. The conflict study provides characteristics of unsafe events and relationships between traffic volumes and unsafe events are identified. This study provides topics for future directions on bicycle street safety, and takeaways for policy makers and road designers for safer implementation of bicycle streets.

REFERENCES

[1] DiGioia, J., Watkins, K. E., Xu, Y., Rodgers, M., & Guensler, R. Safety impacts of bicycle infrastructure: A critical review. Journal of Safety Research, 105-119. 2017.
[2] van Boggelen, O., & Hulshof, R. Fietsberaadnotitie aanbevelingen fietsstraten binnen de kom. Utrecht: CROW Fietsberaad. 2019.
[3] Khut, R. Bicycle Boulevards: Statistical analysis of the presence of bicycle boulevards and their influence on bicycle-to-work rates in Portland, Oregon. Thesis, University of Oregon, Department of Planning, Public Policy and Management. 2012.
[4] Denvall, H., & Johansson, S. Bicycle Priority Street. Master thesis, Chalmers University of Technology, Department of Civil and Environmental Engineering, Gothenburg, Sweden. 2013.
[5] Olsson, S. R., & Elldér, E. Are bicycle streets cyclist-friendly? Micro-environmental factors for improving perceived safety when cycling in mixed traffic. Accident Analysis and Prevention. 2023.
[6] CBS. Meer verkeersdoden in 2022, vooral fietsende 75-plusser vaker slachtoffer [More traffic casualties in 2022, especially cycling elderly 75+ more often the victim]. Retrieved from CBS: https://www.cbs.nl/nl-nl/nieuws/2023/16/meer-verkeersdoden-in-2022-vooral-fietsende-75-plussers-vaker-slachtoffer. 2023, April 18.
[7] BRON. (2016-2021). Verkeersveiligheid en ongevallencijfers [Traffic safety and crash data].
[8] Schoeters, A., Large, M., Koning, M., Carnis, L., Daniels, S., Mignot, D., . . . van der Horst, M. Economic valuation of preventing fata and serious road injuries. Results of Willingness-To-Pay study in four European countries. Accident Analysis and Prevention, 173. 2022.
[9] Tobin, J. Estimation of relationships for limited dependent variables. Econometrica, 26, 24-36. 1958.
[10] Morris, C., & Yang, J. J. Effectiveness of resampling methods in coping with imbalanced crash data: Crash type analysis and predictive modeling. Accident Analysis and Prevention. 2021.
[11] Godefrooij, H., & Hulshof, R. Toepassingsmogelijkheiden Fietsstraten [Application possibilities of bicycle streets]. Nationaal verkeerskundecongres. DTV Consultants and CROW. 2017.

Evaluating (Protected) Bike Lanes in a Bicycle Simulator

M. Naujoks[*], **M. Vollrath**[*], **A. K. Huemer**[#]

[*]Department of Traffic and Engineering Psychology
Technische Universität Braunschweig
Gaußstraße 23, 38106, Braunschweig, Germany
email: melina.naujoks@tu-bs.de
email: mark.vollrath@tu-bs.de

[#]Institute for Transport and Spatial Planning
Universität der Bundeswehr München
Werner-Heisenberg-Weg 39, 85577, Neubiberg, Germany
email: anja.huemer@unibw.de

Keywords: protected bike lanes, cycling safety, overtaking behavior, bicycle simulator.

1 INTRODUCTION

Increasing volume of cycling traffic and the associated requirements for greater cycling safety make it necessary to construct new cycling facilities. In order to increase safety in shared road space, the implementation of protected bike lanes with buffer spaces and physical separating elements from moving traffic is increasingly demanded by cycling associations [1]. During the pandemic, the temporary implementation of pop-up bike lanes with protecting elements was found to evoke positive resonances among cyclists and motorists [2]. Such installations on parking lanes or motorist’s lanes could be used for permanent rededication of shared road space [3].

Systematic influences on the safety perception of individual infrastructure features such as width and color of cycling facilities as well as types of buffer to motorist’s traffic have so far mainly been tested in online studies or field surveys [4], [5], [6]. There are positive effects on cyclist’s perception of safety for physical separation like bollards, flower boxes and curbs [4], [5], [6]. In contrast, such physical separators can also lead to higher injury risks [7]. Bike lanes with green surface coloring were found to increase the perception of safety [4]. Wider bike lanes are also associated with both higher ratings in subjective safety and more lateral space during overtaking other cyclists [4], [8]. The aim of the present study is to investigate the influence of the cycle lane features 'width', 'type of buffer', 'surface color' and 'position of cyclists ahead' on both, the subjective perception and the objective driving and overtaking behavior of cyclists.

2 METHODS

2.1 Procedure

The study was conducted in a 3x3x2x2 within-subjects design with repeated measures on 50 participants on the bicycle simulator at the Department of Traffic and Engineering Psychology at the Technische Universität Braunschweig. The participants cycled on 18 different bike lanes that differed in the width (narrow: 1.60 m; medium: 2.00 m; wide: 2.40 m), the type of buffer on the left side of the cycle lane towards the motorists’ lane (wide line marking: 0.25 m; striped buffer marking: 0.75 m; bollards on striped buffer markings: 0.75 m with bollards placed in regular intervals in the middle of the striped buffer) and the surface color (asphalt grey or green) (see Figure 1). In addition, there were two cyclists riding ahead slowly on every bike lane for a specific section with one cyclist riding close to the curb (0.20 m from curb) and the other one riding more in the center of the bike lane (0.80 m from curb). Due to their low speed, participants were very likely to overtake these two slow cyclists. Each participant cycled each scenario, but in randomized order. After each scenario, participants were given a short questionnaire to rate their subjective level of safety, stress, possibility of free riding as well as the lateral clearance to other cyclists and the motorist’s lane. Data for lateral clearance and speed were taken from the simulator.

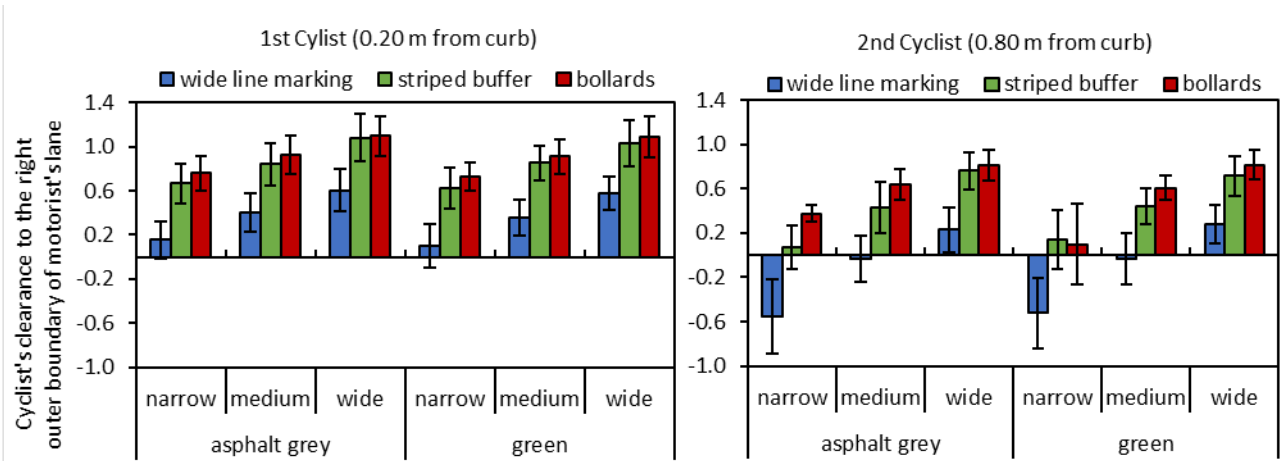
Figure 1: Screenshots of the different scenarios #01 on the left (narrow, wide line making, asphalt grey), #10 in the middle (medium, striped buffer marking, green) and #17 on the right (wide, bollards, asphalt grey).

2.2 Bicycle simulator

The bicycle simulator consists of a trekking bicycle standing on a motion platform that allows the bicycle to tilt slightly to the left and right. Twelve monitors assembled in a hexagon allows a 360°-view. Via noise-cancelling headphones the participant can hear simulated surrounding noises such as motor vehicles. The simulator runs with the simulation software SILAB 7.0 [9].

3 RESULTS

The results show an increase of perceived safety as well as greater overtaking distances to other cyclists and to moving traffic on wide protected bike lanes (3.25 m) with bollards as physical separators from moving traffic. Narrow cycle lanes with wide line markings (1.85 m), on the other hand, lead to irregular and risky overtaking maneuvers (see Figure 2). In general, greater widths are associated with an increase of perceived safety, the possibility to ride freely, better ratings for sufficient space to motorists and a decrease of perceived stress. Moreover, wider bike lanes lead to greater lateral passing distances to other cyclists and to motorists. For the type of buffer, positive effects on the subjective perceptions of safety and stress as well as more sufficient space to both, cyclists and motorists, are found for striped buffers and bollards respectively. However, on narrow or medium bike lanes, striped buffers significantly increase the possibility to ride freely over wide line markings or bollards. For lateral distances while overtaking other cyclists, bollards lead to decreased passing distances on narrow or medium bike lanes when the cyclists ahead are in the middle of the bike lane. For the cyclist’s position ahead, greater overtaking distances are found to cyclists riding close to the curb on the right side (0.71 m) and reduced overtaking distances to cyclists riding more in the center of the bike lane (0.43 m). In general, the results show no superiority for green surface coloring over asphalt grey on subjective variables or passing distances to cyclists or motorists.



4 DISCUSSIONS AND CONCLUSIONS

Using a bicycle simulator as compared to pictures and videos as in previous online studies, is a more realistic approach that enables the cyclists to experience the different infrastructure features while riding in a virtual environment. However, a bicycle simulator is not fully able to provide an experience like riding on a real bike, especially when it comes to cyclist-cyclist-interactions. However, the study provides the benefits of the experimental design of the simulator approach, that is a controlled setting and systematically varying specific characteristics of the cycling infrastructure.

The results of this study show clear benefits of wider bike lanes and sufficient buffer space to motorists. In order to increase cycling safety, the widest possible bike lanes of approx. 3.25 m width should be built, protected by bollards from moving traffic. In contrast to previous findings, positive effects of green surface colorings are small and can be neglected considering a higher risk of slipping in wet conditions. Further research is needed on the influence of protected bike lanes on the driving behavior of motorists and the safe design of junctions.

REFERENCES

[1] Allgemeiner Deutscher Fahrrad-Club e.V., "*ADFC-Positionspapier: Geschützte Radfahrstreifen [ADFC position paper: protected bike lanes*" (2018), Berlin.

[2] K. Götting, & S. Becker, "*Reaktionen auf die Pop-Up-Radwege in Berlin. Ergebnisse einer explorativen Umfrage zur temporären Radinfrastruktur im Kontext der Covid-19 Pandemie [Reactions to the pop-up bike lanes in Berlin. Results of an exploratory survey on temporary cycling infrastructure in the context of the Covid-19 pandemic]"* (2020), Berlin.

[3] K. Kurth, A. Keler, & K. Bogenberger, "Bewertung der Pop-Up Infrastruktur im Radverkehr als erfolgsversprechendes Instrument der urbanen Verkehrsplanung [Evaluation of pop-up infrastructure in cycling as a promising instrument of urban transport planning]", *Zeitschrift für Verkehrsplanung, Verkehrsmanagement, Verkehrssicherheit und Verkehrstechnik* 11 (2022), pp. 847–855.

[4] R. von Stülpnagel, & N. Binnig, "How safe do you feel? - A large-scale survey concerning the subjective safety associated with different kinds of cycling lanes". *Accident; Analysis and Prevention*, 167 (2022), 106577.

[5] N. McNeil, C. M. Monsere, & J. Dill, "Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists". *Transportation Research Record: Journal of the Transportation Research Board* 2520(1) (2015), pp. 132–142.

[6] N. Foster, C. M. Monsere, J. Dill, & K. Clifton, "Level-of-Service Model for Protected Bike Lanes" *Transportation Research Record: Journal of the Transportation Research Board*, 2520(1) (2015), pp. 90–99.

[7] J. B. Cicchino, M. L. McCarthy, C. D. Newgard, S. P. Wall, C. J. DiMaggio, P. E. Kulie, B. N. Arnold, & D. S. Zuby, "Not all protected bike lanes are the same: Infrastructure and risk of cyclist collisions and falls leading to emergency department visits in three U.S. cities". *Accident Analysis & Prevention*, 141 (2020), 105490.

[8] S. Grüner, "*Attraktive Radfahrrouten: Analyse der Routenwahlentscheidungen von Radfahrpendlern in den Dimensionen Sicherheit, Komfort und Effizienz [Attractive cycling routes: Analysis of route choice decisions of cycling commuters in the dimensions of safety, comfort and efficiency]*", [Dissertation] (2021), Braunschweig.

[9] Würzburger Institute for Traffic Sciences GmbH (WIVW), *Simulationssoftware SILAB 7.0,* (2021), Veitshöchheim.

Evaluating safety risks for micromobility users in protected bike lanes based on vertical element selection

A. M. Pérez-Zuriaga*, J. Dols#, M. Nespereira#, A. García*

*Highway Engineering Research Group
Universitat Politècnica de València
Camino de Vera sn, 46022, Valencia, Spain
email: anpezu@tra.upv.es; agarciag@tra.upv.es

#Institute of Design and Manufacturing
Universitat Politècnica de València
Camino de Vera sn, 46022, Valencia, Spain
email: jdols@upvnet.upv.es; marnes@etsid.upv.es

Keywords: micromobility, vulnerable road users, protected bike lanes, simulation.

1 INTRODUCTION

A protected bike lane, also called separated bike lane, is an exclusive facility for micromobility users (bicycles and e-scooters) that is physically separated from motor-vehicles with a vertical element. They can be separated from the adjacent roadway with a variety of treatments including but not limited to raised curbs or medians, bollards, landscaping, or planters [1]. However, risk of crashes or falls can vary among protected bike lanes. For instance, the risk of crashing or falling was found to be elevated in some protected lanes with light separation, especially in crashes and falls at midblock not involving moving vehicles [2]. In fact, especially in older cyclists, there is a high risk of injuries and falls when colliding with infrastructure such as curbstones. Curbstones is the major contributor considering factors related to construction in single-bicycle crashes occurrence [3]. Head injuries are the most common injuries in this type of crashes, not only for cyclists but also for e-scooter users, which have increased in recent years. Head-ground impact velocities and locations after a cyclist [4] and a e-scooter user [5] falls caused by the collision with a curb have been evaluated with Madymo software and finite element models, respectively.

When a micromobility user collides with the vertical element located at the buffer area, in addition to the risk of head injuries, there is also the risk of the user falling on the adjacent roadway with the corresponding risk of being run over.

Current study focuses on the consequences when a micromobility user collides to different vertical elements located to separate bike lane users and motor vehicle traffic, considering both head injuries and the distance from the bike lane to the roadway where the user falls. The analysis is based on numerical simulations with PC-Crash software.

2 METHODOLOGY

In order to assess the safety risk for micromobility users in protected bike lanes when they collide to the vertical element installed, different scenarios have been simulated with PC-Crash software (see figure 1). PC-Crash is a crash reconstruction program allowing the user to perform simuations with multibody objects that collide with 3D objects. In the current study, a bicycle (length: 1.821 m, width: 0.6 m, height: 0.992 m, weight: 15 Kg), an e-scooter (length: 1.180 m, width: 0.680 m, height: 1.232 m, weight: 16 Kg) and their riders (height: 1.75 n, weight: 80 Kg) multibody systems have been used. The modeled vertical elements are: bollards (20cm x 20 cm x 80 cm), parking stops (height: 10 cm and 20 cm), continuous concrete curb (height: 10 cm and 20 cm), continuous mountable curb (height: 10 cm, width: 120 cm), and armadillo shape delineator in oblique configuration (length: 82 cm, width: 20 cm, height: 13 cm).

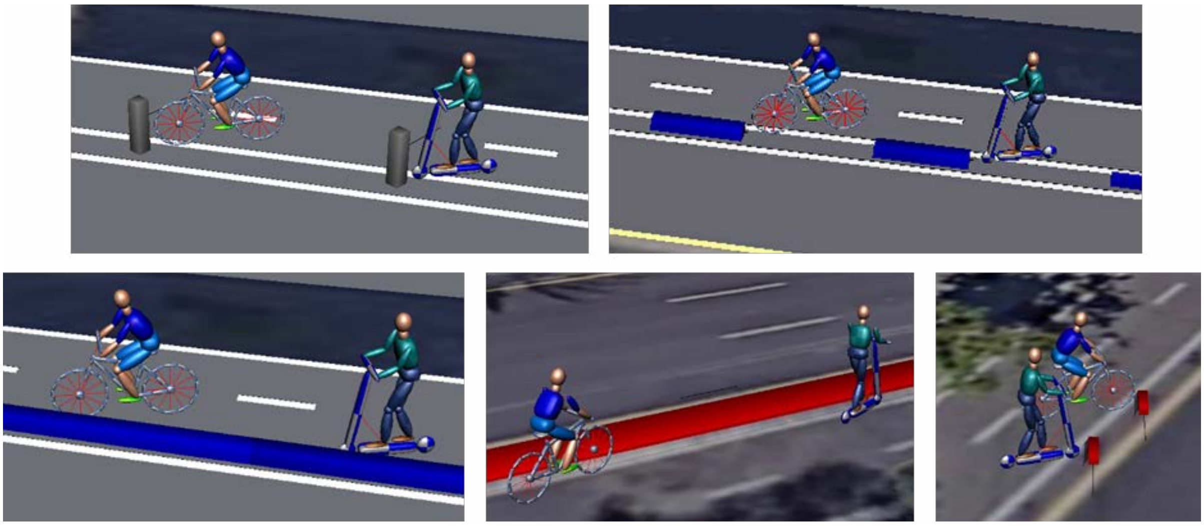


Figure 1: Scenarios simulated with PC-Crash

Numerical simulations have been conducted at different bicycle and e-scooter speeds (from 10 km/h to 30 km/h). The results of these simulations have been analyzed considering the HIC (head injury criterion) and the fall distance into the roadway. Federal Motor Vehicle Safety Standards adopted HIC as injury criterion with the safety margin of HIC15=700.

3 RESULTS

Considering the results of the simulations, the variations in the HIC15 as a function of micromobility user speed for each type of user and for each type of separator element, as well as the fall distance, have been studied. Figure 2 shows the variation of HIC15 depending on the micromobility user speed for the vertical separators that present the worst results. In all cases, the e-scooter user is the one that suffers the most severe injuries. However, in no case the safety margin of 700 is reached.

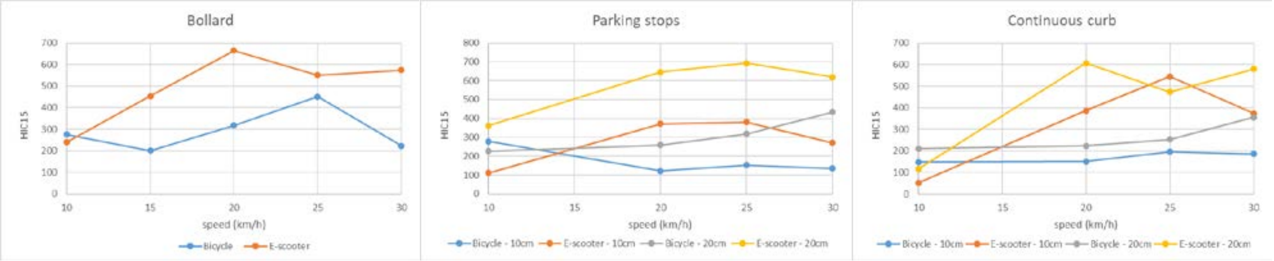


Figure 2: Variation of HIC15 as a function of micromobility user speed

On the other hand, the distance from the bike lane to the roadway that each micromobility vehicle reaches depends on the dynamics of the own vehicle (see Figure 3). For instance, when a micromobility vehicle collides to a bollard, it rolls over, regardless of whether it is a bicycle or a e-scooter. However, when they collide to a 10 cm height parking stop or a 10 cm height continuous curb, whereas a e-scooter rolls over after the collision, a bicycle, thanks to its bigger wheels, jumps the curb and rolls over after that. Therefore, in that case, the fall distance is considerably higher for bicycles than for e-scooters. In all cases, the fall distance increases with the micromobility vehicle speed, and in some cases they even can reach the second motor vehicle lane with the consequent risk of being run over.

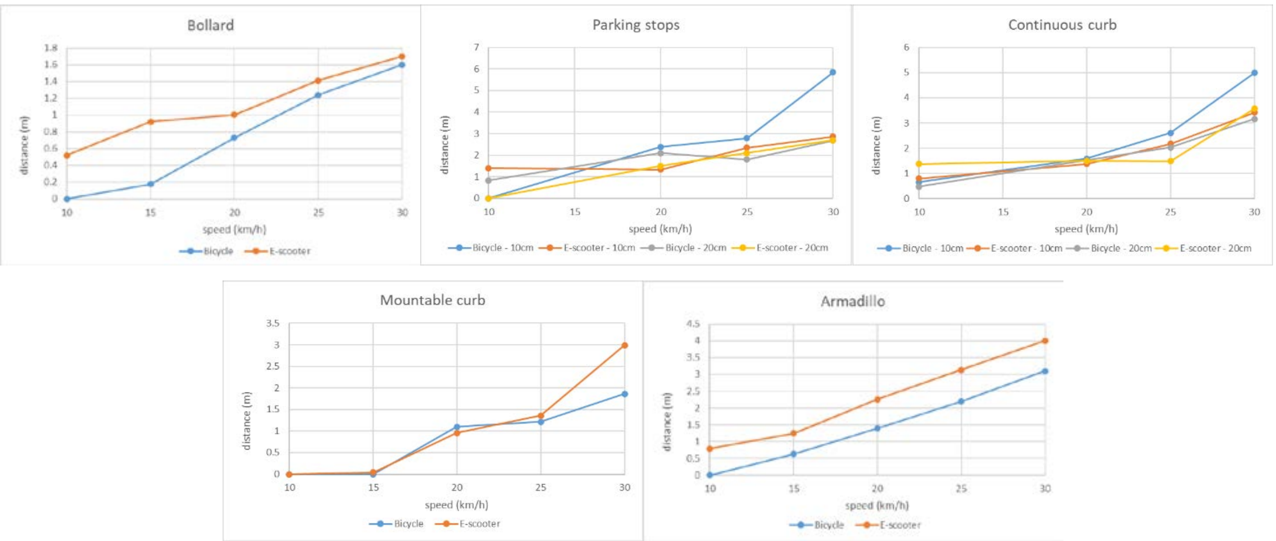


Figure 3: Variation of fall distance as a function of micromobility user speed

4 CONCLUSIONS

Protected bike lanes are one of the safest facilities for micromobility users. However, in case of collision with the vertical element used for separation at buffer area, crash dynamics are different regarding the chosen element. The consequences of a collision of a micromobility vehicles (bicycle and e-scooter) to different types of separators have been analyzed. This analysis has been based on the results of different scenarios simulated with PC-Crash.

Results show that, in general, riding a bicycle is safer than rising an e-scooter since the observed HIC is lower. However, when colliding to a small curb (continuous or not), the bicycle jumps the curb thanks to the size of its wheels and invades more width of the roadway. This situation increases the risk of run over.

ACKNOWLEDGEMENTS

This research is part of the research project PID2019-111744RB-I00 funded by MCIN/AEI/10.13039/501100011033.

REFERENCES

[1] Federal Highway Administration. “Separated bike lane planning and design guide”, Washington, DC., 2015.

[2] J. B. Cicchino, M. L. McCarthy, C. D. Newgard, S. P. Wall, C. J. DiMaggio, P. E. Kulie, B. N. Arnold and D. S. Zuby, “Not all protected bike lanes are the same: infrastructure and risk of cyclist collisions and falls leading to emergency department visits in three U.S. cities”, *Accident Analysis and Prevention* 141 (2020), 105490.

[3] A. V. Olesen, T. K. O. Madsen, T. Hels, M. Hosseinpour and H. S. Lahrmann, “Single-bicycle crashes: An in-depth analysis of self-reported crashes and estimation of attributable hospital cost”, *Accident Analysis and Prevention* 161 (2021, 106353.

[4] N. Bourdet, C. Deck, R. P. Carreira and R. Willinger, “Head impact conditions in the case of cyclist falls”, *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology* 226(3-4) (2012), pp. 282-289.

[5] W. Wei, Y. Petit, P. Arnoux and N. Bailly, “Head-groung impact conditions and helmet performance in e-scooter falls”, *Accident Analysis and Prevention* 181 (2023), 106935.

Evaluation and acceptance of an online cycling training for adults to master complex traffic situations

M.A. B. van Eggermond[*], N. Studer[#], L. Johnson[#], L. Knecht[#] , D. Schaffner[#]

[*] Faculty of Architecture, Geomatics and Civil Engineering
University of Applied Sciences Northwestern Switzerland (FHNW)
Hofackerstrasse 30, 4132 Muttenz, Switzerland
email: michael.vaneggermond@fhnw.ch

[#] School of Applied Psychology
University of Applied Sciences Northwestern Switzerland (FHNW)
Riggenbachstrasse 16, 4600 Olten, Switzerland

Keywords: cycling skills, online cycling training, acceptance.

1 INTRODUCTION

Overall, the number of road fatalities in the European Union has decreased over the last decade. Between 2010 and 2019, the number of fatalities and serious injuries decreased by 23%. During the same period, the proportion of cycling accidents resulting in fatalities or serious injuries has increased from 7% in 2010 to 9% in 2019 [1].

The most obvious way to improve cycling safety is by improving cycling infrastructure. However, in many urban areas the development of cycling infrastructure lags behind the demand for cycling. Moreover, independent of infrastructure, cycling in a safe manner also requires a set of competences, including bodily fitness, steering and balancing skills and knowledge of local traffic systems and rules [2]. Additionally, safe cycling in urban areas requires more elaborate cycling skills, such as recognizing traffic hazards or predicting traffic situations ahead [9] that have been shown to be equally important for preventing cycling accidents [9]. In exisiting cycling trainings, these skills are not included. Also, existing trainings focus on children and even trainings for adults are conducted in-situ, thus limiting potential participation particularly for adult cyclists, as such a program might not meet individuals' schedules. [3].

The study at hand addresses these shortcomings by evaluating a cycling training program that focuses on safety motive related cycling skills, using an online training approach. A digital *online* training has the advantage that it is more convenient to participate. The study aims to answer research questions regarding the take-up of a cycling training, the acceptance of the training and whether cycling skills improve.

2 METHODOLOGY

Procedures: The study developed and implemented an online cycling training program that was designed specifically to develop cycling skill for adults. The concept of the online cycling training program was based on the concept of gamification [5], [6]. Thereby, established behaviour change techniques such as feedback, monitoring and tangible as well as intangible incentives were used to ensure users' engagement with the training.

Six relevant cycling skills had been identified in a prior survey study [7]. Skills were trained using 24 quizzes (3 quizzes for each of the six skills; 12 quizzes for each training block). For each cycling skill, a series of photographs, videos and sketches were developed to support questions and provide feedback. The online training was implemented in the survey software Qualtrics and pre-tested.

The training consisted of three blocks: two training blocks and a final test, framed as challenge, to test the acquired skills. Potential participants were invited by letter to partake in the training. The invite to each block was separated by approximately a one-week time gap. Participation was incentivized through a raffle.

Measures and data analysis: To evaluate the acceptance of the online cycling training this study applied the extended version of the Unified Theory of Acceptance and Use of Technology (UTAUT2) [8]. Four key constructs of UTAUT were adapted to the context of the online training: performance expectancy; effort expectancy , hedonic motivation, and facilitating conditions. Influence of these factors on usage intentions was measured by means of an ordinal regression analysis.

The effect of the online cycling training on cycling skills was measured by participants' subjective assessment of their cycling skills prior to commencing with the training and after completing the training. Four skills, appropriate for the skills trained in the training, were from the cycling skills inventory [9]: Knowing how to act in particular traffic situations: (1) recognizing hazards in traffic, (2) predicting traffic situations ahead, (3) showing consideration for other road users and (4) knowing how to act in certain situations. Additionally, the item "Feeling comfortable while cycling" was included to measure an overall sense of mastery to cycle on urban roads. To evaluate the effect of this repeated measures design, we analyze the results by multilevel regression models, with the cycling training as fixed effect and the individual as a random effect. Additional interactions (e.g. effect of cycling frequency) were explored as an interaction term in the analysis.

3 RESULTS

Sociodemographic: 9670 citizens between the age of 18 and 59 were randomly selected out of the Zurich city registry and invited per mail to participate in the online training program. 1182 participants completed the first block, resulting in a response rate of 12%. 723 participants completed all three blocks including the final test, resulting in a final response rate of 7.5%. Hence, the completion rate is 61%. The participants consisted of 53% men, 46% women and 1% of diverse gender. Mean age was 35.5 years, the median age was 34 years. 72% of participants cycled several times per week, 20% cycled several times per month and 8% cycled once per month or less.

Acceptance: Ordinal regression models were estimated to evaluate whether respondents would continue with the cycling training. Paradoxically, the acceptance is larger for participants that report higher levels of cycling frequency. The acceptance of the online cycling training is mainly driven by performance expectancies such as *learning* or *winning prizes* as well as by a hedonic motivation (*participating in the online cycling training is fun*). Factors such as the design, perceived ease of use or facilitating conditions seem not to influence acceptance on an online cycling training program.

Cycling Skills: .

Table 1 shows the results of a multilevel regression analysis for predicting the subjective assessment of cycling skills before and after taking part in the training.

Table 1 Results of multilevel regression models evaluating subjective cycling skills, cycling frequency and the effect of the training.

	Recognizing hazards	Predicting traffic situations	Showing consideration	Knowing how to act	Feeling comfortable
Intercept	4.272 (0.030)***	4.217 (0.029)***	4.316 (0.030)***	4.272 (0.030)***	3.479 (0.041)***
Cycling frequency [Low]	-0.338 (0.058)***	-0.252 (0.056)***	0.238 (0.056)***	-0.338 (0.058)***	-0.302 (0.077)***
After training	0.107 (0.036)**	0.073 (0.032)*	0.122 (0.032)***	0.107 (0.036)**	0.146 (0.037)***
Cycling frequency [Low] x After training	0.244 (0.069)***	0.196 (0.060)**	-0.072 (0.060)	0.244 (0.069)***	0.392 (0.070)***
N (subjects)	704	704	704	704	704
R2 (conditional)	0.32	0.43	0.44	0.32	0.60

Model results reveals that, considering self-assessed cycling skills, participants with lower levels of cycling benefit from the training. Most of these effects are small. Nevertheless, after the training cyclists that cycle less, report to have a similar level of skills as experienced cyclists, if the coefficients 'After training' and 'Cycling frequency[Low] x After training] are summed. Noteworthy is that the strongest effect is measured for comfort riding on urban roads.

4 DISCUSSION

The study shows that a considerable share of urban cyclists is willing to complete an online cycling training program to improve the mastering of complex traffic situations. Once started with the training, there is a relatively high rate of participants accepting to complete three waves of training. Moreover, the study reveals that motivating those target groups that benefit the most from the training turn out to be the most difficult to persuade to participate. Nevertheless, the study shows that an online training for cycling skills positively influences participants sense of comfort while riding in urban streets. An online training could be one measure to motivate a larger share of cyclists to use this sustainable and healthy mode of transportation.

5 ACKNOWLEDGEMENTS

This research has been funded by the AXA foundation for accident prevention. We would like to thank our project partners Wernher Brucks (City of Zurich), Yvonne Ehrensberger (ProVelo Zurich), Chantal Bourloud (Am Steuer Nie) and Petra Gartenmann (Am Steuer Nie) for their valuable inputs and feedback.

REFERENCES

[1] European Commission, "Facts and Figures Cyclists. European Road Safety Observatory.," European Commission, Directorate General for Transport, Brussels.

[2] J. Larsen, "The making of a pro-cycling city: Social practices and bicycle mobilities," *Environ Plan A*, vol. 49, no. 4, pp. 876–892, Apr. 2017, doi: 10.1177/0308518X16682732.

[3] P. Gálvez-Fernández, P. Chillón, M. J. Aranda-Balboa, and M. Herrador-Colmenero, "Preliminary Results of a Bicycle Training Course on Adults' Environmental Perceptions and Their Mode of Commuting," *IJERPH*, vol. 19, no. 6, p. 3448, Mar. 2022, doi: 10.3390/ijerph19063448.

[4] C. Rissel and G. Watkins, "Impact on cycling behavior and weight loss of a national cycling skills program (AustCycle) in Australia 2010–2013," *Journal of Transport & Health*, vol. 1, no. 2, pp. 134–140, Jun. 2014, doi: 10.1016/j.jth.2014.01.002.

[5] J. Hamari, J. Koivisto, and H. Sarsa, "Does Gamification Work? – A Literature Review of Empirical Studies on Gamification," in *2014 47th Hawaii International Conference on System Sciences*, Jan. 2014, pp. 3025–3034. doi: 10.1109/HICSS.2014.377.

[6] E. Wallius, A. C. T. Klock, and J. Hamari, "Playing it safe: A literature review and research agenda on motivational technologies in transportation safety," *Reliability Engineering & System Safety*, vol. 223, p. 108514, Jul. 2022, doi: 10.1016/j.ress.2022.108514.

[7] D. Schaffner and M. van Eggermond, "Whitepaper: Analyse der Velofahrkompetenzen zur Vermeidung von Unfällen," Fachhochschule Nordwestschweiz, Olten, 2021. [Online]. Available: https://www.fhnw.ch/de/forschung-und-dienstleistungen/psychologie/innovative-marktangebote-und-konsum/velofahrkompetenzen/media/velofahrkompetenz-whitepaper-fhnw-aps

[8] Venkatesh, Thong, and Xu, "Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology," *MIS Quarterly*, vol. 36, no. 1, p. 157, 2012, doi: 10.2307/41410412.

[9] J. C. F. de Winter, N. Kovácsová, and M. P. Hagenzieker, "Cycling Skill Inventory: Assessment of motor–tactical skills and safety motives," *Traffic Injury Prevention*, vol. 20, no. sup3, pp. 3–9, Dec. 2019, doi: 10.1080/15389588.2019.1639158.

Road users' attitudes about present and future active mobility in Munich, Germany

S. Ruf[*][#], S. Aumann[†]

[*]Associate Professorship of Urban Design
TU Munich
Arcisstr. 21, 80333 Munich, Germany
email: stefanie.ruf@tum.de

[#]Chair of Assessment and Intervention
TU Dresden
Chemnitzer Str. 46b, 01189 Dresden, Germany

[†] Chair of Urban Structure and Transport Planning
TU Munich
Arcisstr. 21, 80333 Munich, Germany
email: simone.aumann@tum.de

Keywords: cycling, future mobility, survey, car-reduction.

1 INTRODUCTION

In order to mitigate the – already tangible – effects of the climate emergency, the mobility sector needs to drastically change, shifting the focus from motorized forms of transportation towards active forms of travel like walking and cycling [1]. But what will the future hold? Looking at scenarios for future mobility, an emphasis on technology and smart city solutions, on multimodality, sharing and autonomous driving from an expert's point of view can be found in the literature (see for example [2, 3]). However, citizens' attitudes about future mobility remain unclear [4]. To shed light on this, a survey was developed by three out of a total of 14 projects within the interdisciplinary *Munich Cluster for the Future of Mobility in Metropolitan Regions (MCube)*, funded by the German Federal Ministry of Education within the Clusters 4 Future initiative. The three projects aim at investigating a more sustainable future of mobility from different angles: The project *Car-reduced neighborhoods for a livable city (aqt)* looks at the influence of temporary interventions aiming at a reduction of motorized private transport on mobility patterns, while the project *Holistic and user-centered utilization concepts of vehicles for passenger as well as freight transportation (STEAM)* looks at shuttle bus capacity optimization for passengers at peak times and freight at off-peak times. Lastly, the project *Transformative mobility experiments (TrEx)* looks at future mobility in the face of crises. The three projects started in 2021 and will continue until 2024, all focusing on Munich, a city of about 1,6 million inhabitants in the south of Germany, as a research site. Our research questions aim at investigating how people move in Munich and how safe they feel using different modes of transportation, but also how they think about interventions focusing on walking and cycling instead of driving. Additionally, we want to know what currently frustrates them when cycling and what they wish for with regards to the future – and whether their attitudes about the future differ from those posited by mobility experts in the literature.

2 METHODS

Within the *aqt* project, two neighborhoods in central Munich (*Südliche Au*, an area with around 11 000 inhabitants, and *Walchenseeplatz*, an area with around 5 000 inhabitants, for a spatial overview see also Figure 1) have been selected for living labs focusing on car-reduction interventions. In the winter of 2022/2023, several shorter living labs like a future mobility Christmas wish tree and curling rinks replacing several parking spots were already carried out in the two neighborhoods in preparation for a longer five-month living lab that starts in May 2023. Then, parking spots will be completely removed and streets will be closed for motorized traffic, instead providing space for active forms of mobility and community events. This process is accompanied by before-and-after-surveys to investigate how citizens' attitudes regarding mobility living labs change with time. The present study is part of the before-survey.

For the survey, those in the living lab areas were recruited by posting the survey to their household mailbox via a specialized service. They received a letter informing them about the purpose of the study and providing

Figure 1: Overview over the selected neighborhoods in Munich, with interventions aiming at car-reduction being implemented at Südliche Au (left) and Walchenseeplatz (middle), while no such interventions are implemented in Untersendling (right).

them with a link and QR code to the online survey. Additionally, they were given a neighborhood-specific code to insert on the first page of the online survey to ensure that only people from this neighborhood actually took part in the study (as only they had the code). Furthermore, to compare the results from respondents living in the living lab areas where interventions aiming at car reduction take place, residents in the *Untersendling* area in Munich (with around 15 000 inhabitants) where no car-reduction measures are implemented were also informed about the survey via posting the survey to their mailbox. Munich residents who didn't live in one of the three neighborhoods selected for posting were informed via different online channels like the LinkedIn webpage of the *MCube* cluster or newsletters aiming at cyclists, motorists or pedestrians in Munich. This way, a convenience sample was recruited. Recruiting respondents from the two *aqt* and a reference neighborhood enables comparisons between those in whose surroundings interventions aiming at car-reduction are taking place and those where no such measures are implemented. Including respondents from the rest of Munich helps to additionally understand who is represented in the selected neighborhoods versus the rest of Munich and how their attitudes differ with regards to future mobility.

3 RESULTS

At the time of abstract submission (one week after survey start; total survey time is one month), *N* = 1 001 respondents have filled out the survey. Preliminary results show that out of these respondents, 189 had no code and thus were not residents of one of the three neighborhoods that were informed about the survey by mailbox posting. Of those that lived in one of the three neighborhoods (*N* = 812), 49.1% lived in *Südliche Au*, 18.3% in *Walchenseeplatz* and 32.5% in *Untersendling*. 50.8% of the 1 001 respondents indicated they were male, while 42.2% were female; the rest had not indicated a gender or identified as diverse. On average, respondents were 45 years old (*SD* = 13.9 years, range from 16 to 91 years, *N* = 903). 37.4% said they cycled (almost) daily (*N* = 899), 10.3% drove (almost) daily (*N* = 902) and 67.0% walked (almost) daily (*N* = 908). 46.7% said they very much identified with the group of cyclists (*M* = 3.8, *SD* = 1.34, *N* = 904), while 13.9% identified as motorists very much (*M* = 2.6, *SD* = 1.37, *N* = 904) and 45.0% very much identified as pedestrians (*M* = 4.1, *SD* = 1.02, *N* = 909; 5-point Likert scale for each item from 1 = *not* to 5 = *very*). Due to the length of the survey, not all respondents were asked all questions; for example, only those that had no neighborhood code were asked about their perceived safety and comfort when using different modes of transport. We found that participants generally rated walking as safer (*M* = 4.0, *SD* = 0.96, *N* = 151) and more comfortable (*M* = 3.8, *SD* = 0.91, *N* = 150) than cycling or driving, with respondents rating cycling as more comfortable (*M* = 3.3, *SD* = 1.09, *N* = 143) than driving (*M* = 3.0, *SD* = 1.16, *N* = 128), but at the same time perceiving cycling as less safe (*M* = 2.8, *SD* = 0.98, *N* = 142) than driving (*M* = 3.7, *SD* = 0.86, *N* = 127; 5-point Likert scale for each item from 1 = *not safe/comfortable* to 5 = *very safe/comfortable*).

Based on an item of the *Climate Anxiety Scale* [5], the respondents indicated that they felt that the climate emergency had a strong impact on current (*M* = 4.6, *SD* = 0.77, *N* = 806) and future generations (*M* = 4.7, *SD* = 0.70, *N* = 806) and that they rather felt burdened by it (M = 3.6, SD = 1.13, N = 800; 5-point Likert scale for each item from 1 = *not* to 5 = *very*). When asked what frustrated them about cycling in Munich, aspects like the lack of cycling infrastructure as well as parking on cycling infrastructure, too many and especially too many big cars and a general lack of space for cyclists were mentioned. In free-text fields, the respondents could paint a picture for future mobility as they envisioned it; we found that – in line with their frustrations voiced – most wished for better public transportation, more and safer cycling infrastructure and less cars. They stated that to achieve the future as they see it, change is very much necessary in Munich (*M* = 4.2, SD = 1.00, *N* = 705, 5-point Likert scale from 1 = *no change necessary* to 5 = *change very much necessary*).

Presented with three different scenarios for the future of mobility in Munich in 5-10 years, the respondents indicated that they found a scenario on keeping the status quo with a focus on motorized private transport to be rather likely (*M* = 3.7, *SD* = 0.94, *N* = 794) and plausible (*M* = 3.1, *SD* = 1.21, *N* = 780), but not very desirable (*M* = 1.9, *SD* = 1.06, *N* = 790). In comparison, they rated a scenario with a focus on active mobility and participation to be more desirable (*M* = 4.0, *SD* = 1.30, *N* = 788) and plausible (*M* = 3.5, *SD* = 1.22, *N* = 784), but as less likely (*M* = 2.6, *SD* = 0.83, *N* = 796). A scenario focusing on technology-driven mobility with autonomous shuttles at the center was rated as moderately desirable (*M* = 3.2, *SD* = 1.29, *N* = 796), but as not that likely (*M* = 1.8, *SD* = 0.81, *N* = 798) and plausible (*M* = 2.5, *SD* = 1.18, *N* = 788; 5-point Likert scale for each item from 1 = *not desirable/ likely/plausible* to 5 = *very desirable/likely/plausible*). The respondents indicated that future mobility should rather be shaped by active modes of transport (*M* = 4.0, *SD* = 1.08, *N* = 807) than by private car ownership (*M* = 2.3, *SD* = 1.19, *N* = 802; 5-point Likert scale for each item from 1 = *do not agree* to 5 = *very much agree*).

4 CONCLUSIONS

Once data collection is completed, multivariate analyses of (co-)variance will be carried out to determine how the level of identification with the group of cyclists, pedestrians or motorists relates to perceived safety and comfort as well as to visions and scenarios for future mobility and the support of active forms of mobility. Furthermore, differences between the various neighborhoods that use or don't use car-reduction interventions and possible effects on attitudes towards future active mobility will then be investigated. Additionally, in summer 2023, in-depth scenario workshops will be carried out with citizens on future mobility to reveal in further detail what exactly they envision. At this point in data collection, we can conclude that the finding that people wish for more and safer cycling infrastructure is not new [6–8]; however, our preliminary results from a citizen survey reveal that contrary to previous findings based primarily on expert opinions [2, 3], technology-driven scenarios are not seen as the desirable way forward. In order to shape future urban mobility in a sustainable and safe way, citizens' wishes need to be respected in order to gain acceptance and support for implementation.

5 REFERENCES

[1] P. Jaramillo, S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead, "Transport", in IPCC (ed.), *Climate change 2022: Mitigation of climate change. Contribution of working group III to the sixth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 2022.

[2] A. Ceder, "Urban mobility and public transport: Future perspectives and review", *International Journal of Urban Sciences* 25 (2021), 455.

[3] M. Miskolczi, D. Földes, A. Munkácsy, M. Jászberényi, "Urban mobility scenarios until the 2030s", *Sustainable Cities and Society* 72 (2021), 103029.

[4] E. Ebbesson, "Towards a co-creation framework based on citizens' dreams of future mobility", *Transportation Research Interdisciplinary Perspectives* 16 (2022), 100686.

[5] S. Clayton, B.T. Karazsia, "Development and validation of a measure of climate change anxiety", *Journal of Environmental Psychology* 69 (2020), 101434.

[6] Sinus Markt- und Sozialforschung GmbH, "Fahrrad-Monitor Deutschland 2019: Ergebnisse einer repräsentativen Online-Befragung [Cycling monitor Germany 2019: Results of a representative online survey]", 2019, available at https://www.bmvi.de/SharedDocs/DE/Anlage/K/fahrradmonitor-2019-ergebnisse.pdf?__blob=publicationFile

[7] R.L. Sanders, "Examining the cycle: How perceived an actual bicycling risk influence cycling frequency, roadway design preferences, and support for cycling among Bay Area residents", *Dissertation*, University of California 2013.

[8] R. von Stülpnagel, N. Binnig, " How safe do you feel? - A large-scale survey concerning the subjective safety associated with different kinds of cycling lanes", *Accident Analysis & Prevention* 167 (2022), 106577.

Bicycle crashes involving commuters – a special group of crash victims. Results of a detailed survey of crash victims.

V. Zuser[*]

[*] Austrian Road Safety Board (KFV)
Schleiergasse 18, 1100 Vienna, Austria
e-mail: veronika.zuser@kfv.at

Keywords: single-bicycle crashes, collisions, cause of accident, circumstance of accident, commuting, survey.

1 INTRODUCTION

According to the last official mobility survey in Austria, which dates back 10 years, journeys to or from work account for almost half of the daily journeys of employed persons (44%) on working days. 7% of those commuting journeys are made entirely or at least partly by bicycle [1]. Since then, this share has risen. According to (unpublished) surveys commissioned by KFV (Austrian Road Safety Board), 21% of Austrians of working age used a bicycle at least occasionally to get to work in 2020/2021. AUVA, the social insurance for occupational risks for more than 3.3 million employees in Austria, recognized 12,264 commuting accidents in 2017, of which cyclists accounted for 25% (1,795 persons). In 2021, this share had risen to 29% (1,436 persons). Comparing the proportion of persons who cycle to work with the proportion of commuters' bicycle crashes, it is evident that bicycle commuters are a group of above-average risk and that targeted measures to reduce their crashes have a high prevention potential. Therefore, KFV and AUVA conducted a detailed study of bicycle crashes of commuters to develop prevention measures.

2 METHOD AND SAMPLE

2.1 Basic considerations

Bicycle crashes in general and bicycle commuters' crashes in special are difficult to investigate in official statistics because of the high proportion of (officially) unrecorded crashes. In addition, available statistics either do not include the purpose of the journey (e.g. official road accident statistics), or they include information on the purpose of the journey but lack relevant information about the crash itself on the other hand (e.g. AUVA's statistics and hospital surveys such as IDB). The topic of commuters' bicycle crashes could therefore not be approached with the available statistics.

2.2 Method

Therefore, AUVA and KFV decided to contact persons who had had a crash by bicycle while commuting and asked them to fill out a detailed questionnaire (online survey). In April 2019, AUVA sent a letter to all persons who had been involved in a crash while commuting by bicycle in the years 2016-2018 and asked them to participate in the online survey. To increase the response rate, participants could take part in a prize draw for vouchers. The online survey was available for 3 weeks.

The purpose of the survey was to obtain the victims' subjective views on the causes and the course of the crash, to obtain a more nuanced and comprehensive picture of the occurrence of commuters' bicycle crashes. The following topics were covered in detail: information about the crash (type, location, month, time of day); injuries, treatment, recovery; police record; information about the bicycle; behavior of other road users and own riding behavior and maneuvers; helmet use; road and weather conditions; visibility and sight distances; distraction, haste, time pressure, impairment; behavior changes as a result of the crash; subjective assessment of the person responsible for the crash; usage patterns; riding experience and ability; demographic data.

2.3 Description and representativeness of the sample

Of the total of 5,628 persons who were contacted, 571 took part in the online survey, which corresponds to a response rate of 10%. The sample drawn from the completed questionnaires was compared with the entire AUVA data set in terms of gender, type of accident, month, time of day, etc. to ensure that it reflected the latter. In summary, it can be assumed that the persons who participated in the survey represent the basic dataset well in the mentioned framework parameters. The year 2018 is overrepresented in the sample. This may be due to the fact that recent accidents are better remembered.

3 RESULTS

The majority (93%) of all crashes occurred in built-up areas. Routes to work are mostly recurring routes, 96% of the persons knew their route well. The way to work is clearly more accident-prone than the way back: two thirds (64%) of the crashes occurred on the way to work. The split between singe-bicycle crashes and crashes involving third parties was nearly half and half (54% single-bicycle crashes vs. 46% collisions). There are large differences between single-bicycle crashes and collisions in their characteristics.

Table 1: Overview of the crashes in the sample by crash type.

Type of crash	Detail	Sample	Share in %
Single-bicycle crashes		308	54%
Crashes involving third parties	total *of which: with a car* *with a bicycle*	263 *173* *59*	46% *66%* *22%*
Total		571	100%

There is a very high proportion of crashes not reported to the police in the sample, both in singe-bicycle crashes and in collisions: Only 17% of single-bicycle crashes were recorded by the police, but also only 58% of crashes involving third parties. This means that a total of 64% of the crashes described are not included in the official road accident statistics compiled by the police.

3.1 Characteristics of single-bicycle crashes

Particularly striking is the high proportion of single-bicycle crashes, in which road conditions played a decisive role (76%): In detail, it was a slippery or wet road in 28%, in 18% tracks were involved, snow and ice in 12%, rolling chippings or gravel in 9%, other kind of dirt in 8% and kerbs in 8%. In addition, single crashes occur more often than average in darkness or dusk/dawn (23%), during precipitation (16%), while (internally or externally) distracted (21%), while in a hurry or under time pressure (26%), on a downhill slope (21%) and with the own speed (more likely) too fast for the conditions (20%). 61% of single-bicycle crashes involved a driving maneuver such as driving around bends (41%) or a lane change or swerving (20%).

3.2 Characteristics of crashes involving third parties

Crashes with other road users involved occur most frequently at intersections (both with and without traffic lights) (60%). An important factor in crashes with third parties is restricted visibility due to vegetation, objects, or other road users (21%). Own distraction is a contributing factor in only 9% of collisions, 2% disregarded rules or laws. By far the most relevant opponent is the car (66%), followed by other cyclists (22%). Pedestrians were the other party in 6% of crashes, HGVs in 5%. Also remarkable was the fact that 5% of third-party crashes involved more than 1 opponent.

Crashes with cars: Most crashes involving passenger cars occurred at intersections or road junctions (68%). 55% of the accidents took place on the road in mixed traffic, 29% on cycle paths or mixed pedestrian and cycle paths. According to the respondents' assessment, the car driver was to blame for the accident in 94%

of the cases. The most frequent misconduct of the car driver was a violation of the right of way (55%), 18% were travelling too fast or at an inappropriate speed, 7% were dooring crashes.

Crashes with other cyclists: One in 7 bicycle-bicycle-crashes had more than 1 opponent involved (14%). 86% of the opponents did not behave correctly. 12% of the participants assessed that they had caused the crash themselves, 75% blamed the other cyclist, and 13% another road user involved. The most common misconduct of others was violation of the right of way (24%), excessive or inappropriate speed (19%), or unexpected lane change (14%).

Accident location: While cars are the by far the most frequent crash opponent on intersections (76%), the picture is different on sections without intersections, where only 45% of crash opponents were cars, 29% cyclists and 18% pedestrians. The most relevant crash causes on road stretches without intersection were dooring, unexpected lane changes and sudden crossings by pedestrians.

3.3 Injury patterns and consequences in behavior after the accident

80% of the crash victims were treated as outpatients, 20% had to be admitted to hospital as inpatients. The most common injuries were bruises (61%) and abrasions (53%), most often of the knees (32%), the shoulders (26%) and the head (25%). However, 17% of the injured did not or not (yet) fully recover after the accident. Among permanent injuries, bone fractures (58%) and tendon or muscle injuries (30%) were more common than in the overall sample. Permanent injuries mainly affected the knees (41%) and the shoulders (37%).

After the accident, only 69% continued to use the bicycle for their commute to work. Of those who continued cycling to work, half (50%) changed their behavior after the accident, e.g., by riding slower or more carefully overall, by riding more carefully at the crash site or by changing the route.

4 DISCUSSION, CONCLUSIONS AND OUTLOOK

Commuters are a special cyclist group. They are mostly experienced cyclists, who travel on paths usually well known. Factors such as time pressure and haste are much more determining for them than for other types of cyclists. It is very unfortunate that almost a third of the cyclists involved in an accident are "lost" to cycling. This makes it even more important to prevent these accidents. A point that needs to be discussed and investigated in further studies is that the majority of participants – even if their opponents were other cyclists – believe that the opponents were to blame for the crash. Were those who were innocent of the collision more likely to respond to the survey, or is the subjective assessment of who is to blame partly wrong?

Prevention measures should include improvements of (cycling) infrastructure conditions and surface, redesign of high-conflict intersections, speed limits in sensitive areas, or lower speed limits in built-up areas in general. Awareness-raising activities should focus on what cyclists can do to avoid accidents (e.g. braking techniques, behavior in adverse road conditions, improving their own visibility, strategies for coping with time pressure).

An update of the study is planned, as the proportion of bicycle commuter crashes has increased due to the growing number of cyclists and the large increase in the number of bicycle messenger services since the pandemic. The update will also include e-scooter commuter crashes.

REFERENCES

[1] Tomschy, R., Herry, M., Sammer, G., Klementschitz, R., Riegler, S., Follmer, R., Gruschwitz, D., Josef, F., Gensasz, S., Kirnbauer, R. and Spiegel, T., “Österreich unterwegs 2013/2014”, Ergebnisbericht zur österreichweiten Mobilitätserhebung „Österreich unterwegs 2013/2014“, Austrian Federal Ministry of Transport, Innovation and Technology (ed), Vienna, 2016.

Using body sensors for evaluating experiences with smart cycling technology

M.R. Boot
Transport Engineering and Management
University of Twente
Email:
m.r.boot@utwente.nl

M.B. Ulak
Transport Engineering and Management
University of Twente
Email:
m.b.ulak@utwente.nl

P.J.M. Havinga
Pervasive Systems
University of Twente
Email:
p.j.m.havinga@utwente.nl

K.T. Geurs
Transport Engineering and Management
University of Twente
Email:
k.t.geurs@utwente.nl

Keywords: cycling, experience, body sensors, smart connected bicycles

1 INTRODUCTION

The submission to ICSC 2023 consists of a summary of a research article that is under review for the Transportation Reviews journal. This article is indicated by “the paper” in the text below.

Many citizens and experts worldwide desire to promote cycling usage and safety. These intentions have sparked interest in Smart Cycling Technologies (SCTs), cycling experiences, and body sensors. SCTs employ smartness to help cyclists, for example, in case of speed adaptation systems (Kapousizis et al., 2022). SCTs are increasingly popular, are often integrated in e-bikes, and are increasing in market share (Berge et al., 2022; Nikolaeva et al., 2019; Oliveira et al., 2021), their influence on cycling experiences is important to understand. Cycling experiences are diverse, complex, and under- researched. Existing research shows that next to safety and stress, meaningful and memorable cycling experiences are highly valuable and desirable for cyclists (van Hagen et al., 2019). Cycling experiences interact with travel behavior and wellbeing, for example, when perceptions of unsafe conditions discourage cyclists from cycling more often (Popan, 2020; Spinney, 2009). Cycling experiences may be understood via data from body sensors, which are sensors directly connected to the human body, and which can measure variables like heart rate, breathing, brain activity, and body movements. These sensors can provide real-time data and are increasingly used in cycling research (Lai et al., 2013; Lim et al., 2022). Body sensors may help to overcome limitations in well-known data collection. For example, approaches including crash statistics, qualitative data, and questionnaires are highly subjective and/or measure at suboptimal moments in place and/or time (Ryerson et al., 2021).

Some studies have already employed body sensors to evaluate behavioral and experiential effects of SCTs on cycling research, yet several knowledge gaps remain in this specific domain of research. Not enough is known about the applicability of body sensors in evaluations of the influence of SCTs on cycling experience. The reliability and validity of sensed data is not always clear, not enough is known about causal analysis of data from multiple types of sensors in mixed methods approaches, and it is challenging to rule out effects of confounding variables when trying to understand causes for experiences (Bigazzi et al., 2022; Kalra et al., 2022; Lim et al., 2022). To address these knowledge gaps, the paper proposes a conceptual framework for body sensor-based evaluations of the influence of SCTs on cycling experience. The framework is based on a systematic review of existing literature about body sensors for cycling experience evaluations. The framework and review guide future evaluations with knowledge about types of sensors, types of cycling experiences, factors that influence experiences with SCTs, and approaches for data analysis.

2 METHODOLOGY & RESULTS

The approach for the systematic literature review is based on the PRISMA method (Preferred Reporting Items for Systematic reviews and Meta-Analyses, (Page et al., 2021)) for searching, screening, and selecting the literature that is to be included in the review. This method ensures reproducibility, transparency, and extended reach into existing literature, which overcomes omissions in many previous reviews that did not describe the review methodology used (Van Wee et al., 2016).

The conceptual framework is depicted in Figure 1. The framework shows four categories of components: smart cycling technologies, cyclists and their experiences, evaluation methods, and contextual factors. The blue-filled boxes in the framework denote factors and methods that are important to consider in each of the categories. The blue lines between categories and components denote interactions.

The paper draws several conclusions based on the literature review. In the existing literature, few papers exist about studies that use body sensors in field evaluations of SCTs. These studies are limited in scope, and their results are not conclusive. Sample sizes are generally small. The diversity, amount, and complexity of SCTs evaluated is generally rather low. Several types of sensors such as sensors for eye tracking and brain activity are only evaluated in a handful of studies which is not enough for strong conclusions. Various studies use different terms to denote the same and/or slightly different concepts. Several studies use the same or very similar physiological measurements to examine “perceived safety”, “stress”, “stress response”, “risk perception”, and “arousal”. Lack of replication and inconsistency in terminology makes it difficult to understand what the consensus is in studies that use this terminology. Moreover, body sensor data is subject to strong effects of confounding variables, which makes it difficult to link objective sensor data to specific subjective experiences. Nevertheless, interest in body sensors for analysis of cycling experience was and still is warranted because selected studies show that using these types of sensors has led to new knowledge and new opportunities about understanding what cyclists experience.

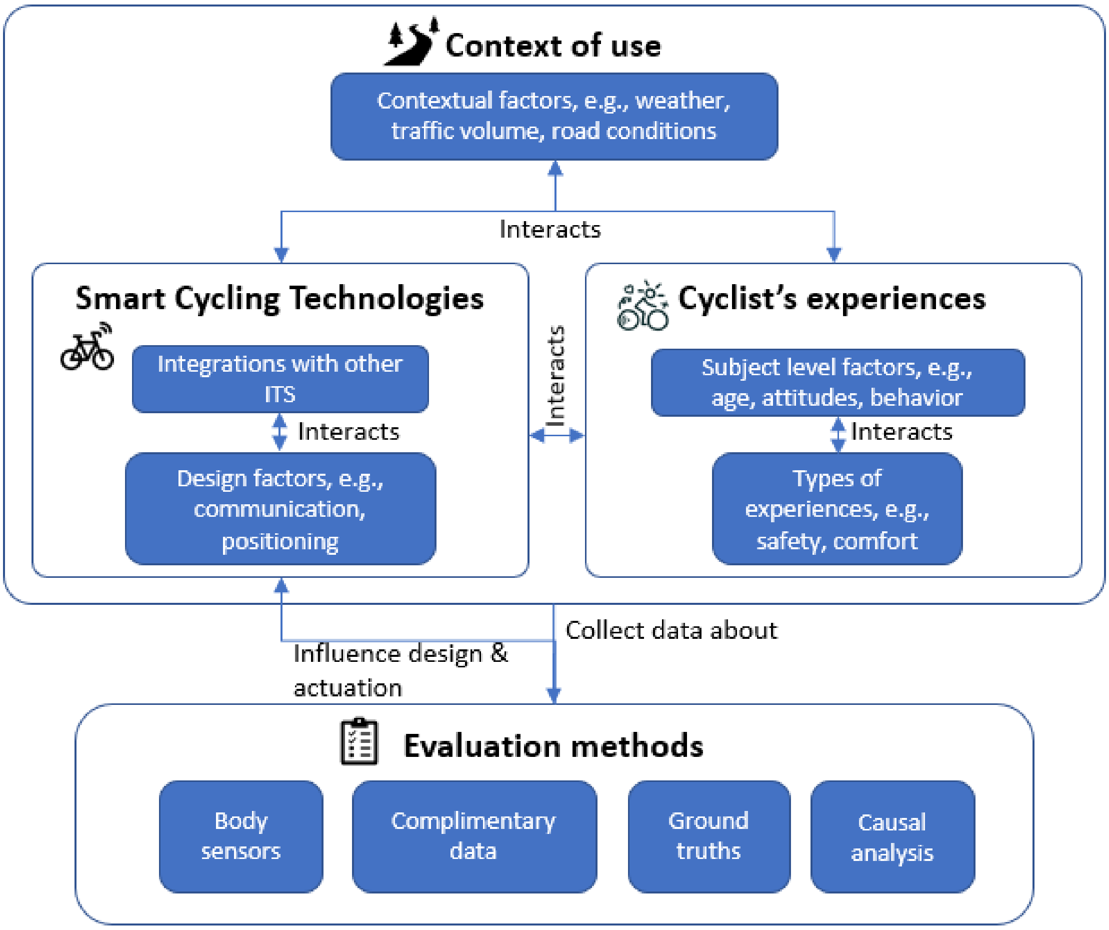


Figure 1 - Conceptual framework of factors and methods in body sensor-based evaluations of the influence of Smart Cycling Technologies on cycling experience.

Seven studies were found that use body sensors already in field tests of the influence of SCTs on cycling experience. These studies show different ways of using the body sensors: only as input for human-computer interaction mechanisms in the bicycles (e.g., (Walmink et al., 2014)), only as input for evaluation by human experts (e.g., (Venkatachalapathy et al., 2022)), or as a mix of both (e.g., (De La Iglesia et al., 2018)). Evaluations of SCTs that use real-time experience data as input to determine actions of SCTs point to an interesting research field. In this research field, SCTs adapt their course of action to the experiences of the cyclists in-the-moment. One example is an e-bike that adapts the support levels of e- bike motors to cyclist fitness levels, and another example is a helmet that communicates heart rates visually to other cyclists to stimulate social interactions. Future research is recommended to investigate the mechanics and value of designs that use experience data in this way. Furthermore, it is important to mention that some types of SCTs may have only marginal influence which may therefore not be observed in sensor data (e.g., (Venkatachalapathy et al., 2022)). These conclusions point to a need for more rigorous research into methods for evaluations of the influence of SCTs on e.g., perceived safety, comfort ratings, etc. Also, these conclusions point to a need to investigate whether marginal influences of SCTs on experience will remain undetectable, or whether more accurate sensors will become able to identify differences in experiences with and without various types of SCTs.

The conceptual framework and the literature review partially answered knowledge gaps that were open until now. Regarding SCTs, attention needs to be paid to: the goals of the SCT, degrees of being smart, positions of devices, communication types, and physical interventions. Regarding sensors, the paper shows which sensor types may fit to which experiences. For example, physiology data from heartbeats and skin response may link to stress response while brain activity data may link to cognition. The reliability of sensor data to link to certain experiences remains however relatively unclear and is therefore an interesting topic for future research. Regarding experiences, it is worth continuing the interest in improving safety and comfort. Yet, high novelty can be reached by investigating under-researched types of cycling experiences such as experiences of flow and bliss. Furthermore, future evaluations may appreciate the inclusion of novel types of sensors, for example, IMUs or sensors integrated in new types of material and new integrations with human bodies (Lai et al., 2013). Body sensor data as input to determine real-time actuation in human–computer interaction in SCTs deserves more attention. This way of using sensor data can lead to interesting kinds of experiences – see also other research on experiences with human-robot and human-AI interaction (Andres, 2020). To mitigate the complexities of mixed methods approaches, advancements in analytical approaches are required to work with subject- and context-level confounding factors and to determine causality.

3 CONCLUSION & OUTLOOK

The paper supports future evaluations by clarifying which types of sensors may fit to which types of cycling experiences, the factors that influence cycling experiences with SCTs, and how statistical methods for causal analysis should be advanced. Furthermore, the review shows that more rigorous research is necessary about linking sensor data to specific types of experiences, about more diverse types of experiences, and about emerging types of body sensors. Also, this review shows that SCTs can use real-time body sensor data in novel ways. Altogether, this study can help to determine which SCTs truly improve cycling experiences.

REFERENCES

Andres, J. (2020). *Integrated Exertion–Understanding the Design of Human–Computer Integration in an Exertion Context.* (PhD Dissertation). RMIT University, Retrieved from https://exertiongameslab.org/wp-content/uploads/2020/11/josh_andres_phd.pdf

Berge, S. H., De Winter, J., & Hagenzieker, M. (2022). *Support systems for cyclists in automated traffic: A review and future outlook* Preprint. Retrieved from http://doi.org/10.13140/RG.2.2.29549.05606

Bigazzi, A., Ausri, F., Peddie, L., Fitch, D., & Puterman, E. (2022). Physiological markers of traffic-related stress during active travel. *Transportation Research Part F: Traffic Psychology and Behaviour, 84*, 223-238.

De La Iglesia, D. H., De Paz, J. F., Villarrubia González, G., Barriuso, A. L., Bajo, J., & Corchado, J. M. (2018). Increasing the intensity over time of an electric-assist bike based on the user and route: The bike becomes the gym. *Sensors, 18*(1), 220.

Kalra, A., Lim, T., Pearson, L., & Beck, B. (2022). Methods used to capture subjective user experiences in adults while riding bicycles: a scoping review. *Transport Reviews*, 1-25.

Kapousizis, G., Ulak, M. B., Geurs, K., & Havinga, P. J. (2022). A review of state-of-the-art bicycle technologies affecting cycling safety: level of smartness and technology readiness. *Transport Reviews*, 1-23.

Lai, X., Liu, Q., Wei, X., Wang, W., Zhou, G., & Han, G. (2013). A survey of body sensor networks. *Sensors, 13*(5), 5406-5447.

Lim, T., Kalra, A., Thompson, J., Caldwell Odgers, J., & Beck, B. (2022). Physiological measures of bicyclists' subjective experiences: A scoping review. *Transportation Research Part F: Traffic Psychology and Behaviour, 90*, 365-381.

Nikolaeva, A., te Brömmelstroet, M., Raven, R., & Ranson, J. (2019). Smart cycling futures: Charting a new terrain and moving towards a research agenda. *Journal of Transport Geography, 79*.

Oliveira, F., Nery, D., Costa, D. G., Silva, I., & Lima, L. (2021). A Survey of Technologies and Recent Developments for Sustainable Smart Cycling. *Sustainability, 13*(6).

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., . . . Brennan, S. E. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic reviews, 10*(1), 1-11.

Popan, C. (2020). Beyond utilitarian mobilities: cycling senses and the subversion of the car system. *Applied Mobilities, 5*(3), 289-305.

Ryerson, M., Long, C., Fichman, M., Davidson, J., Scudder, K., Kim, M., . . . Harris, M. (2021). Evaluating cyclist biometrics to develop urban transportation safety metrics. *Accident analysis & prevention, 159*, 106287.

Spinney, J. (2009). Cycling the city: Movement, meaning and method. *Geography Compass, 3.2*, 817-835. Van Hagen, M., Spoorwegen, N., Govers, B., & BV, G. C. (2019). Durven, kunnen en willen fietsen! *De klantenwensenpiramide voor reizigers toegepast op het fietsbeleid*.

Van Wee, B., & Banister, D. (2016). How to write a literature review paper? *Transport Reviews, 36*(2), 278-288.

Venkatachalapathy, A., Hamann, C., Spears, S., Shirtcliff, E. A., & Sharma, A. (2022). A naturalistic study assessing the impact of daytime running lights and vehicle passing events on cyclist's physiological stress. *Transportation Research Interdisciplinary Perspectives, 16*.

Walmink, W., Wilde, D., & Mueller, F. F. (2014). *Displaying heart rate data on a bicycle helmet to support social exertion experiences.* Paper presented at the 8th International Conference on Tangible, Embedded and Embodied Interaction 2014.

A Systematic Review on Significant Factors Contributing to the Bikeability

***Yang Ligu, #Kum Yung Juan, +Tan Chek Tien, ⊗Yap Hui Jin**

*Engineering
Singapore Institute of Technology
10 Dover Drive Singapore 138683
email: 2103234@sit.singaporetech.edu.sg

Engineering
Singapore Institute of Technology
10 Dover Drive Singapore 138683
email: Juan.Kum@singaporetech.edu.sg

+Infocomm Technology
Singapore Institute of Technology
10 Dover Drive Singapore 138683
email: chektien.tan@singaporetech.edu.sg

⊗Active Mobility Group
Land Transport Authority
1 Hampshire Road, Block 11, Level 4, Singapore 219428
email: Yap_Hui_Jin@lta.gov.sg

Keywords: Bikeability, Systematic review, Users expectation

1 ABSTRACT

This study aimed to conduct a systematic review of literature to identify factors associated with bikeability and select factors to develop the Bikeability Index of Singapore (Bikeability_SG). The review analyzed 25 studies and identified six groups of factors that influence bikeability.

The study highlights the increasing global interest in studying bikeability over the past decade and how advances in technology have led to innovative methodologies for defining bikeability. However, there is a need for greater consensus to establish a universally applicable set of factors that influence bikeability worldwide. The study proposes a framework for a bikeability index study for Singapore based on the framework used by most of the selected literature and the grouping of various factors.

The paper also explores the potential applicability of these factors to bikeability indices in other cities. The study presents limitations that should be addressed, such as potential bias or errors in variable selection and different measurements of the selected variables.

To develop a comprehensive and reliable bikeability index that matches user expectations, both objective and subjective data should be collected from a wide range of users. A robust bikeability index can provide policymakers, transport planners, designers, and implementation parties with a priority list for areas that require improvement in the city.

2 INTRODUCTION

There is increasing number of studies to assess what environmental and/or personal factors influencing cycling. Environmental factors include both the physical built environment and users' perceptions of their surroundings, which are often linked to personal factors. While some studies mentioned what specific environmental factors (i.e. street connectivity (Ma, L.et al, 2019), cycling infrastructure and its quality, land use density and traffic environment, etc.) influence cycling in various scales of community, no systematic review has yet been conducted to identify the most common environmental factors across various studies.

3 RECORDS SELECTEF FOR REVIEW

This paper aims to conduct a systematic review of the literature published between 2012 and 2022 to identify the various factors associated with bikeability. 25 records are selected from 128 papers following the steps shown in Figure 1.

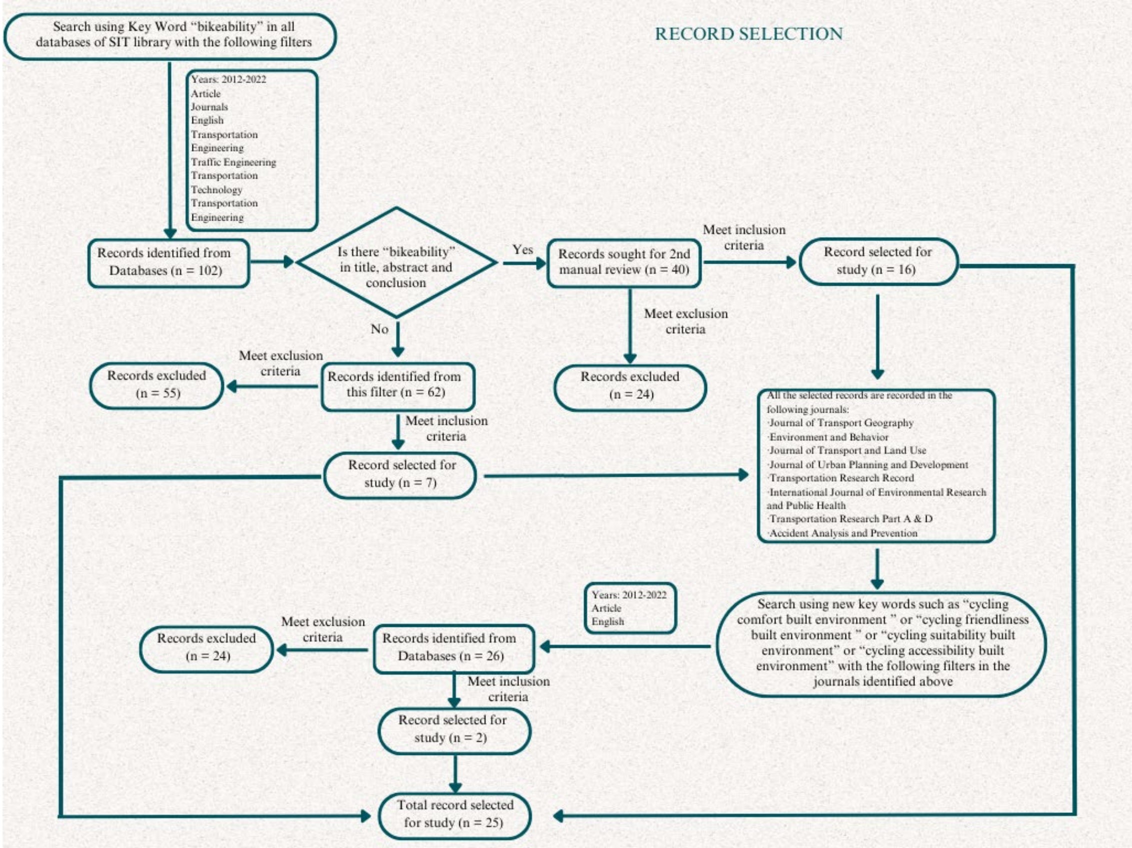


Figure 1: Identification of Studies

4 RESULTS FROM THE REVIEW

The following items are derived from the systematical review for further evaluation.

- Geographical Location of Bikeability Studies
- Bikeability Measures
- Factors and Components for Measuring Bikeability
- Coefficient Ranking for Various Factors

REFERENCES

[1] Ma, L., Dill, J., & Mohamadi, H. (2019). Do people's perceptions of neighborhood bikeability match "reality"? Transportation Research Part A: Policy and Practice, 123, 139-154. doi: 10.1016/j.tra.2019.02.002

Public opinion on smart bicycle technologies enhancing cycling safety: A survey study among 1354 cyclists across Europe

G. Kapousizis*, Mehmet Baran Ulak[#], Karst Geurs[†]

Department of Civil Engineering,
University of Twente
Drienerlolaan 5 7522 NB, Enschede, The Netherlands
[*] g.kapousizis@utwente.nl; [#] m.b.ulak@utwente; [†] k.t.geurs@utwente.nl

Keywords: e-bike, cycling safety, smart technologies, European survey, multinomial logit model.

1 INTRODUCTION

The Covid-19 pandemic and the recent energy crisis motivated many people to switch to more active transport modes such as cycling [1]. Despite the numerous benefits of cycling, certain barriers, such as low fitness levels, topographical difficulties, and established habits, prevent more people from embracing cycling as their everyday transportation [2]. E-bikes can help overcome some of these barriers and people, especially elderly or commuters, are eager to use them since e-bikes require less effort to cycle. However, e-bikes potentially lead to a higher number as well as more severe crashes since they are usually faster and heavier than regular bicycles [3]. Worldwide, e-bike users are facing many crashes, and many countries are developing or adjusting bicycle infrastructure to address this issue. Despite the improvements in the infrastructure, countries such as the Netherlands, with the best and well designed bicycle network [4], still experience many e-bike crashes [5].

Recent years have witnessed a growing academic interest in addressing cycling safety issues by adopting new technologies, such as bicycle sensors and the Internet of Things (IoT), to prevent and reduce e-bike crashes [6]. However, research to date has not yet determined users' intention to adopt new bicycle technologies that increase safety and comfort. To adress this gap, the aim of this study is twofold: 1) to investigate users' opinions of new technologies on e-bikes by collecting data from e-bike users and people interested in buying an e-bike across six European countries (Austria, Belgium, Germany, Greece, Netherlands and Switzerland) and 2) to examine the role of different safety-related factors such as available cycling infrastructure, perceived safety and shared road with motor vehicles on people's perception towards smart features on e-bikes that enhance cycling safety.

2 METHODOLOGY

An online survey was launched between November 2022 and January 2023 in Austria, Belgium, Germany, Greece, the Netherlands and Switzerland. The survey was translated into five languages (Dutch, English, German, Greek, and French), targeting people who already use an e-bike or are willing to buy one. The countries were not selected randomly; on the contrary, we chose them due to the different quality of cycling infrastructure to understand people's perceived safety and cycling culture. These countries vary in size, cycling rate and cycling safety. While the Netherlands has a high-quality cycling infrastructure, a dense network, and a high bicycle rate [4], Austria, Belgium and Germany have medium cycling infrastructure and bicycle rates. On the other hand, Greece has scarce and low-quality infrastructure network and a low cycling rate [7].

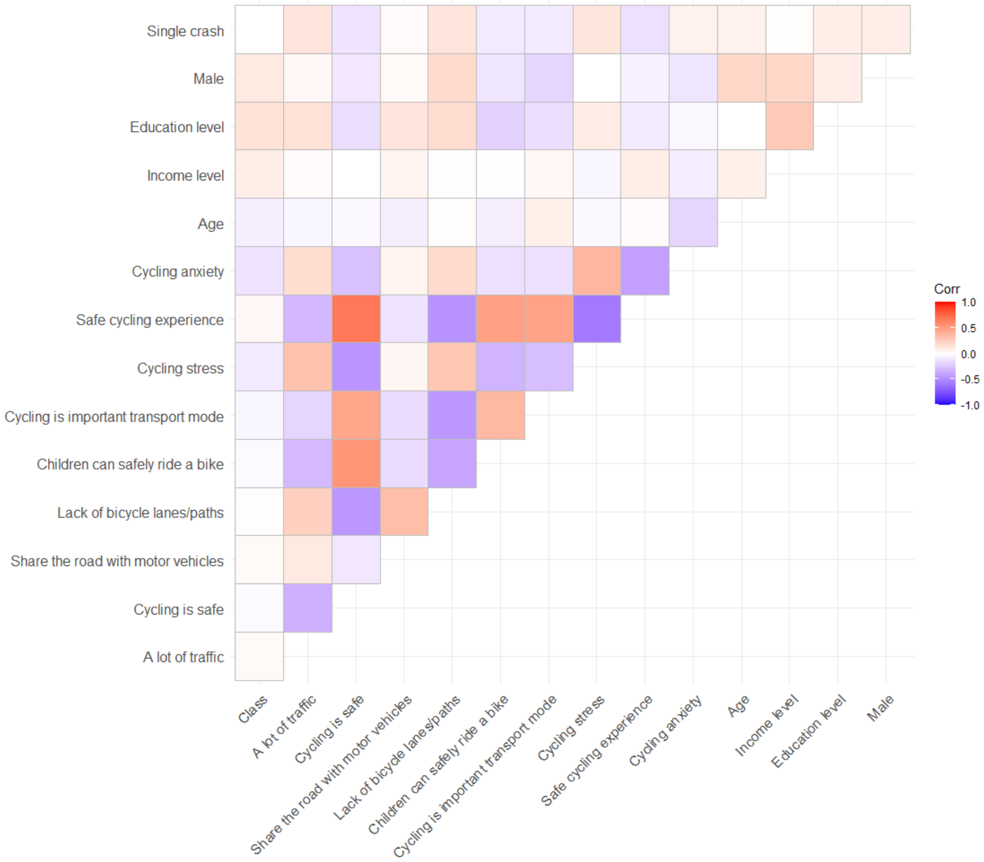
The survey consisted of three parts. Firstly, screening questions such as mobility habits, bicycle ownership and intention to buy an e-bike were asked of participants. Secondly, questions were asked regarding the use of the e-bike and the perceived safety of new smart bicycle systems enhancing cycling safety by rating these systems. Lastly, sociodemographic characteristics were obtained. The questions in the first two parts were mainly asked on a 5-point Likert scale. The survey provided quantitative data from 1354 cyclist participants from six European countries. 54% of the respondents were male, 56% were highly educated (university degree and higher), and 33% earned more than 3000€ per/month net. Note, the Dutch sample is representative based on the Mobility Panel Data for e-bike users. No available databases for cyclists could be found to compare our samples for the rest of the countries.

A Multinomial Logit model (MNL) was applied to the collected data estimating to what extent socio-demographic characteristics, safety-related factors (i.e. perceived safety, traffic volume, cycling infrastructure), and cycling culture affect respondents' opinion towards smart features on e-bikes.

3 RESULTS

This section presents the model estimated regarding the usefulness of new smart features on e-bikes to increase cycling safety and a correlation matrix of the variables can be found in Figure 1. Before we conducted the analysis, we clustered the respondents using k-means into three groups; based on respondents' perception toward bicycle technologies: 1) not useful, 2) moderately useful and 3) very useful. The estimation of the MNL model for the groups mentioned above is presented in Table 1.

Figure 1: Correlation matrix



The model uses the category technology is "not useful" as a reference group in order to estimate the results. The results of the second category, "moderately useful", indicate that age, education and cycling anxiety are the only significant variables with β = 0.021, β = -0.241 and β = 0.181, respectively. Indicating that elderly perceived that new technologies could positively affect their safety while cycling. Also, people who feel anxious when cycling have a positive opinion towards new bicycle technologies. In contrast, highly educated people have a negative opinion of smart bicycle technologies. Considering the results from the third category, "very useful", males believe that smart bicycle technologies could positively affect their safety than females with β = 0.382. Furthermore, people who live in areas with high traffic have a positive view of these technologies, while people who live in areas with few bicycle paths do not think the smart bicycle technologies will affect their safety. Lastly, in a question related to cycling stress people who stated neutral stress when cycling believe that smart cycling technologies will not affect their safety β = 0.421. The remaining variables are not significant in both categories.

4 CONCLUSIONS

Using an European base survey, we identified which variables influence users' opinions towards smart bicycle technologies. This study provides novel results for the user acceptance of new technologies on e-bikes as a potential solution to improve e-bike safety and comfort. Despite the fact that this is the first survey investigating smart bicycle technologies, there is evidence that such technologies are perceived positively by an important portion of respondents.

Table 1: MNL model results for users' perception towards bicycle technologies

Reference Class: Technology is not very useful	Moderately Useful			Very Useful		
Variables	Beta	St.Error	p-value	Beta	St.Error	p-value
(Intercept)	- 0.319	0.762	0.675	0.309	0.843	0.714
Age	0.021	0.005	0.0	0.002	0.005	0.727
Income	- 0.001	0.028	0.985	0.024	0.03	0.427
Education	- 0.241	0.059	0.0	0.079	0.065	0.229
Male	- 0.265	0.139	0.057	0.382	0.157	0.015
Single crash	- 0.105	0.134	0.432	- 0.196	0.149	0.189
Cycling stress	0.13	0.144	0.366	- 0.421	0.164	0.01
Cycling anxiety	0.181	0.076	0.017	- 0.081	0.088	0.363
Cycling experience	- 0.1	0.102	0.326	- 0.06	0.113	0.595
There is a lot of traffic in my town	0.038	0.064	0.56	0.145	0.073	0.048
Cycling is safe in my town	0.115	0.088	0.189	- 0.104	0.097	0.284
Cyclists share the road with motor vehicles in my town	- 0.046	0.061	0.451	- 0.028	0.069	0.679
There is a lack of bicycle lanes/paths in my town	- 0.092	0.065	0.156	- 0.159	0.072	0.028
Children can safely ride a bike to their school in my town	- 0.091	0.064	0.154	- 0.095	0.071	0.182
Cycling is an important transport mode in my country	- 0.031	0.058	0.596	0.024	0.065	0.708

REFERENCES

1. Nikitas, A., et al., *Cycling in the Era of COVID-19: Lessons Learnt and Best Practice Policy Recommendations for a More Bike-Centric Future.* Sustainability, 2021. **13**(9).
2. Fishman, E. and C. Cherry, *E-bikes in the Mainstream: Reviewing a Decade of Research.* Transport Reviews, 2016. **36**(1): p. 72-91.
3. Panwinkler, T. and C. Holz-Rau, *Causes of pedelec (pedal electric cycle) single accidents and their influence on injury severity.* Accident Analysis and Prevention, 2021. **154**.
4. Schepers, P., et al., *The Dutch road to a high level of cycling safety.* Safety Science, 2017. **92**: p. 264-273.
5. Statistics Netherlands (CBS). *610 traffic deaths in 2020*. 2021 [cited 2023 April 22]; Available from: https://www.cbs.nl/en-gb/news/2021/15/610-traffic-deaths-in-2020
6. Kapousizis, G., et al., *A review of state-of-the-art bicycle technologies affecting cycling safety: level of smartness and technology readiness.* Transport Reviews, 2022: p. 1-23.
7. European Commission, *Special Eurobarometer Mobility and Transport*. 2020.

How to design road safety campaigns for e-scooter riders – a mixed-method study

J. Anke[*], M. Ringhand[*], T. Gehlert[#]

[*]Chair of Traffic and Transportation Psychology
Technische Universität Dresden
Hettnerstr. 1, 01069 Dresden, Germany,
juliane.anke@tu-dresden.de,
madlen.ringhand@tu-dresden.de

[#] German Insurers Accident Research (UDV),
Berlin, Germany,
t.gehlert@gdv.de

Keywords: micro-mobility, e-scooter, critical events, focus groups, road safety campaigns.

1 INTRODUCTION

In parallel with the introduction and rise of e-scooter mobility, questions concerning the safety of these vehicles arose. Road safety campaigns in this field are as new as e-scooters, which is why data-based or theory-driven road safety approaches have been rare until now. This study aimed to close this gap and develop a guide for e-scooter road safety campaigns focusing on education and information. Experiences by frequent e-scooter riders form the basis of this guide called the ‘E-scooter road safety matrix’ [1] and that practitioners can apply in designing road safety programs or campaigns.

2 METHODS

The guide was developed based on the results of a mixed-methods approach with a literature review and two empirical studies (one online survey and six online focus groups in Germany).

Literature review

A literature review was conducted to identify current gaps in e-scooter road safety campaigns and learn from best practices. Within this review, 35 existing e-scooter education and information road safety campaigns, their used formats/ media, the contents addressed, and the theoretical models (if applicable) they were based on were systematized. Moreover, literature reviews were consulted to identify relevant theoretical models, promising frameworks, and constructs to target e-scooter riders.

Online survey

The online survey collected quantitative data from 99 frequent e-scooter riders in September. The survey’s main focus was to collect incidences of critical events experienced by e-scooter riders (near-misses, actual crashes) and their characteristics (e.g., single-vehicle crashes, others involved). In addition, data on perceived risk factors and preferred formats (e.g., video clips, app contents, training) for road safety campaigns were gathered.

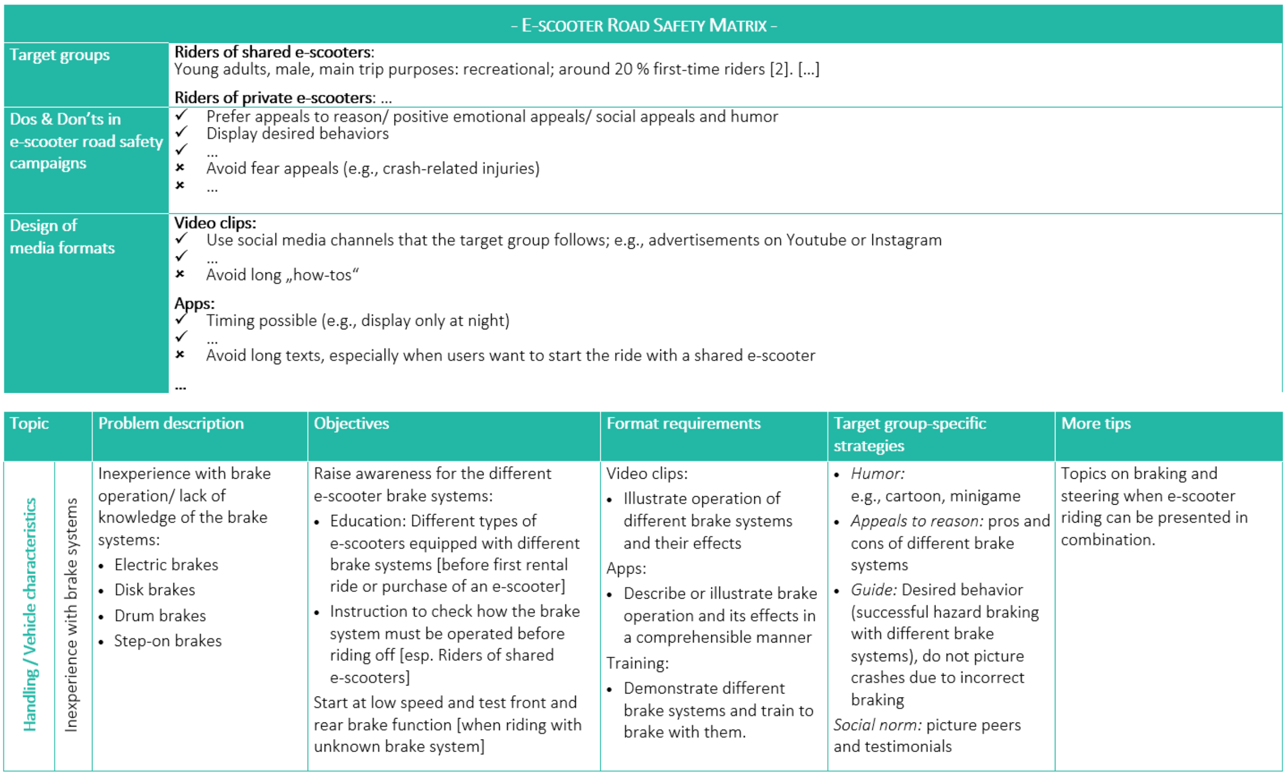
Focus groups

In November 2021, six online focus groups with twenty frequent e-scooter riders were conducted. Each focus group was led by two trained moderators and lasted around two and a half hours. The focus groups were script-based and recorded via the online meeting service Zoom. The records of the focus groups were transcribed and, utilizing the MAXQDA software, coded following a codebook. The main categories of the focus group scripts and the codebook included: e-scooter use, biggest risk factor, other risk factors and insecurities, critical events, and crashes, handling of critical events, contents of road safety campaigns, formats/ media type of road safety campaigns, specific ideas for road safety campaigns.

3 RESULTS

The results from the literature review and the empirical studies were used to design the ‘E-scooter road safety matrix’ (see Figure 1 for an excerpt). The matrix header contains the definitions of the target groups of users of shared and private e-scooters, dos and don’ts in e-scooter road safety campaigns (e.g., “avoid fear appeals”), and straightforward advice on the design of the media formats: video clips, apps, and training (e.g., “pictured person should correspond with the target group”).

Subsequently, the matrix is structured into three main categories: 1) critical events, 2) handling/ vehicle characteristics, and 3) traffic and behavior rules. The three main categories include twelve specific problems relevant to e-scooter road safety, e.g., dooring, standing position, and riding two on one vehicle, described in detail. For each of the twelve problems, the matrix provides practical information regarding: prevention aims, format requirements (specified for video clips, apps, and training), and more tips (e.g., parallels to cycling safety).



- E-SCOOTER ROAD SAFETY MATRIX -	
Target groups	**Riders of shared e-scooters:** Young adults, male, main trip purposes: recreational; around 20 % first-time riders [2]. [...] **Riders of private e-scooters:** ...
Dos & Don’ts in e-scooter road safety campaigns	✓ Prefer appeals to reason/ positive emotional appeals/ social appeals and humor ✓ Display desired behaviors ✓ ... × Avoid fear appeals (e.g., crash-related injuries) × ...
Design of media formats	**Video clips:** ✓ Use social media channels that the target group follows; e.g., advertisements on Youtube or Instagram ✓ ... × Avoid long „how-tos“ **Apps:** ✓ Timing possible (e.g., display only at night) ✓ ... × Avoid long texts, especially when users want to start the ride with a shared e-scooter ...

Topic		Problem description	Objectives	Format requirements	Target group-specific strategies	More tips
Handling / Vehicle characteristics	Inexperience with brake systems	Inexperience with brake operation/ lack of knowledge of the brake systems: • Electric brakes • Disk brakes • Drum brakes • Step-on brakes	Raise awareness for the different e-scooter brake systems: • Education: Different types of e-scooters equipped with different brake systems [before first rental ride or purchase of an e-scooter] • Instruction to check how the brake system must be operated before riding off [esp. Riders of shared e-scooters] Start at low speed and test front and rear brake function [when riding with unknown brake system]	Video clips: • Illustrate operation of different brake systems and their effects Apps: • Describe or illustrate brake operation and its effects in a comprehensible manner Training: • Demonstrate different brake systems and train to brake with them.	• *Humor:* e.g., cartoon, minigame • *Appeals to reason:* pros and cons of different brake systems • *Guide:* Desired behavior (successful hazard braking with different brake systems), do not picture crashes due to incorrect braking *Social norm:* picture peers and testimonials	Topics on braking and steering when e-scooter riding can be presented in combination.

Figure 1: Excerpt of the e-scooter road safety matrix, in [1].

4 CONCLUSIONS

As e-scooter road safety work is still in its early stages, this study provides an essential basis for designing successful campaigns and programs. The developed guide is open to be used by practitioners, like the police, municipalities, road safety councils, and other stakeholders, to design and improve road safety campaigns for e-scooter riders. The described requirements for road safety campaigns are a starting point - sufficient time, capacity, pretesting, and evaluation are required to ensure a holistic, theory-based, and target group-oriented implementation. As e-scooter mobility is still developing, the current state should be considered each time (e.g., a decline of first-time users) when designing new campaigns.

REFERENCES

[1] J. Anke, M. Ringhand, T. Petzoldt and T. Gehlert, “Präventionsmaßnahmen für E-Scooter-Nutzer:innen” (87), Unfallforschung der Versicherer (UDV), Gesamtverband der Deutschen Versicherungswirtschaft e.V., Berlin, 2022.

[2] M. Orozco-Fontalvo, L. Llerena and V. Cantillo, “Dockless electric scooters: A review of a growing micromobility mode”, *International Journal of Sustainable Transportation (2022)*, pp. 1-17.

E-scooter riding: Prediction of hazards from the perspective of users and non-users

T. Jung*, **M. Ringhand**#, **J. Anke**†

*Chair of Traffic and Transportation Psychology
Technische Universität Dresden
01062 Dresden, Germany
email: theresa.jung1@mailbox.tu-dresden.de

Chair of Traffic and Transportation Psychology
Technische Universität Dresden
01062 Dresden, Germany
email: madlen.ringhand@tu-dresden.de

†Chair of Traffic and Transportation Psychology
Technische Universität Dresden
01062 Dresden, Germany
email: juliane.anke@tu-dresden.de

Keywords: hazard perception, hazard prediction, cycling, road safety, rider training.

1 INTRODUCTION

Electric kick scooters (e-scooters) still represent a relatively new group of powered-two wheelers that, in many countries, must be used on cycling infrastructure if available. Road safety concerns have been rising because e-scooter-related crashes increased rapidly [1–3]. One explanation for an increased crash risk might be shortcomings in perceiving e-scooter-related hazards in traffic.

Perceiving hazardous situations in road traffic is considered a crucial ability of road users to prevent crashes and participate in traffic safely [4, 5]. While research on the hazard perception of car drivers is plentiful [6], there is only little evidence referring to the hazard perception abilities of vulnerable road users like cyclists [7] or pedestrians [8]. In particular, regarding e-scooter riding, it remains unclear what factors could play a part in contributing to a better perception of e-scooter-related hazards. One could assume that inexperienced e-scooter riders are less skilled at anticipating hazardous traffic situations than experienced ones. Still, other factors like experience in cycling, driving, or owning a driver's license could also enhance hazard perception skills when dealing with e-scooter-related hazards.

The present study's objective was to evaluate the hazard perception and prediction skills of different road users when adopting the perspective of an e-scooter rider and being confronted with e-scooter-specific hazards.

2 METHODS

2.1 Survey design and procedure

A hazard prediction test was created featuring hazardous driving situations recorded from the point of view of an e-scooter rider based on a structured approach of previous research [9, 10]. For this purpose, hazardous (and non-hazardous) driving situations for e-scooter riders were recorded and then implemented in an online survey. Findings on safety-critical situations of micro-mobility users were taken as a basis for the hazardous traffic-scene clips [7, 11, 12]. They were differentiated between hazards that might cause single-user or multiple-road-user events.

The video clips were occluded before the actual hazard fully materialized with two different occlusion points as a controlling feature to consider a possible influence of varying imminence of hazards. Conditions were based on the moment when the actual hazard was inevitable, so-called *point zero*. In the first condition, the clips were occluded five frames before point zero while the hazard was already unfolding (*proximal* to the hazard). In the second condition, the clips were occluded 23 frames before point zero (approximately 600ms earlier than proximal occlusions), while they only contained hazard instigators before their materialization (*distal* to the hazard). After occlusion, participants were asked to predict how the situation would develop by selecting one of four options [9]. A pre-test was conducted before the main study to generate distractors for the multiple-choice questions and test the video clips' general suitability. On top of that, before the hazard prediction question, participants were asked to rate whether they had seen evidence of an upcoming hazard.

2.2 Sample

In sum, 772 participants with varying road user profiles completed the main study by assessing 18 traffic-scene clips, including multiple-road-user events, single-user events, and non-hazardous events. There were 324 participants in the proximal occlusion point condition and 448 participants in the distal occlusion point condition. Participants were recruited via advertising on various social media sites. The request was distributed to students and employees of the university. Of the sample, 31.1 % (n = 240) indicated that they used an e-scooter before, whereas 68.5% (n = 529) had no experience with e-scooters. Furthermore, 6.1% (n = 47) of the total sample indicated using an e-scooter one to three times a week or (almost) daily. This very subsample is labeled as frequent e-scooter riders.

3 RESULTS

Descriptive data of hazard perception and hazard prediction rates are shown in Table 1. One can see that proximal hazards were better anticipated and perceived than distal hazards. In general, findings show that safety-critical situations involving other road users were more correctly predicted than those associated with the environment or road conditions. At the same time, the former hazards were considered more hazardous than the latter. Further results suggest that frequent bicycle use and holding of a driver's license enhance the performance of predicting hazardous events of e-scooter riding. However, regular e-scooter use did not contribute to better hazard perception abilities.

Table 1: Rates of correct responses regarding hazard identification and hazard prediction per hazard. Total N = 772 (n = 324 for proximal occlusion point; n = 448 for distal occlusion point), sample sizes for each video slightly differ due to missing responses to the hazard identification question. Recognition rates < 50% are in bold. HID = hazard identification; HP = hazard prediction.

Hazard	**Proximal**				**Distal**			
	HID		**HP**		**HID**		**HP**	
	n	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Car overtaking too close	275	84.9	313	96.6	261	58.3	382	85.3
Dooring	208	64.2	171	52.8	317	70.8	106	**23.7**
Cyclist coming from the opposite direction	306	94.4	290	89.5	369	82.4	125	**27.9**
Two bicycle lanes coalescing	267	82.4	271	83.6	384	85.7	365	81.5
Overlooked by turning lorry	310	95.7	307	94.8	423	94.4	421	94.0
Crossing pedestrian	311	96.0	310	95.7	412	92.0	396	88.4
Car not disregarding the right of way when turning right	264	81.5	297	91.7	345	77.0	397	88.6
Car disregarding the right of way at junction	282	87.0	302	93.2	406	90.6	413	92.2
Pile of leaves on the cycleway	223	68.8	227	70.1	279	62.3	254	56.7
Cobbled driveway	101	**31.2**	242	74.7	145	**32.4**	269	60.0
On-road cycle lane suddenly ending	201	62.0	228	70.4	228	50.9	245	54.7
Uneven manhole cover on the cycleway	95	**29.3**	193	59.6	94	**21.0**	197	**44.0**
Crossing tramway tracks	288	88.9	299	92.3	393	87.7	393	87.7
Road works on the cycleway	270	83.3	289	89.2	379	84.6	370	82.6
Uneven dropped curb	128	**39.5**	267	82.4	179	**40.0**	334	74.6

4 DISCUSSION AND CONCLUSION

The presented study is one of the first to examine the hazard prediction skills of various road users regarding safety-critical situations when e-scooter riding from the perspective of an e-scooter user. The study's results contribute to the road safety of e-scooter riders by identifying factors that influence the awareness of e-scooter-related hazards. The findings demonstrate that frequent bicycle use and holding a driver's license improved the accuracy of predicting hazardous events. In contrast, regular e-scooter use did not contribute to enhanced hazard prediction skills.

It could be argued that e-scooter riders need to become more familiar with the cycling infrastructure and hazards related to e-scooter riding than expected. Considering that, yet, in Germany, everyone aged 14 and older can use e-scooters, independent of driver's license status and experience in bicycle riding, the issue is highly relevant. Thus, more educational efforts are needed to make users more aware of potential e-scooter-related hazards and improve road conditions and infrastructure, which are desirable to preserve and enhance road safety.

In conclusion, the developed hazard prediction test was an effective instrument for investigating anticipating skills regarding hazardous events associated with e-scooter riders. Given the physical vulnerability of the concerned users, evaluating these cognitive abilities was essential to better understand the causes of e-scooter-related crash risk.

5 REFERENCES

1. Brauner T, Heumann M, Kraschewski T, Prahlow O, Rehse J, Kiehne C, Breitner MH (2022) Web content mining analysis of e-scooter crash causes and implications in Germany. Accident; analysis and prevention 178, 106833. 10.1016/j.aap.2022.106833.
2. Stigson H, Malakuti I, Klingegård M (2021) Electric scooters accidents: Analyses of two Swedish accident data sets. Accident; analysis and prevention 163, 106466. 10.1016/j.aap.2021.106466.
3. Toofany M, Mohsenian S, Shum LK, Chan H, Brubacher JR (2021) Injury patterns and circumstances associated with electric scooter collisions: a scoping review. Injury prevention journal of the International Society for Child and Adolescent Injury Prevention 27(5), 490–499. 10.1136/injuryprev-2020-044085.
4. Borowsky A, Shinar D, Oron-Gilad T (2010) Age, skill, and hazard perception in driving. Accident; analysis and prevention 42(4), 1240–1249. 10.1016/j.aap.2010.02.001.
5. Meir A, Oron-Gilad T, Parmet Y (2015) Are child-pedestrians able to identify hazardous traffic situations? Measuring their abilities in a virtual reality environment. Safety Science 80, 33–40. 10.1016/j.ssci.2015.07.007.
6. Cao S, Samuel S, Murzello Y, Ding W, Zhang X, Niu J (2022) Hazard Perception in Driving: A Systematic Literature Review. Transportation Research Record 2676(12), 666–690. 10.1177/03611981221096666.
7. Meir A, Dagan B (2020) Can young novice e-bike riders identify hazardous traffic situations? An exploratory study. Travel Behaviour and Society 21, 90–100. 10.1016/j.tbs.2020.06.001.
8. Salducco A, Abati D, Bina M, Bertani B, Calarco S, Balzarotti S, Biassoni F (2022) Young pedestrians' behaviours and risk perception: a pilot study with Italian early adolescents. Transportation Research Part F: Traffic Psychology and Behaviour 90, 512–523. 10.1016/j.trf.2022.06.006.
9. Ventsislavova P, Crundall D (2018) The hazard prediction test: A comparison of free-response and multiple-choice formats. Safety Science 109, 246–255. 10.1016/j.ssci.2018.06.004.
10. Ventsislavova P, Rosenbloom T, Leunissen J, Spivak Y, Crundall D (2022) An online hazard prediction test demonstrates differences in the ability to identify hazardous situations between different driving groups. Ergonomics 65(8), 1119–1137. 10.1080/00140139.2021.2016999.
11. Anke J, Ringhand M, Petzoldt T, Gehlert T (2022) Präventionsmaßnahmen für E-Scooter-Nutzer:innen. Berlin.
12. Morgner L (2021) Verkehrspsychologische Untersuchung von Gefahrensituationen und Gefahrenwahrnehmung bei E-Scooter-Fahrenden. Masterarbeit. Dresden.

Comparison of Electromechanical Means of Stabilizing a Bicycle

Jason K. Moore

Faculty of Mechanical Engineering
Delft University of Technology
Mekelweg 2, 2628 CD Delft, The Netherlands e-
mail: j.k.mooore@tudelft.nl

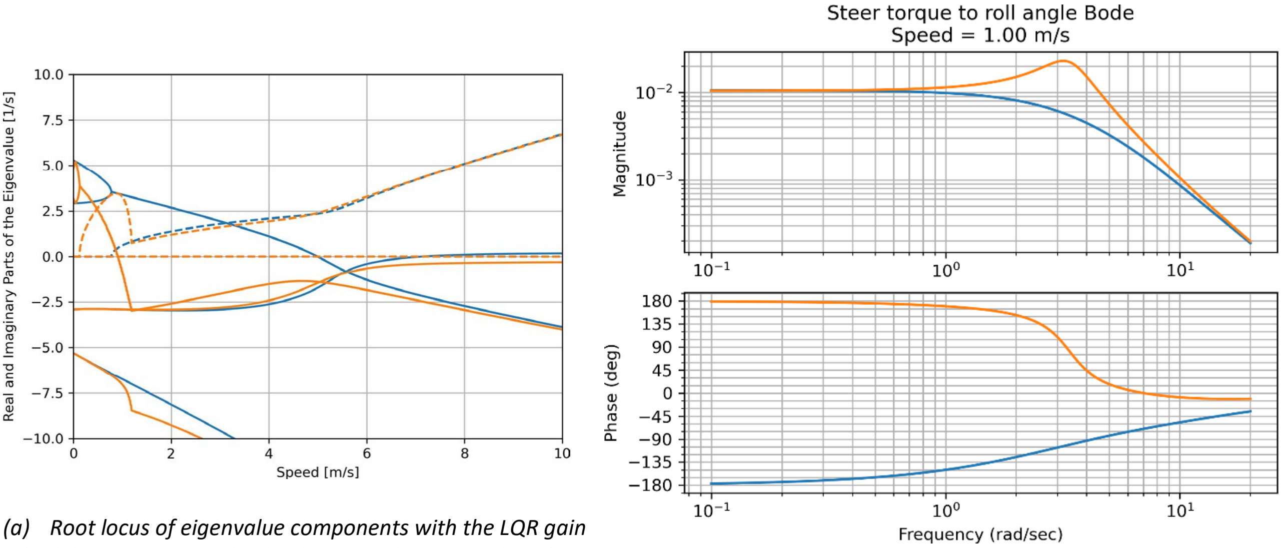
Keywords: bicycle, stability, control, robot, gyroscope, ADAS

1 INTRODUCTION

An uncontrolled bicycle can be self-stable at some travel speeds due to the nature of its design [1]. This self-stability relieves the rider of some of the burden of control and at high speeds riders can balance a bicycle without much conscious thought. At low speeds, a bicycle becomes more difficult to control, increasing the chance of falls. It has long been hypothesized that adding electromechanical sensing and actuation can stabilize the vehicle relieving some of the human control burden. For safety purposes, I am interested in systems that share control with the rider but most past work focus on human independent "robot riders".

Van Zytveld [5] was likely the first to investigate and build a robot rider for his 1975 Stanford PhD thesis. He used an actuated inverted pendulum that mimicked rider lean, but was not successful in demonstrating what his theoretic control model predicted. It was not until the mid 1980s that someone successfully demonstrated an automatically balanced motorcycle [2]. Ruijs and Pacejka used a steering motor to stabilize the motion recognizing that simple positive roll rate feedback can stabilize the vehicle at low speeds, i.e. "steer into the direction of roll motion". In 2005, the Murata Manufacturing company demonstrated "Murata Boy", a bicycle robot which utilized a reaction wheel capable of generating stabilizing roll torques [8]. In 2006, several Dartmouth University undergraduates developed a simple motor driven flywheel encased in the front wheel that increases the front wheel spin momentum providing a roll motion stabilizing effect [6]. This application used the same principle as the rear wheel flywheel of the 1921 Giesberger Gyrocar [4]. In 2013, Lit Motors Inc. demonstrated a pair of control moment gyros capable of balancing a two seater enclosed motorcycle at low speed that used the same principle used in Brennan's 1903 Gyro monorail [7]. There have been numerous other theoretical and realized machines that utilize one or more of these five actuation methods throughout the years.

With over a century of innovations in automatically stabilizing single track vehicles, nothing has ever become commercially viable or demonstrated enhanced rider or passenger safety. In this study, I will describe how each of these roll stabilization methods work, what their advantages and disadvantages are, and discuss whether they can be useful for bicycle safety.



(a) Root locus of eigenvalue components with the LQR gain scheduling across speed. Blue lines are the passive bicycle dynamics and orange are the automatically controlled dynamics. Solid lines are real parts and dotted lines are imaginary parts.

(b) Bode plots for rider applied steer to roll dynamics for the uncontrolled bicycle (blue) and automatically controlled bicycle (orange).

Figure 1: Uncontrolled and controlled dynamics.

2 STEER MOTOR SYSTEM

As an example for this abstract, I will demonstrate roll and steer motion stabilization using an ideal motor actuator that applies equal and opposite torque to the steered frame from the ridden frame; same as [2]. I start by assuming that the bicycle's basic state (steer and roll configuration and motion) can be accurately measured by using inertial measurement units and state estimation. The bicycle dynamics model is based on the linearized Carvallo-Whipple model from [1] but populated with more realistic numerical parameters. By assuming full state feedback, the system can be modeled by these linear state space equations:

$$\dot{\bar{x}} = (\mathbf{A} - \mathbf{BK})\,\bar{x} + \mathbf{B}\bar{u} \tag{1}$$

$\mathbf{A}$ represents the passive dynamics of bicycle and B gives the input dynamics from the rider or steer motor applied steering torque. Full state feedback can be used to drive the steering motor torque $T_{\delta,m} = -\mathbf{K}\bar{x}$, giving the closed loop dynamics $\mathbf{A} - \mathbf{BK}$. The state and input vectors are:

$$\bar{x} = \begin{bmatrix} \phi \\ \dot{\phi} \\ \delta \\ \dot{\delta} \end{bmatrix} = \begin{bmatrix} \text{roll angle} \\ \text{roll rate} \\ \text{steer angle} \\ \text{steer rate} \end{bmatrix} \text{and } \bar{u} = [T_\delta] = [\text{rider applied steer torque}] \tag{2}$$

By applying a maximum torque scaled linear quadratic regulator (LQR) across all speeds the scheduled feedback gains $\mathbf{K}$ can be found to stabilize the vehicle at almost all speeds with minimal effect to the dynamics of the vehicle besides the positive aspect of stabilization, similar to [3]. Figure 1a shows that the bicycle can be stabilized down to 1 m/s and that the natural frequencies and time constants do not change drastically, leaving the bicycle's dynamics intact. It is also important to note that from the rider's perspective $\mathbf{A} - \mathbf{BK}$ is simply a new plant they must control, yet through the same passive input filter which is a function of the unchanged $\mathbf{B}$ matrix governing the rider's steer input. Figure 1b shows that at 1 m/s the rider will experience a less damped response to steering in the 0.3 to 0.8 Hz bandwidth, so the handling is not necessarily maintained when applying automatic control. To keep the handling the same, more elaborate model reference control would be required.

3 CONCLUSIONS

In the presentation, I will share similar analyses for a moving mass actuator, paired control moment gyros, reaction wheel, and front wheel internal flywheel and show how most are equivalent ways of achieving the same goal. I will then compare them for feasibility and effectiveness. This will be presented in a both historical and modern context of realized vehicles and why the vehicles may or may not be able to enhance safety and be commercially viable.

REFERENCES

[1] J. P. Meijaard, Jim M. Papadopoulos, Andy Ruina, and A. L. Schwab. Linearized dynamics equations for the balance and steer of a bicycle: A benchmark and review. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 463(2084):1955–1982, August 2007.

[2] P.A.J. Ruijs and H.B. Pacejka. Recent Research in Lateral Dynamics of Motorcycles. Vehicle System Dynamics, 15(sup1):467–480, January 1986.

[3] A. L. Schwab, J. D. G. Kooijman, and J. P. Meijaard. Some recent developments in bicycle dynamics and control. In A. K. Belyaev and D. A. Indeitsev, editors, Fourth European Conference on Structural Control (4ECSC), pages 695–702. Institute of Problems in Mechanical Engineering, Russian Academy of Sciences, 2008.

[4] Douglas Self. Gyrocars. http://douglas-self.com/MUSEUM/TRANSPORT/gyrocars/gyrocar.htm, 2023.

[5] P. van Zytveld. A Method for the Automatic Stabilization of an Unmanned Bicycle. PhD thesis, Stanford University, 1975.

[6] L. Ward. Gyrobike: Preventing scraped knees. Popular Mechanics, November 2006.

[7] Wikipedia Authors. Gyro monrail. Wikipedia, 2012.

[8] Wikipedia Authors. Murata Boy and Murata Girl. Wikipedia, March 2023.

Experimental evaluation of Rideability Index as a Handling quality indicator

J. Ronné*, L. Dubuis#, T. Robert†

*LBMC UMR_T 9406
Univ Lyon, Univ Eiffel, Univ Claude Bernard Lyon
F-69622 Lyon, France
email: jules.ronne@univ-lyon1.fr

#LBMC UMR_T 9406
Univ Lyon, Univ Eiffel, Univ Claude Bernard Lyon
F-69622 Lyon, France
email: laura.dubuis@univ-lyon1.fr

†LBMC UMR_T 9406
Univ Lyon, Univ Eiffel, Univ Claude Bernard Lyon
F-69622 Lyon, France
email: D.E. thomas.robert@univ-eiffel.fr

Keywords: bicycle, bike, Rideability index, bicycle handling quality, perceived difficulty

1 INTRODUCTION

The growing popularity of urban cycling has led to a need for bicycle designs that can accommodate increased payload capacity, while still maintaining good handling quality for user safety and comfort. However, the understanding of bicycle handling quality is not yet advanced enough to recommend highly controllable designs based solely on theoretical calculations. The literature on bicycle handling quality proposes several theoretical indicators such as HQM [1], modal controllability [2], Rideability index [3], lateral sensitivity [4] or the stability approach [5]. The HQM although promising based on its validity in aeronautics requires a significant computational complexity due to the adjustment of the controller gains. Modal controllability, or mode damping, provides a multi-dimensional quantification of the system whose link to handling quality is still unknown. Lateral sensitivity is unidimensional and requires a low computational cost. However, it is a static indicator mainly adapted to cornering. Finally, the Rideability Index is a one-dimensional, continuous and dynamic indicator that requires a relatively low computational cost. The latter, like the other indicators, lacks experimental validation. To address this issue, this study aims to compare the Rideability Index with the subjective experience of a group of individuals who tested two bicycles with vastly different designs.

2 MATERIAL AND METHODS

2.1 Model and Rideability Index

Rideability index (D) [3] was calculated thought the sequences presented in Figure 1. According to this definition, the greater D, the more difficult it is to ride the bicycle.

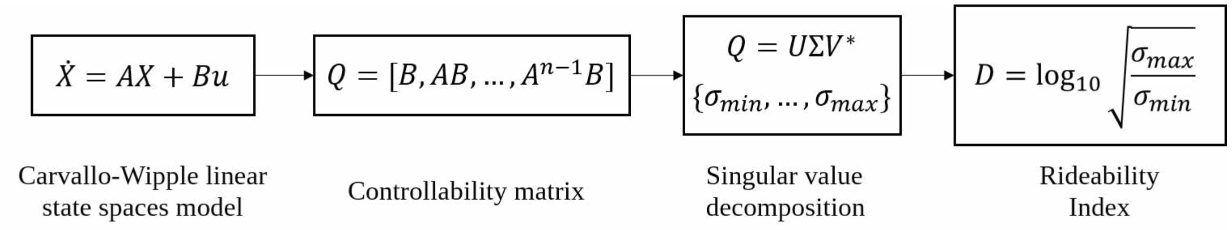


Figure 1: Computational methodology of Rideability Index applied on Carvallo-Whipple model. Where σ_{max} and σ_{min} are the extreme singular values of the controllability matrix Q, and A and B are the linear state spaces matrices of the Carvallo-Wipple linear model.

A and B were extended from Carvallo-Whipple model equations [6] to integrate $\dot{y}_F$ as a state variable. This change aims to consider path tracking objective instead of vertical equilibrium control. The Q matrix is highly speed dependent, thus D was calculated across a range of speed (from 1 to 35 km/h). Numerical calculation used three sets of parameters: one per experimental bicycle considered (see below) plus the benchmark bicycle set of parameters from [6]. To take potential uncertainties in parameters estimation into account, mean value of D and 95% confidence interval were calculated across speed range from measurement uncertainties for experimental bicycle and with a 5% variation of these input parameters for benchmark bicycle.

2.2 Experiments

Experiments aimed to evaluate the mean handling quality of two experimental bicycles (Strida foldable bike and Omnium cargo bike). Thirty young adults, self-declared as beginner to advanced riders, were instructed to ride two experimental bicycles while maintaining a constant speed and following a 9 cm wide white line painted on the track. The track consisted of one straight line, one left turn, a slalom, and a right turn. At the end of each lap, participants evaluate the experimental handling quality as the perceived difficulty of the task thanks to the Cranfield Aircraft Handling Qualities Rating Scale (CAHQRS) [7]. Which is from 0 to 9, where 9 is the highest level of difficulty. The bicycles were equipped with one IMU (XSens DOT) on the rear wheel to estimate the mean bicycle speed of each lap.

For each of the two experimental bicycles, a set of 25 design parameters was experimentally estimated and used as input for the Carvallo-Whipple model: masses were measured with a scale, geometries with a measuring tape and inertias were identified from oscillation periods measured with an IMU.

2.3 Statistic model

The effect of bicycle and speed on the experimental handling quality were tested with an ANOVA assuming that speed has a quadratic effect and considering the bicycle used as a categorical variable.

3 RESULTS AND DISCUSSION

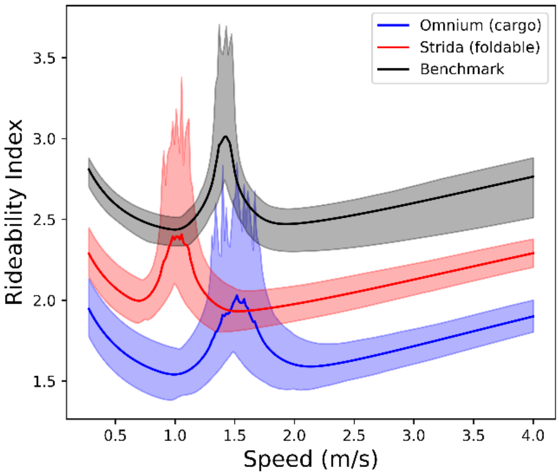


Figure 2: Rideability Index mean value and 95% confidence interval for the experimental and benchmark bicycles.

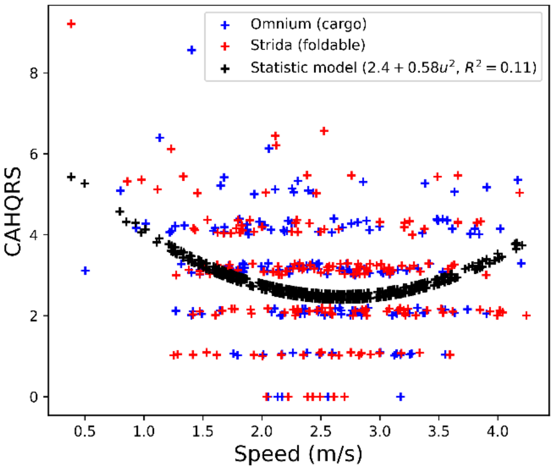


Figure 3: experimental handling quality measured on CAHQRS (0 to 9 scale, 9 being the most difficult) and statistic model (p<0.001).

Figure 2 displays the Rideability Index over speed for the three bicycles. The overall shapes were similar for the three bicycles, with a peak around 1,5 m/s, a valley around 2 m/s and a close-to-linear increase with speed for higher velocity. A small offset off Rideability index can be observed between the three bicycles despite their different geometries.

Figure 3 displays the experimental handling quality over speed for the two experimental bicycles, together with the fitted model. The model was significant ($p>0.001$) but explain only a small percentage of the variance ($R^2=0.11$), due to the large experimental variability. It shows a significant quadratic effect of speed ($p<0.001$) but no effect of the bicycles ($p=0.28$).

This model thus highlights that experimental handling quality exhibit a non-monotonous effect of speed. This effect is consistent with theoretical results that exhibit high value of Rideability Index below 1.5 m/s and above 3.5 m/s. Rideability Index and experimental data does not exhibit the exact same handling quality optimal speed because, unlike D, the experimental data are track dependent. The absence of bicycles effect on the experimental handling quality is consistent with the theoretical results showing relatively small differences between bikes. It could also be explained by the non-specificity of the protocol to compare bicycles to each other.

4 CONCLUSIONS

These preliminary results tend to show that Rideability Index could be an interesting theoretical indictor of the handling quality experienced by the riders. Future work will consider more experimental designs in order to assess the Rideability Index's ability to compare bicycles with each other.

REFERENCES

[1] R. Hess, Modeling the Manually Controlled Bicycle, *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* (2012), pp. 545-557.

[2] A. L. Schwab, Lateral dynamics of a bicycle with a passive rider model: stability and controllability, *Vehicle System Dynamics* (2012), pp. 1209-1224.

[3] K. A. Seffen, Observations on the controllability of motion of two-wheelers. *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering* (2001), 215(2), pp. 143-156.

[4] S. M. Cain, Comparison of experimental data to a model for bicycle steady-state turning, *Vehicle System Dynamics* (2012), pp. 1341-1364.

[5] A. L. Schwab, On the Design of a Recumbent Bicycle With a Perspective on Handling Qualities, *Proceedings of the ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, *Volume 6: 1st Biennial International Conference on Dynamics for Design; 14th International Conference on Advanced Vehicle Technologies*, Chicago, Illinois, USA, August 12–15, 2012, 303-308 pp.

[6] J.P. Meijaard, Linearized dynamics equations for the balance and steer of a bicycle: A benchmark and review, *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *463* (2007), pp. 1955-1982.

[7] D. Harris, The Cranfield aircraft handling qualities rating scale: A multidimensional approach to the assessment of aircraft handling qualities, *Aeronautical Journal* (2000), pp. 191-198.

Exploring the Spatiotemporal and Behavioral Patterns of Utilitarian E-Bike Users in North America

Mojdeh Azad*, **John MacArthur#**, **Christopher R. Cherry†**

*Department of Civil and Environmental Engineering
The University of Tennessee
311 John D. Tickle Building, 851 Neyland Drive,
Knoxville, TN 37996, United States
email: mazaddis@vols.utk.edu

#Transportation Research and Education Center
Portland State University
Portland OR 97201, United States
email: macarthur@pdx.edu

† Department of Civil and Environmental Engineering
University of Tennessee, Knoxville
321 John D. Tickle Building, 851 Neyland Drive, 37996, Knoxville, TN, USA
email: cherry@utk.edu

Keywords: electric-bicycle, utilitarian, commute, trip substitution mode.

1 INTRODUCTION

In North America, electric bicycles (e-bikes) have become increasingly popular over the past decade as a convenient means of transportation and recreational activity [1]. E-bike sales have surpassed electric car sales in the United States and are expected to continue to rise in the coming years, with COVID-19 accelerating the industry's growth rate. Meanwhile, transportation-related carbon emissions in the US were estimated to be 1.7 billion metric tons in 2021, with personal vehicles accounting for 58% of that total [2].

While e-bikes have the potential to accelerate the transition towards a more environmentally friendly transportation system by promoting a shift away from personal vehicles, the mode substitution choices can create safety challenges that require further consideration. Studies worldwide have found that the preferred mode substitution varied depending on the location and their characteristics [3]. For instance, studies have shown that e-bike riders would opt for buses or standard bicycles in China if e-bikes were unavailable [4]. In North America, e-bikes are most commonly used for commuting and personal errands [1], and in Australia, older adults are more likely to shift from private vehicles to e-bikes [5]. In the Netherlands, e-bikes were found to reduce car usage in commute and shopping trips, but longitudinal data suggested that substitution rates of transit and cars with e-bikes are less significant than previously reported [6-8]. Compared to other modes, e-bike users may have net safety impacts (positive or negative) based on: mode substitution from other less or more safe modes, e-bike riders may adopt different route choices based on safety perceptions, e-bike riders may have different characteristics and risk taking behavior than other road users (e.g., older, less experienced), and e-bike riders may ride differently because of the technology (e.g., ride faster) or trip purpose (e.g., recreation, utility trips). Understanding these questions requires high resolution data collection platforms that are enabled by app-based technologies. This study describes a research effort to track individual e-bike riders over time to assess high resolution rider behavior, augmented by machine learning tools, that can ultimately inform safety analysis of e-bikes and other sensor-enabled micromobility modes (e.g., shared bikes or scooters).

In this study, we designed a low-impact instrumentation platform that utilizes the distinctive features of widespread smartphone usage to collect Global Positioning System (GPS) data and overcome inaccuracies such as self-selection bias, self-reported behavior, or the limitations associated with traditional GPS-enhanced travel dairies. Leveraging pre-existing technologies and incorporating rider feedback, we constructed an efficient and unobtrusive instrumentation platform for gathering data on e-bike trips. We generated a novel and comprehensive two-year longitudinal dataset comprising data on the e-bike use of about 40 riders. Coupled with two surveys conducted before and after data collection, we investigated the behavior of utilitarian e-bike riders during the COVID-19 pandemic and compared the stated behaviors and choices to the real-world data collected from the same group of riders.

2 METHODS

We followed a multi-method approach with various components: First, we developed a low-impact instrumentation platform that takes advantage of the unique capabilities of both e-bikes and smartphones in terms of sensors and GPS data, as well as additional user input through our developed iOS application for the phone. Second, we gathered trip-related information from other resources, such as weather, and utilized them in addition to the extracted information from the GPS data to predict trip substitution modes and trip purposes with machine learning algorithms. We analyzed trip speed (e.g., average, percentiles, moving speed, cruising speed), trip duration, trip distance, and mode substitution and trip purpose patterns. Furthermore, we compared real-world data with trip distance and trip time estimations using the Google Distance Matrix API. Following the analysis and modeling of travel behavior, we were able to provide a comprehensive analysis of general e-bike use, changes, and mode substitution behavior over time.

3 RESULTS

Upon completion of the data labeling process, a total of 5771 trips made by 38 active riders (i.e., made trips for at least a typical week) were included in the analyses, covering a total distance of 42,355 kilometers during the data collection period. The number of trips by each purpose is 1113 commute (29% of them predicted labels), 1653 recreation (17% of them predicted labels), and 3005 social/errands (28% of them predicted labels). Due to the global outbreak of COVID-19 and associated restriction orders, there was a significant disruption to people's daily routines and activities, including travel behavior. Our data also showed a clear impact of the pandemic on trip purposes, particularly for commute trips. Starting from the second quarter of 2020, participants dramatically reduced making commute trips, which was reflected in a sharp drop in the percentage of commute trips from 43% in Q1 2020 to 8% in Q2 2020 and 2% in Q3 2020 (Figure 1).

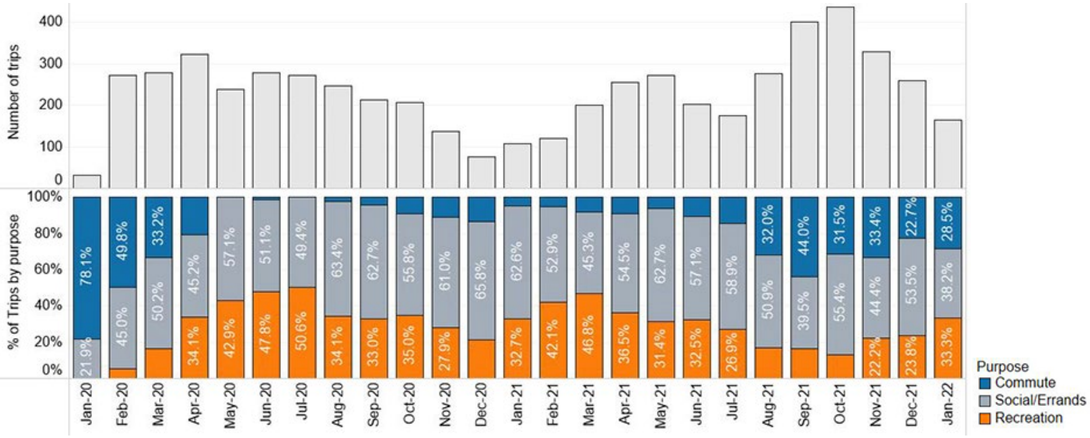


Figure 1: Number of active users, trips, and rate of trips by trip purpose by month

The average moving speeds were 18.46 km/h, 20.35 km/h, and 21.12 km/h for social/errand, commute, and recreational trips, respectively. On average, for commute trips, 63% of the distance was covered at a speed above 20 km/h and 6.7% at above 40 km/h. For recreational trips, 68% of the distance was covered at a speed above 20 km/h and 4.9% at above 40km/h, while for social/errands trips, 51.8% of the distance was covered at speed above 20km/h and 5.5% at above 40km/h (Figure 2). To better understand substitution mode choices, we evaluated the trip characteristics considering both trip purpose and substitution mode. A total of 1113 commute trips were made by 24 participants, with an average of 46 trips per rider (SD=68.0, Min=1, Max=267, Median=15.5). Our data shows that regarding e-bike unavailability, participants would have made 60% of the total commute trips using a car and around 31% of the total commute trips using a standard bike. However, it is essential to exercise caution in drawing conclusions from these findings, as some participants had very high numbers of commute trips and tended to only choose car or bike as the substitution mode. These choices changed throughout the data collection period. For commute and social/errand trips, car was selected as the substitute mode for 59% and 62% of the trips, respectively. For recreational trips, a bike was chosen as the substitute mode for 83% of the trips. Further comparisons of surveys, collected GPS data, and collected data from Google Distance API showed similarities and differences among reported and actual mode substitution choices considering distance and purpose of the trips.

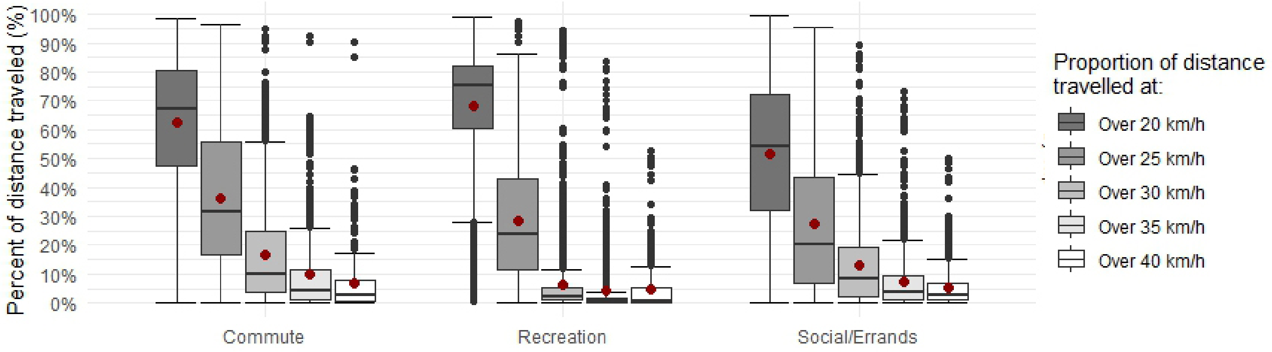


Figure 2: Distance traveled at above different speed values, arranged by purpose

4 CONCLUSIONS

As e-bikes become more popular, it is important to understand how riders are using them and how their behavior may differ among different types of users and trips. This information can be used to improve safety for all road users. This study aimed to investigate the behavior of e-bike riders and gain insights into the factors that influence their mode choice. While aware of the impact of the pandemic on travel behavior and choices, we used a descriptive approach to explain and compare the findings about modes of transportation among personal e-bike riders in the United States. Our findings demonstrate that e-bikes are increasingly used for trips previously made by other modes of transport, such as cars and bikes. The fact that our participants were utilitarian e-bike riders may indicate that switching from bicycles to e-bikes was more about improving the quality of cycling. Additionally, recreational and utilitarian e-bike rides have different travel characteristics and needs. While recreational e-bike riders may ride at an average faster pace than utilitarian riders, commute rides covered larger percentage of the trip distances at higher speeds. Substitution mode share is influenced by factors such as trip purpose, trip distance, and day/time of the trip. A large proportion of utilitarian e-bike trips are substitutes for car travel. This would improve system safety over time, but safety risks may arise during the transition period when more residents switch from cars to e-bikes without adequate infrastructure. Additionally, the average speeds tend to be faster for recreational trips, followed by commute and social/errand trips, but commute and social/errand trips cover a relatively greater portion of trip distances at higher speeds. Integrating surveys throughout the data collection period and additional data sources, such as Google travel information, can aid in assessing trips, travel choices, and shifts in mode preferences over time.

5 ACKNOWLEDGEMENTS

This study was funded by the National Science Foundation (NSF) under grant number CBET-1706939. The views expressed in this paper are solely those of the authors and do not necessarily reflect those of the funding agency.

REFERENCES

1. MacArthur, J., et al., *A North American survey of electric bicycle owners*. 2018, National Institute for Transportation and Communities (NITC).
2. Shirley, C. and R. Gecan, *Emissions of Carbon Dioxide in the Transportation Sector.* 2022.
3. Fishman, E. and C. Cherry, *E-bikes in the Mainstream: Reviewing a Decade of Research.* Transport reviews, 2016. **36**(1): p. 72-91.
4. Cherry, C. and R. Cervero, *Use characteristics and mode choice behavior of electric bike users in China.* Transport Policy, 2007. **14**(3): p. 247-257.
5. Johnson, M. and G. Rose, *Extending life on the bike: Electric bike use by older Australians.* Journal of Transport Health, 2015. **2**(2): p. 276-283.
6. Sun, Q., et al., *Modal shift implications of e-bike use in the Netherlands: Moving towards sustainability?* Transportation Research Part D: Transport and Environment, 2020. **78**.
7. Lee, A., et al., *Electric bicycle use and mode choice in the Netherlands.* Transportation Research Record, 2015. **2520**: p. 1-7.
8. de Haas, M., et al., *E-bike user groups and substitution effects: evidence from longitudinal travel data in the Netherlands.* Transportation, 2022. **49**(3): p. 815-840.

Experimentally validated models that predict cyclist falls

M.M. Reijne[*], **F.H. van der Meulen**[#], **F.C.T van der Helm**[*], **A.L. Schwab**[*]

[*]Faculty of Mechanical Engineering
Delft University of Technology
Mekelweg 2, 2628CD Delft, The Netherlands
email: a.l.schwab@tudelft.nl

[#] Department of Mathematics
Vrije Universiteit Amsterdam
De Boelelaan 1105, 1081HV Amsterdam, The Netherlands
email: f.h.van.der.meulen@vu.nl

Keywords: cycling safety, cyclist falls, statistical models, mechanical models, experiments.

INTRODUCTION

Falls during cycling are responsible for about two thirds of serious injuries among cyclists [1]. This is not surprising as the bicycle-cyclist system is inherently unstable [2]. A common emergency operation is recovering balance after an unexpected external perturbation. For some external perturbations a cyclist is likely to recover balance while for others not. To choose targeted and effective interventions to prevent falls, it is necessary to know the threshold for which the cyclist can no longer recover balance. This provides information what perturbations should be eliminated from the bicycle paths and which cyclist-bicycle combinations have a higher (or lower) risk of falling. The problem is that this threshold is unknown.

A common approach is to use statistical models for drawing conclusions from experimental data. Although cycling balancing experiments have been performed in the past, none of these include actual falls, they all stay within the small perturbation regime [3].

Another approach to investigate the stability of a dynamical system is to investigate the effect of small perturbations about a steady motion in a model, the so-called linearized stability approach. For cycling, this approach works well because the dynamical models of the uncontrolled bicycle have been well established and recently much more is known about a model for the cyclist as a human controller [4]. Unfortunately, these models have never been validated for large perturbations where the rider falls.

Therefore, the goal of this work is to predict the threshold of perturbations for which the cyclist will fall and the dependency of this threshold on forward speed and bicycle-cyclist system specific characteristics. For this we developed two models, a statistical model and a Newtonian mechanics model. Preliminary results show that the models can predict this threshold for a wide range of bicycle-cyclist combinations.

METHODS

The cyclist fall experiments were conducted in a safe environment, where the rider is riding on a treadmill, supported by an intelligent harness, and surrounded by a soft padding environment, see Fig 1(left). After getting used to riding the treadmill, the riders were perturbed during cycling at a constant speed by pulling at the handlebar by motor-controlled ropes. In order to find the boundary between falling and not falling, a random staircase procedure was used with varying size of perturbations. Recorded data was: forward speed, pull force and direction, kinematics of the bicycle-cyclist system, and arm muscle EMG. The experiments were performed with 24 healthy experienced Dutch cyclists, distributed evenly among young (20-35 y) and old (>65 y) and among male and female.

The statistical model was a Bayesian multilevel logistic regression model with parameters that were estimated on data from cyclist fall experiments. The independent variables considered for the model were forward speed, cyclist's age, mass, length, reaction time, cycling skill and effort, the perturbation's magnitude, identification number and direction. The Newtonian mechanics model is based on the Carvallo- Whipple bicycle model [5] together with a one-parameter rider control model [6].

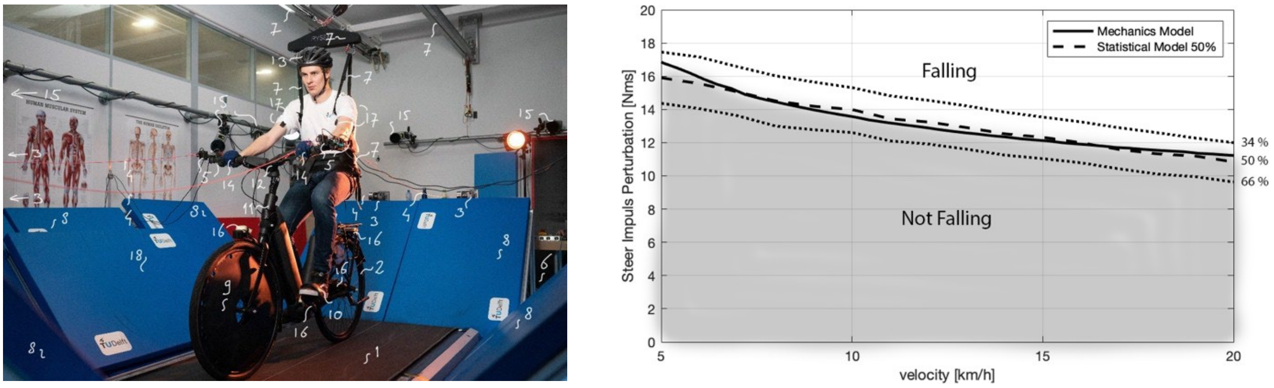


Figure 1. (left) Overview of the experimental setup, with: 1-treadmill, 2-bicycle, 3-pull force motor (4), 4-pull rope (4), 5-force sensor (4), 6-speedgoat real-time controller, 7-intelligent harness, 8-soft padding (8), 9-disc wheel cover (2), 10-foot strap (2), 11-mechanical rotation limiter, 12-rear-brake handle, 13-helmet, 14-protective gloves (2), 15-motion capture camera (12), 16-IMU (4), 17-EMG measurement unit (4), 18-folding fence, and (right) threshold value for the steer impulse perturbation for which the cyclist (45 year, average skill) will not fall as a function of forward speed, the solid line is the mechanics model, the dashed line is the statistical model with a 50 % change of not falling, the dotted lines are the 66 % and 34 % boundaries.

RESULTS

Preliminary results for both the mechanics and the statistical model are shown in Fig 1(right). The threshold values for the steer impulse perturbation for which the cyclist will not fall from the mechanics model show a good agreement with the 50% of not falling from the statistical model. The threshold values show a decrease with increasing forward velocity. The basic balance mechanism on a bicycle is to steer into the direction of the undesired fall [5]. At higher forward speeds there is just not enough lateral space for this balancing action and the cyclist rides off the treadmill. This also happens in real life where there is usually limited lateral space. The figure shows the results for a middle-aged rider (45 y) with average riding skills. The trends are +/- 16% of the threshold values for younger (25 y) highly skilled and older (65 y) less skilled cyclists.

CONCLUSIONS

Preliminary results show that the two models perform good in predicting the threshold of perturbations for which a cyclist will not fall. The advantage of the mechanics model is that the effect of changes in the cyclist, bicycle and environment, on the threshold value for which the cyclist will not fall, can be determined.

REFERENCES

[1] R. Utriainen, S. O'Hern, and M. Pöllänen, "Review on single-bicycle crashes in the recent scientific literature," *Transport Reviews*, pp. 1–19, 2022.

[2] J. Kooijman, J. P. Meijaard, J. M. Papadopoulos, A. Ruina, and A. L. Schwab, "A bicycle can be self-stable without gyroscopic or caster effects," *Science*, vol. 332, no. 6027, pp. 339–342, 2011.

[3] J. K. Moore, J. Kooijman, A. L. Schwab, and M. Hubbard, "Rider motion identification during normal bicycling by means of principal component analysis," *Multibody System Dynamics*, vol. 25, no. 2, pp. 225–244, 2011.

[4] A. L. Schwab and J. P. Meijaard, "A review on bicycle dynamics and rider control," *Vehicle system dynamics*, vol. 51, no. 7, pp. 1059–1090, 2013.

[5] J. P. Meijaard, J. M. Papadopoulos, A. Ruina, and A. L. Schwab, "Linearized dynamics equations for the balance and steer of a bicycle: a benchmark and review," *Proceedings of the Royal society A*, vol. 463, no. 2084, pp. 1955–1982, 2007.

[6] K. D. Wendel, "Bicycle-rider control identification", MSc thesis, Delft University of Technology, 2020.

Increasing safety through geofencing based regulations for e-scooter parking: Evaluation of impact and acceptance among e-scooter users in Munich

S.-T. Graupner[*], J.-H. Müller[#], J. Schade[*], R. Alfahel[°]

[*]Chair of Traffic Psychology
Technical University of Dresden
01062, Dresden, Germany
email: sven-thomas.graupner@tu-dresden.de

[#] Mobility Department
City of Munich
Munich, Germany
email: jan-hendrik.mueller@muenchen.de

°Lindholmen Science Park
CLOSER
Lindholmspiren 3-5, SE-402 78, Gothenburg, Sweden
email: rodrigue.alfahel@lindholmen.se

Keywords: e-scooter, parking, regulation, geofencing, acceptance, impact, safety

1 E-SCOOTER PARKING AS A CHALLENGE

Rental e-scooter were first introduced in German cities in 2019. Much of the success for rental e-scooters services is related to a free floating usage scheme, i.e. e-scooters can be picked up and dropped off at almost any place the user wants. This made it a very flexible, convenient and time-saving means of transport for its users. At the same time, it created inconveniences for others, primarily pedestrians, because suddenly parked vehicles were blocking access and right of way and producing obstacles on sideways (or even worse, creating hazards for blind, seeing-disabled, or walking-disabled people). Irregular parking is, beside unsafe e-scooter riding, a big challenge for cities and causes acceptance problems in the public [1]. Cities and e-scooter operators have acknowledged the problem and tried to improve the situation, either by educating users about correct parking, incentivizing correct or penalizing incorrect parking, creating designated parking spaces, or adding dedicated street furniture for e-scooter parking [2]. While these measures have proven to be somewhat effective, issues with misparked e-scooter persist even in cities where free floating schemes have been abandoned in favor for a net of dedicated parking zones (e.g. Paris). One of the current barriers is the lack of technical solutions to easily control and enforce stricter parking regulations. Geofencing is seen as a technology that might help to achieve this [3]. However, the lack of GPS/GNSS accuracy currently still causes problems with the practical implementation of geofencing based parking regulations. A location may be incorrectly identified as being outside a parking zone, leaving users frustrated because they cannot return an e-scooter. Or, users can still return the e-scooter outside a parking zone in a place that is actually prohibited.

2 GEOFENCED BASED PARKING REGULATION FOR E-SCOOTERS: A CASE STUDY IN MUNICH

2.1 E-scooter situation in Munich

Currently, four companies operate about 17.500 e-scooter in Munich. The operation of e-scooters is regulated by a voluntary agreement between the city and the companies which was developed in 2019 and updated in 2022 by order from the city council in order to better regulate e-scooter parking and improve related safety issues in future. However, due to increasing numbers of rentals, complaints about e-scooters parking violations continued to occur. Given this situation, a new parking regulation for e-scooters was developed in 2022 in a cooperation between the municipal authorities and the e-scooter operators with the aim to decrease the amount of irregular parked e-scooters and to improve the safety for visitors of Munich's old town district.

2.2 New parking regulation for e-scooters

Forty-three designated parking zones were set up between May and Oct 2022 as part of a pilot project to improve e-scooter parking in Munich's old town. Many of the parking zones were installed on streets, at locations of former car parking spaces and all were marked by a street sign and road markings, sometimes including road furniture like posts or brackets. All parking zones as well as non-parking areas were defined digitally by geofences. E-scooter providers are required to implement zones and regulations in their back-ends. Since Oct 2022 e-scooter parking is allowed only within (or close to) designated parking zones and restricted everywhere else in Munich’s old town. Due to the generally positive results of the pilot test, the new parking regulation was made permanent in the second quarter of 2023.

2.3 Evaluation of the new regulation

The implementation and evaluation of the new geofencing-based parking regulation for e-scooters was carried out as part of the activities in the European joint project GeoSence. Historical data on e-scooter locations for a period before (2021) and during (2022) the pilot and after the completion of the installation process (from October 2022) was used to analyse the impact of the regulation. Furthermore, an online survey was conducted to assess the impact and acceptance for the new parking regulation among the e-scooter users. The survey contained questions related to the effectivity of the regulation to improve e-scooter parking, its effects on e-scooter usage, experiences when parking an e-scooter, acceptance for the regulation and intentions for future usage. The survey was conducted in spring 2023 and was supported by all four local e-scooter companies, who invited their users to participate. The survey was completed by 347 participants.

3 RESULTS

3.1 Change in parking behaviour

Comparing the e-scooter locations data within the Munich’s old town from October 2021 and 2022 revealed a higher clustering and density of returned e-scooters around the locations of established parking zones in 2022. It indicates that users have parked more frequently within (or near) dedicated parking zones in 2022 compared to 2021. Still, some vehicles were returned at locations where it shouldn’t be possible, indicating persisting problems to control and enforce desired parking behaviour.

3.2 Impact and acceptance evaluation with the online survey

When asked, whether the new regulation had an impact to reduce problems with misparked e-scooters, about 80 % of e-scooter users judged it to be slightly or highly efficient. More specifically, over 50 % of users rated that situations with lying or blocking e-scooters on sideways or at intersections had improved. Other aspects (order and tidiness in the cityscape, safety on sideways for pedestrians, or large numbers of unorderly parked vehicles in one spot) did also improve but to somewhat smaller degree.

Despite its effectiveness for improving e-scooter parking, the new regulation also came with costs for important aspects of e-scooter usage. More than 60 % of users reported that flexibility and convenience of e-scooter usage, and aspects as time to reach a destination and quickly finding a place to park an e-scooter had worsened. Overall, more than 50 % reported that the new regulation resulted in disadvantages for usage.

When asked for the acceptance of the regulation and how much users agreed to the implementation of the new regulation in the old town, 56% reported to agree with it and 29% disagreed with it. However, only 40% of users would agree with extending the regulation to other parts of the city, while 49% would disagree (11% had a neutral opinion). Concerning their intentions for future usage a majority of users (59%) responded that they would not refrain from a trip to the city center due to the new regulation, but 54% consider it somewhat or very likely to use some other means of transport instead in the future. Of these, 18% indicated they would use a private car for the journey.

Questions of the survey also focused on experiences and problems that occurred when returning an e-scooter in a parking zone. 66% of users reported that returning the e-scooter during their last trip worked quickly and seamless. Still, 57% indicated problems with easily finding a parking zone near their destination. Distance of the parking zone (36 %) and unfamiliarity with the location (20%) where named as main problems when returning an e-scooter. Other reported problems were visibility of the parking zone, overcrowding of the parking zone with other e-scooters and technical malfunctions/problems (each about 15%).

4 CONCLUSIONS

Taken together, the evaluation indicates that the new regulation has led to an improvement in parking behaviour. E-scooters park more frequently and more densely in the vicinity of the established parking zones. In generally, this should lead to improved safety for other road users, especially pedestrians. However, it is presently unclear how many e-scooters are actually parked in the parking zones and whether there is an increased risk of obstructive parking near a parking zone now, as there is still a considerable amount if dispersion in e-scooter location data around the parking zones. A systematic survey via on-site observations has not yet been conducted. The dispersion can be partly explained by a tolerance range (20m) around parking zones within the system, which is presently necessary because the GPS signal is too inaccurate to achieve reliable positioning within a parking zone. In follow-up studies, additional sensors at parking zones will be tested and evaluated to improve the accuracy of the positioning.

An improvement for parking e-scooters as result from the new regulation was also reported by a majority of participants in the online survey. At the same time, the consequences of the parking regulations are perceived by the majority of users as a restriction of important aspects of e-scooter use and are generally assessed as a disadvantage. Our analysis also revealed a number of problems experienced by users. Finding quickly a parking zone near to a destination was reported a problem by more than one third of the participants. This may be related to their visibility in city space but sometimes also to overcrowded parking zones, requiring users to look for a place to park somewhere else with negative side effects for travel time and costs. In addition, few reports indicate that the zones were not displayed consistently in the providers' software. And finally, technical problems occurred, e.g. the positioning in a parking zone was not recognised. Despite these problems, a majority of users agreed and accepted the introduction of the regulation in the Munich's old town, but at the same time a majority also rather rejected an extension to other areas of the city. In addition, the answers indicated that there is a risk that users will either forego travelling to the city centre sometimes or switch to less sustainable forms of mobility in the future due to the regulation.

To summarize, regulation has effects and leads to improved parking behaviour. We therefore expect that it also affects traffic safety in a positive way. How the regulation is perceived among non-users and visitors of the Munich's old town will be evaluated in a follow-up study. However, the implementation of the regulation is not yet perfect and might be improved on several practical, technical and organisational aspects in order to increase its acceptance both among e-scooter users and other affected groups.

The technical ecosystem implemented in Munich for geofencing-based regulation of e-scooter parking is also used for other micro-mobility services and can therefore also contribute to improve safety-related aspects for offers like shared e-bikes or cargo bikes.

REFERENCES

[1] Gössling, S. (2020). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. *TRANSPORTATION RESEARCH PART D-TRANSPORT and ENVIRONMENT*, *79*, 102230. https://doi.org/10.1016/j.trd.2020.102230

[2] Klein, N. J., Brown, A., & Thigpen, C. (2023). Clutter and Compliance: Scooter Parking Interventions and Perceptions. *Active Travel Studies*, *3*(1). https://doi.org/10.16997/ats.1196

[3] Hansen, L., Arnesen, P., Graupner, S.-T., Lindkvist, H., Leonardi, J., Fahel, R. A., & Andersson, K. (2021). Current state of the art and use case description on geofencing for traffic management. https://closer.lindholmen.se/sites/default/files/2021-11/report-on-current-state-of-the-art-and-use-case-description-on-geofencing-for-traffic-management.pdf

Video-Based Safety Evaluation of Interactions Between Cyclists and Motorized Vehicles

Stefano Albanello[1], Torben Lelke[2, *], Federico Orsini[1], Walid Fourati[3], Aleksandar Trifunović[3], Bernhard Friedrich[2], Riccardo Rossi[1]

[1] University of Padua, Department of Civil, Environmental and Architectural Engineering, Via F. Marzolo 9, 35131 Padua, Italy

[2] Technical University of Braunschweig, Institute of Transportation and Urban Engineering, Hermann-Blenk-Straße 42, 38108 Braunschweig, Germany

[3] mouver GmbH, Rubensstraße 14, 30177 Hannover, Germany

[*] Corresponding author: t.lelke@tu-braunschweig.de

Keywords: safety parameters, computer vision, trajectory analysis, longitudinal movement, overtaking

1 Introduction and Research Contribution

The issue of cyclist and motor vehicle interaction is a prominent concern for road safety, particularly when considering its longitudinal dimension [1]. Several studies have investigated the factors that contribute to road collisions involving bicycles, with the majority of them highlighting the importance of infrastructure characteristics, albeit not always with consistent outcomes [2]. In particular, there is a lack of established procedures to extract safety-relevant indicators from standard on-field surveys, which hampers the ability of researchers and practitioners to perform reliable and consistent road safety evaluations. A solution for this could be achieved by applying computer vision to accurately observe and analyze objects.

The purpose of this study is to suggest a framework for short-term safety assessment for locations of bicycle traffic, particularly in sections where cyclists ride parallel – and mixed with - motor traffic. We aim to apply computer vision methods to extract trajectories from recordings and use these to identify parameters, which are relevant to interactions between cyclists and motorized vehicles.

2 Experimental Setup

To help develop the indicators, four locations were recorded during three days in the urban area of Hannover, Germany, all involving parallel cyclists and vehicular traffic. Two locations were supposed to showcase safety-related situations, having cyclists and motorists sharing the same road surface or where the bike lane is trafficable by motorists in the absence of cyclists. Two other locations were supposed to be serving as references, having dedicated bicycle lanes.

The obtained videos undergo a computer vision process composed of detection/classification, tracking, and projection. The obtained trajectories from tracking are in camera frame coordinates (pixels) and a 3D-perspective view. To study interactions between objects using distance, speed, and acceleration uniformly at any region of the observed view, a transformation of the coordinates from the 3D perspective to the 2D plan is necessary. A set of reference pairs of points that match between the two views helps create the transformation (homography) matrix. Trajectories plotted in both views as well as the used matching points for the experimental spots are illustrated in Figure 1. The last step in the data preparation is filtering the trajectories data set to keep only situations with car-bicycle interaction.

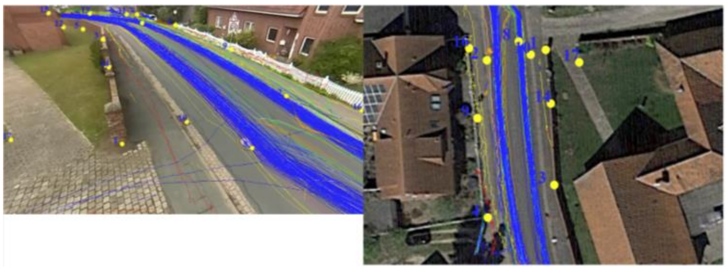


Figure 1: Trajectories in camera perspective (left) and 2D top-down view (right) with matching pairs of points

3 Parameter Extraction Methodology

The strategy for identifying risk indicators under the conditions investigated in this study begins with identifying the nature of the interactions between a bicyclist and a neighboring vehicle. The first step was to identify the individual interactions between bicycles and vehicles based on the trajectories obtained. By referring to the period of time each recorded bicycle was riding, any vehicle detected at the same time and in the same stream was considered as a possible interaction.

The second step was to distinguish the recorded interactions according to their type. Two main scenarios were defined with parameters calculated differently for each. The first scenario we considered was the longitudinal 'Leader-Follower' scenario, in which the following vehicle queues behind the cyclist if there is not enough space to overtake. It can also be considered as the initial scenario of any interaction since it includes those cases where the follower does not complete the approach phase within the field of view in time. In this case, the focus is on deriving the minimum Rear clearance (RC) between the rear wheel of the bicycle and the closest point of the following vehicle, Time-to-Collision (TTC), and Post-Encroachment-Time (PET). Secondly, we defined a lateral scenario, in which the following vehicle performs an overtaking maneuver. In this case, the parameters considered are the Lateral Clearance (LC) and the relative speed of overtaking (ΔV).

Such safety indicators were calculated using formulas that consider the actual physical size of road users; this size was reasonably simplified as their 2D projected rectangle on the ground. For more details on the calculation of these indicators, the reader is referred to [3].

To determine the nature of an interaction, we consider the course of the trajectories in conjunction with a macro area division of the space around the vehicle. Depending on the position of the bicycle in comparison to the vehicle in each frame of the recording, we assigned a numerical index to the situation. Situations where both wheels of the cyclist are in front of the vehicle and where at least one wheel was within the area to the right of the car were assigned the indexes 1 and 0, respectively. If the position of the bicycle does not fit one of these two situations, an index of -1 is assigned. This approach is shown in Figure 2.

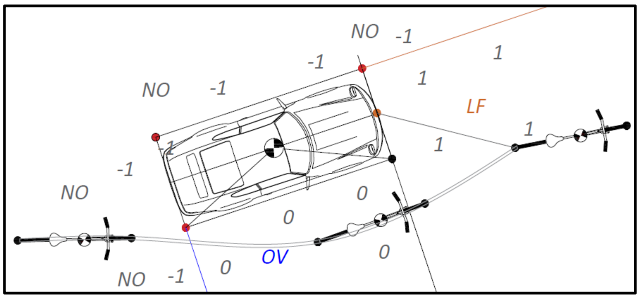


Figure 2: Detection of bicycle position relative to the motorized vehicle

By observing the numerical sequence through the frames of each trajectory, it was possible to deduce the nature of the interaction. If the cyclist is in front (index 1) throughout the trajectory, the interaction was considered to be a Leader-Follower (LF) scenario. However, if the cyclist's sequence included a transition of numbers like (1, 0, -1), the event can be considered as a complete overtaking (OV). If a sequence did not match any of the predefined scenarios, it was identified as an anomalous case and labeled as (NO). The percentage of 'NO cases' depended mainly on the location's characteristics and traffic.

4 Results and Conclusions

We extracted the aforementioned parameters on four case-study locations with varying infrastructure. In locations 1 and 2, a dedicated bicycle path is present, while in the other two locations, the motorized and non-motorized traffic is mixed. A longitudinal interaction was considered if the minimum rear clearance behind the cyclist was lower than 5 meters. Similarly, lateral interactions were considered if the minimum lateral clearance was lower than 3.5 meters. The results of the parameter extraction are shown in Table 1.

Table 1: Results of the parameter extraction for the case-study locations

	1ST SCENARIO – LONGITUDINAL – LEADER-FOLLOWER					2nd SCENARIO – LATERAL - OVERTAKING				
Loc	No. Events (RC < 5m) [#]	Min. Clearance [m]	Average min. Clearance [m]	Min. TTC recorded [s]	Min. PET recorded [s]	No. Events (LC < 3,5m) [#]	Min. Clearance [m]	Average min. Clearance [m]	Avg. Rel. Speed ΔV [km/h]	Max. Rel. Speed ΔV [km/h]
1	6	2.91	3.66	0.4	0.2	79	1.77	2.72	32.25	41.42
2	3	3.09	3.15	1.7	0.6	4	1.41	2.21	15.28	18.10
3	9	3.13	3.88	0.5	0.3	74	0.67	2.18	4.48	5.92
4	12	0.93	2.83	1.2	0.2	59	0.93	1.42	3.95	15.64

The calculated parameters were validated in samples based on the recorded videos. However, a more thorough validation of the parameters and resulting conclusions are planned in further research. We also aim to use the parameters to generate safety indicators for each interaction type, to ease the identification of problematic road sections.

5 Acknowledgment

The authors would like to thank the Region of Hannover for collaborating in collecting the data for this work and the mFUND program for partial funding and supporting it.

REFERENCES

[1] Kovaceva, J., Nero, G., Bärgman, J., & Dozza, M. (2019). Drivers overtaking cyclists in the real-world: Evidence from a naturalistic driving study. *Safety Science*, *119*, 199–206.

[2] Prati, G., Marín Puchades, V., De Angelis, M., Fraboni, F., & Pietrantoni, L. (2018). Factors contributing to bicycle–motorised vehicle collisions: A systematic literature review. *Transport Reviews*, *38*(2), 184–208.

[3] Laureshyn, A., Svensson, Å., & Hydén, C. (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. *Accident Analysis & Prevention*, *42*(6), 1637–1646.

Positioning Human Body Models in Cyclists' postures based on experimental data

M. Oikonomou[1], A. Lioras[2], L. Rorris[3], J. Iraeus[4], A. Mihailides[1]

[1]Department of Mechanical Engineering
Aristotle University of Thessaloniki
Aristotle University of Thessaloniki, 54124,
Thessaloniki, Greece
email: oikonommg@meng.auth.gr

amih@meng.auth.gr

[2]BETA CAE Systems SA
Kato Scholari, 57500, Thessaloniki, Greece
email: alioras@beta-cae.com

[3]BETA CAE Systems International AG
Platz 4, 6039, Root, Switzerland
email: lambros@beta-cae.com

[4]Department of Vehicle Safety
Chalmers University of Technology
Chalmersplatsen 4, 41296, Gothenburg, Sweden
email: johan.iraeus@chalmers.se

Keywords: cyclists, HBM, positioning, experimental data.

1 INTRODUCTION

Crash Simulation and Analysis aims to protect a diverse group of road users, with numerous studies examining occupants' and pedestrians' motion and their potential injuries. Although two-wheel vehicles remain common means of personal transportation, very few analyses have been conducted about other vulnerable road users, such as motorcyclists and bicyclists. Therefore, studying their kinematic behavior in multiple collisions will ensure safe and convenient travel.

These road users may adopt various non-standard seating choices, leading to different kinematic behavior. Thus, analyzing crash simulation results extracted from unique initial positions is critical to protect humans in out-of-position load cases.

Since dummies are established for specific crash situations, Human Body Modeling and Simulation remain the most accurate way to reproduce human motion and assess potential injuries in different crash scenarios. However, Human Body Models (HBMs) are developed only for the seating and standing postures, representing the occupant and pedestrian accordingly. Therefore, moving HBMs to adopt the desired target position is necessary.

Due to the difficulty of the HBM positioning process, most currently published research on cyclist injury and kinematics is performed using multibody models and dummies [1], [2], where a small number of studies simulate cyclists using HBMs [3].

This study aims to develop a method that positions the HBMs in a target posture defined by experimental data. The positioning process of HBM was developed in ANSA Python scripts and using the ANSA HBM Articulation tool.

Considering the expanding use of two-wheel vehicles and increased traffic accidents, data from typical cyclists' postures are extracted to illustrate the positioning tool.

2 METHODS

The reproduction of body posture is the accurate positioning of HBM to replicate the experimentally derived Subject's position. This procedure relies on precisely positioning specific anatomical landmarks, indicative of the whole body's position. These anatomical landmarks are easily identified and palpated points of human bones and are selected via literature [4], [5], [6]. Consequently, the definition of corresponding anatomical points on the Subject's and HBM's Bones is essential in replicating an identical pose between the HBM and the reference Subject.

Skin markers and imaging techniques are the most common ways to extract the coordinates of the Subject's landmarks. While imaging techniques can directly determine the position of bones as required, skin markers require further measurements of the Volunteer's skinfold thickness. Therefore, the coordinates of skin markers are modified as if they were set on the Volunteer's bones.

However, due to anatomical differences between the HBM and the Subject, the HBM's articulation cannot occur by directly using the coordinates of the previously defined Subject's anatomical points. Thus, the goal is to articulate HBM to achieve the same slopes between its successive points with the Subject's successive markers.

An optimized articulation method is built to calculate the slopes' differences in each articulation step. The articulation Procedure uses ANSA Python scripts and the Ansa HBM Articulation tool. The final HBM position is determined based on the minimum slope error.

3 IMPLEMENTATIONS

Experiments using Skin Markers techniques were conducted to implement the above-described methodology. The investigation involves bicycles and motorcycles with known typical dimensions. Volunteers with characteristics similar to the HBM (height and weight) ride the bike, and skin markers are placed in their final position. In addition, a caliper measures skinfold thickness on the markers’ positions. Then, the 3D coordinates of the markers are collected, and a data processing strategy using statistical methods is held.

Finally, the HBM is moved to the reference posture, as determined by the explained methodology. Therefore, examining cyclists’ behavior in different crash situations using HBMs became feasible.

4 CONCLUSIONS

This study develops a method that positions the HBM in a target posture defined by experimental data. The data can be derived from any volunteer matching the features of the to-be-positioned HBM. Consequently, unique initial positions can be examined to protect the cyclist in non-standard load cases.

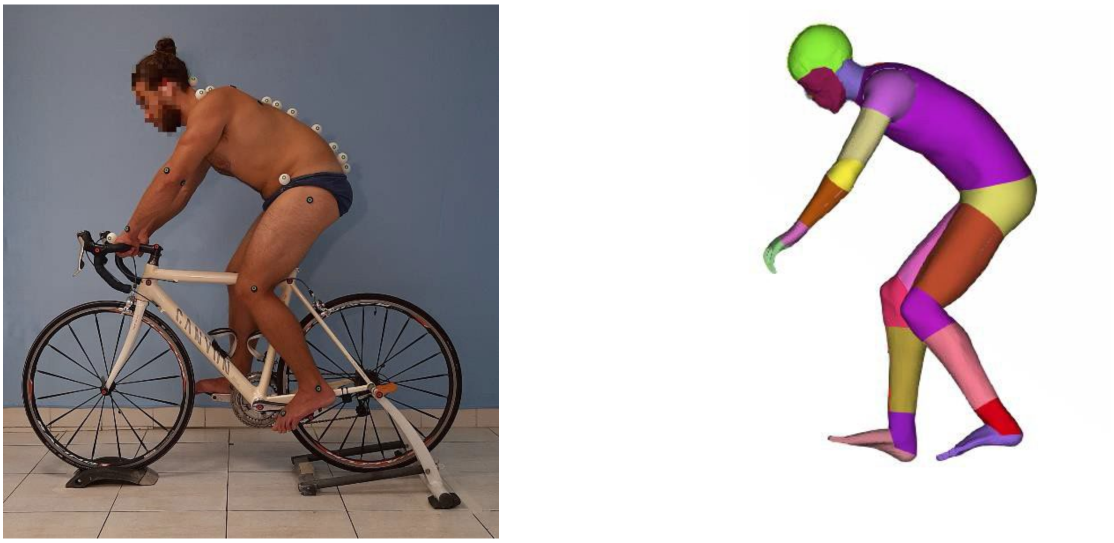


Figure 1: Left: Reference Bicyclist Posture, Right: HBM Bicyclist Final Posture

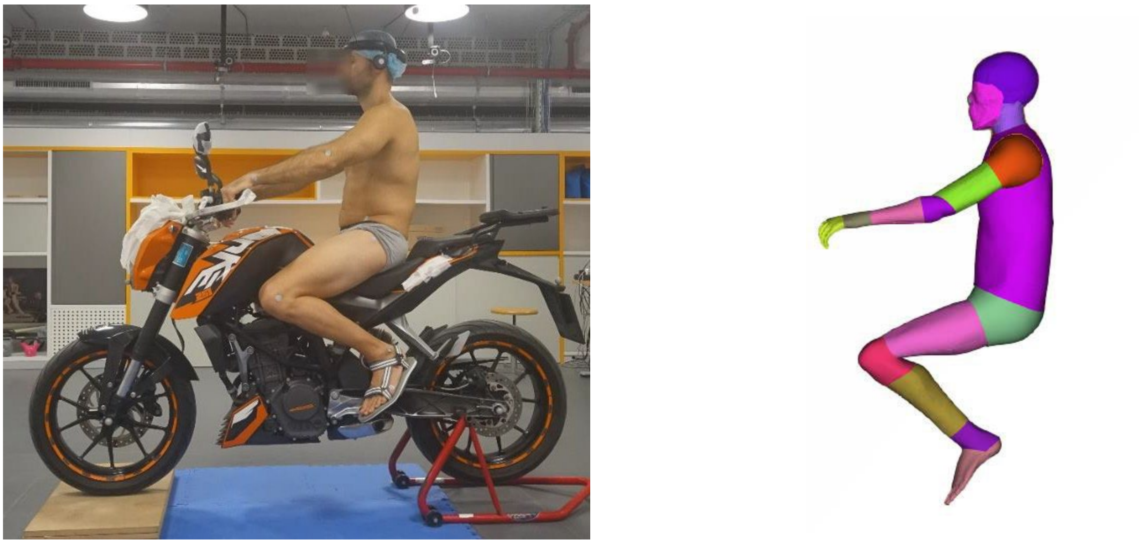


Figure 2: Left: Reference Motorcyclist Posture, Right: HBM Motorcyclist Final Posture

REFERENCES

[1] T. Makia and J. Kajzerb, "The behavior of bicyclists in frontal and rear crash accidents with cars", JSAE Review 22 (2001), pp. 357–363.

[2] Y. Peng, Y. Chen, J. Yang, D. Otte and R. Willinger, "A study of pedestrian and bicyclist exposure to head injury in passenger car collisions based on accident data and simulations", Safety Science 50 (2012), pp. 1749-1759.

[3] T. Katsuhara, H. Miyazaki, Y. Kitagawa and T. Yasuki, "Impact Kinematics of Cyclist and Head Injury Mechanism in Car-to-Bicycle Collision", Proceedings, IRCOBI Conference 2014, Berlin, Germany, 10-12 September 2014, pp. 670-684.

[4] S. Siegler, P. Allard, C. Kirtley, A. Leardini, D. Rosenbaum, M. Whittle, D. D'Lima, L. Cristofolini, H. Witte, O. Schmid and I. Stokes, "ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine", Journal of Biomechanics 35 (2002), pp. 543-548.

[5] G. Wu, F. Van der Helmb, H. Veeger, M. Makhsous, P. Van Roy, C. Anglin, J. Nagels, A. Karduna, K. McQuade, X. Wang, F. Werner and B. Buchholz, "ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand", Journal of Biomechanics 38 (2005), pp. 981-992.

[6] C. Klein, M. González-García, J. Weber, F. Bosma, R. Lancashire, D. Breitfuss, S. Kirschbichler and W. Leitgeb, "A Method for Reproducible Landmark-based Positioning of Multibody and Finite Element Human Models", Proceedings, IRCOBI Conference 2021, Virtual, 8-10 September 2021, pp. 477-489.

[7] A. Frostell, R. Hakim, E. Thelin, P. Mattsson and M. Svensson, "A Review of the Segmental Diameter of the Healthy Human Spinal Cord ", Frontiers in Neurology, 2016.

[8] I. Gilad and M. Nissan: " Sagittal evaluation of elemental geometrical dimensions of human vertebrae", Journal of Anatomy 143 (1985), pp. 115-120.

Safe cycling routes:
Seven road safety indicators for cycling routes

S. E. Gebhard*, W.A.M. Weijermars#

*SWOV Institute for Road Safety Research
Henri Faasdreef 312, 2492 JP, The Hague,
The Netherlands
email: sarah.gebhard@swov.nl

#SWOV Institute for Road Safety Research
Henri Faasdreef 312, 2492 JP, The Hague,
The Netherlands
email: wendy.weijermars@swov.nl

Keywords: safe cycling, bicycle infrastructure, road safety, route choice

1 INTRODUCTION

Cycling is healthy, environmentally friendly, faster than walking, and uses less public space than a car, making the bicycle an attractive mode of transportation, especially for shorter journeys. Unfortunately, however, the numbers of fatalities and serious injuries among cyclists have been increasing in recent years in the Netherlands [1]. A proactive approach to preventing bicycle crashes and reducing crash severity requires identifying and avoiding risks to cyclists in the bicycle infrastructure network. Studies investigating safe cycling infrastructure often focus on design choices at road level, such as the provision of separated bicycle paths. In the Netherlands this has led to the development of Safety Performance Indicators to prioritize safe road design choices [2]. However, sometimes the safest option may be an alternative route altogether; therefore, it is worthwhile to consider how safety varies across different types of cycling routes. For cars, route safety indicators have already been proposed in 2011 [3]. With these as a starting point, this study proposes route safety indicators for cyclists based on established literature on safe cycling infrastructure.

2 SEVEN INDICATORS FOR SAFE CYCLING ROUTES

The proposed indicators for safe cycling routes bring together principles from Sustainable Safety, the already established indicators for cars, and existing literature on safe cycling infrastructure.

2.1 Background

As part of the Sustainable Safety vision, traffic with a 'flow' function should be separated from traffic with an 'exchange' function (Functionality principle) and traffic with a high speed and/or high mass should be separated from traffic with a low speed and/or mass such as vulnerable road users (Biomechanics principle) [4]. For cyclists, the first priority is therefore a separation from motorized vehicles, especially where speeds are higher. In addition, a further distinction between cyclists in terms of their functionality (flow vs. exchange cyclists) or biomechanics (lighter and/or slower cyclists vs. heavier and/or faster cyclists) may be desirable depending on the feasibility of providing different infrastructure and route options for different target groups [5].

A previous study [3] used the Sustainable Safety criteria to develop network safety indicators for car routes. From a safe route choice perspective, the safest car route should coincide with the fastest route. Dijkstra [3] identified nine criteria for safe car routes relating to safe transitions between road types (access, distributor and flow roads), limiting the share of the trip spent on access and distributor roads, minimizing travel distance and travel time to minimize exposure, and limiting the number of intersections and left turns.

2.2 Indicators for safe cycling routes

A literature review [6] has been conducted to identify factors at the levels of road design, route choice, and network structure which are important for the safety of cycling routes. Together with the original indicators for motor vehicles, this led to seven indicators which are relevant for cycling route safety:

1. **Travel distance as short as possible:**
   The shorter the distance of a route, the less risk a cyclist is exposed to.
2. **Travel time as short as possible:**
   The shorter the cycling time, the less risk a cyclist is exposed to.
3. **As few intersections as possible, especially with distributor roads:**
   Relatively many crashes happen at intersections, where cyclists come into potential conflicts with motor vehicles. Especially (at-grade) intersections between distributor roads should be avoided as much as possible as they are relatively unsafe for cyclists. At these intersections, roundabouts are preferred over signalized intersections.
4. **Cyclists should follow exclusive bicycle tracks as much as possible:**
   Exclusive bicycle tracks are not bound to a road and are only accessible to cyclists. This makes the road segments safer compared to roads shared with motor vehicles.
5. **Cyclists should use distributor roads without separate bicycle tracks as little as possible:**
   When speeds are higher than 30km/h, conflicts between motorized traffic and cyclists should be prevented. Therefore, roads with a 50 km/h speed limit or higher should have a separated bicycle track.
6. **As few left-turns as possible:**
   Left-turns at intersections are known to be a risky maneuver for cyclists. They should therefore be limited as much as possible in a route.
7. **As few transitions and discontinuities as possible:**
   Transitions between and discontinuities in the type of cycling infrastructure (e.g. a cycling path that continues on the other side of the street or changes into a cycling lane) lead to an increased safety risk and should therefore be avoided as much as possible.

These seven indicators focus on limiting exposure and conflicts with motorised traffic. In addition, it may be advantageous to protect the most vulnerable road users (pedestrians and vulnerable cyclists) from large flows of fast and potentially higher-weight bicycle through-traffic and other potential users of bicycle facilities, like upcoming Light Electric Vehicles (LEVs). While research is lacking on the safety implications, an eighth route indicator may be considered regarding the separation of these different groups of cyclists (in line with the Sustainable Safety functionality and biomechanics principles).

3 PRACTICAL APPLICATION

The seven indicators identified above can be used to compare the safety levels of different route options between a given origin and destination (origin-destination pair) to identify locations in a network where route safety can be improved. Ideally, the most attractive and popular routes chosen by travelers in the network should also be as safe as possible for both the traveler and other road users. As routes remain the choices of travelers given the infrastructure available to them, for road authorities the route safety can primarily be influenced indirectly by measures taken at the levels of road design and network structure. Examples of measures to improve route safety at the network and road levels are shown in Table 1.

Table 1: Measures at the network-level and road-level to improve cycling route safety

Approach	Measures for safe cycling routes
Network-level measures	• Separate motor vehicle flow traffic from access roads & bicycle traffic • Create direct cycling routes with minimal detour • Create exclusive bicycle paths where possible • Create bicycle through-routes on exclusive bicycle paths • Grade-separate or avoid cycle route intersections with distributor roads • Avoid left-turns and transitions between infrastructure types which require cyclists to cross motorized traffic • Make safe routes more attractive to cyclists, for example by increasing comfort or adapting traffic light settings
Road-level measures	• Create separated bicycle tracks along distributor roads • Limit speeds where conflicts between cyclists & motor vehicles can occur • No obstacles in the cycling infrastructure • Sufficiently wide bicycle paths • Quality surface: smooth, complete, clean, not slippery • Visual guidance • Forgiving cycle path/track edges and verges

4 DISCUSSION AND RECOMMENDATIONS

Consideration for where and how safe cycling routes fit into an infrastructure network is important not just at the level of road design—as is often the focus in cycling research—but also at the level of network structure and route design. The seven identified indicators of safe cycling routes are a tool to aid in decision-making when designing networks for new safe cycling routes and for identifying safety concerns in existing routes. As no weight factors have been estimated, it is at this point not possible to quantify the relative contributions of each indicator to an overall safety level. Rather, the indicators can be used in a primarily qualitative way to compare route alternatives with each other. Future research may focus on the different cyclist subgroups and functionalities and on realizing safe cyclist through-routes (flow function).

REFERENCES

[1] L. T. Aarts, L. J. van den Broek, J. Oude Mulders, R.J. Decae, N.M. Bos, C. Goldenbeld, G. J. Wijlhuizen, C. Mons, A. T. G. Hoekstra, F. D. Bijleveld, “De Staat van de Verkeersveiligheid 2022: Trend in aantal verkeersdoden en -gewonden daalt niet”, SWOV, Den Haag, R-2022-10, 2022.

[2] Kennisnetwerk SPV, “Wanneer zijn wegen en fietspaden ‘voldoende veilig’? Op weg naar een definitie voor bruikbare risico-indicatoren”, Kennisnetwerk SPV, Utrecht, 2020.

[3] A. Dijkstra, “En route to safer roads: How road structure and road classification can affect road safety”, Ph.D. Dissertation, University of Twente, 2011.

[4] SWOV, “Sustainable Road Safety”, SWOV-factsheet, SWOV, Den Haag, 2019. Available: https://swov.nl/en/fact-sheet/sustainable-road-safety

[5] W. A. M. Weijermars, A. Dijkstra, M. J. A. Doumen, H. L. Stipdonk, D. A. M. Twisk, F. C. M. Wegman, “Duurzaam Veilig, ook voor ernstig verkeersgewonden”, SWOV, Leidschendam, R-2013-4, 2013.

[6] T. Uijtdewilligen, S. E. Gebhard, W. A. M. Weijermars, M. Nabavi Niaki, A. Dijkstra, “Safe cycling routes: Road safety indicators for cycling routes”, SWOV, Den Haag, R-2022-6A, 2022.

Analysis of Selective Conflicts between Multiple Bicycles and Left-Turning Vehicle at Signalized Intersections by using Video Tracking Data

Koya Goshona*, Nagahiro Yoshida#

* Graduate School of Engineering
Osaka Metropolitan University
1608-15 Kanaoka-cho, Kita-ku, Sakai City,
591-8022, Osaka, Japan
email: si22034u@st.omu.ac.jp

\# Graduate School of Engineering
Osaka Metropolitan University
Sugimoto 3-3-138, 558-8585, Osaka, Japan
email: yoshida-na@omu.ac.jp

Keywords: Signalized Intersections, Corner Design, Left-Turn Vehicle, Bicycles, Selective Conflicts.

1 INTRODUCTION

Accidents between bicycles and turning vehicles at signalized intersections are one of the most typical patterns of serious accidents [1]. The bicycle infrastructure can be categorized into bicycle track, bicycle lane, shared lane, and shared path, when these are connected to signalized intersections, in some cases interaction between bicycles and turning vehicles can cause dangerous conflicts. In order to better understand the mechanisms of these left-hook accidents in particular, and to guide countermeasures for protected intersections [2], it is necessary to focus on the driving behavior of bicycles and left-turning vehicles to identify design requirements for safer intersection that are compatible with the era of automated vehicles.

Previous studies have suggested that bicycle accidents are associated with cognitive errors in motorists, and studies have been conducted on "selective cognition" or "inattentional blindness" [3][4]. Since these studies have focused on the oversight of objects, it is thought that the selection of conflicts among multiple objects by left-turning drivers may occurs at signalized intersections.

Therefore, the purpose of this study is to identify the characteristics of selective conflicts between bicycles and left-turning vehicle based on trajectory data, and to compare conflict patterns using the Time to Collision (TTC) index [5], in order to gain insight into the design of intersection corners.

2 RESEARCH METHODOLOGY

2.1 Outline of Target Intersections

In order to analyze the relationship between the type of bicycle infrastructure, cycling behaviors and left-turning vehicle driving behavior, four signalized intersections were selected in the study.

2.2 Classification of bicycle traffic patterns

Because bicycles enter intersections in different ways depending on infrastructure conditions, nine patterns were prepared, A1, A2, A3, A4, B1, B2, C1, C2, and D, as shown in Figure 1. The initial letter A represents a bicycle traveling in the same direction with traffic, B represents a bicycle entering from a crossing direction, C represents a bicycle coming from the opposite direction, and D represents a bicycle stationary at a corner.

2.3 Video Analysis and Evaluation Methods

Video recording was conducted at each intersection during October 2020 to November 2021, each lasting approximately 3 hours. The analysis method used was DEEPSORT, which can track the type and coordinates of objects from the captured video using a Kalman filter, as shown in Figures 2 and 3.

The risk of collision was evaluated using the Time to Collision (TTC) index. In this study, the two-dimensional TTC (vector type) index was used, in which potential collision point were calculated sequentially and the distance to the point was divided by the velocity. To identify critical patterns, the selective conflict situations with multiple bicycles against one left-turning vehicle were classified as the first bicycle with the lowest TTC and the second bicycle with the second lowest TTC, and the average minimum TTC for each traffic pattern were compared.

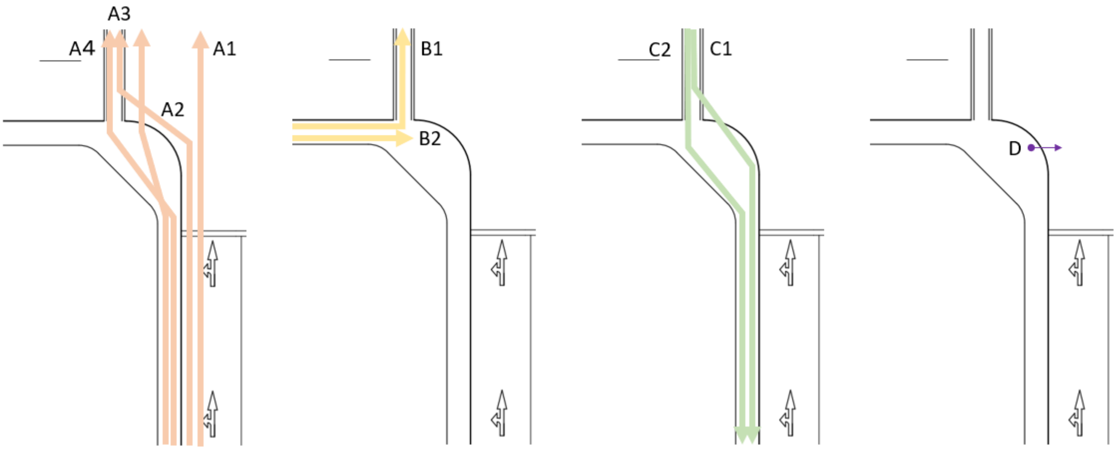


Figure 1: Bicycle traffic patterns (9 types)

Figure 2: Tracking (frame: t)

Figure 3: Tracking (frame: t+1)

Table 1: Combination of passage patterns

		Second bicycle				☐
		A	B	C	D	
First bicycle	A	22	4	3	6	35
	B	2	1	-	2	5
	C	2	-	1	1	4
	D	-	-	-	-	0
total		26	5	4	9	44

Table 2: TTC Combinations

		Second bicycle				☐
		<0.5	<1.0	<2.0	>2.0	
First bicycle	<0.5	-	1	-	-	1
	<1.0	-	-	2	5	7
	<2.0	-	-	6	18	24
	>2.0	-	-	-	12	12
total		0	1	8	35	44

Table 3: TTC calculation results (First bicycle)

	A	B	C
n	35	5	4
Mean	1.6	1.5	2.6
SD	0.77	0.27	0.82

Table 4: TTC calculation results (Second bicycle)

	A	B	C	D
n	26	5	4	9
Mean	2.3	2.2	3.5	-
SD	0.74	0.20	0.29	-

3 RESULTS

3.1 Conflict pattern

The most common combination in the selective conflicts was A-A, as shown in Table 1, and the distribution of TTC showed that the TTC of the second bicycle was slightly larger than that of the first bicycle, as shown in Table 2. Here, there was a statistically significant difference (p<0.01) between the average TTC for the first and second bicycle.

3.2 TTC by traffic pattern

When comparing the average TTC of the first bicycle by traffic pattern, the TTC of A and B was smaller than that of C. The difference was statistically significant (p<0.01).

The comparison of average TTC of the second bicycle by traffic pattern showed that, similar to the first bicycle, the TTC of A and B was smaller than that for C. The difference was statistically significant (p<0.01).

4 CONCLUSIONS

The results obtained and the suggestions based on them are as follows.

The most common combination in the selective conflicts was A-A and the TTC of nearside bicycles tended to be the smaller, suggesting that avoiding multiple nearside bicycles entering the intersection at the same time may contribute to safety at intersection corners.

The TTC of the second bicycle in selective conflicts was almost 2.0 seconds or longer, but in some cases the most dangerous situation was a pattern of nearside shortcuts that made it difficult for drivers of left-turning vehicles to predict the potential conflict point.

The safety of bicycles entering the intersection varies with traffic patterns, and TTC values were significantly lower for nearside bicycles than for far-side bicycles, suggesting that this shortcoming left-turning drivers should be reflected in the design of intersection corners.

ACKNOWLEDGMENTS

This research was carried out as "Development of Traffic Safety Measures for Bicycles on Roadways based on Advanced Data Analysis.", The commissioned research of "National Institute for Land and Infrastructure Management" under technology research and development system of "The Committee on Advanced Road Technology" established by MLIT, Japan.

REFERENCES

[1] Jennifer Warnera, David S. Hurwitza, Christopher M. Monsereb, Kayla Fleskesa, “A simulator-based analysis of engineering treatments for right-hook bicycle crashes at signalized intersections”, Accident Analysis and Prevention (2017), Vol.104, pp. 46-57.
[2] Katerina Deliali, Eleni Christofa, Michael Knodler Jr, “The role of protected intersections in improving bicycle safety and driver right-turning behavior”, Accident Analysis and Prevention (2021), Vol.159, pp. 106295.
[3] Hanne Beate Sundfør, Fridulv Sagberg, Alena Høye, “Inattention and distraction in fatal road crashes – Results from in-depth crash investigations in Norway”, Accident Analysis and Prevention (2019), Vol. 125, pp. 152-157.
[4] Yingying Yan, Shiquan Zhong, Junfang Tian, Liang Song, “Driving distraction at night: The impact of cell phone use on driving behaviors among young drivers”, Transportation Research Part F, Psychology and Behaviour (2022), Vol. 91, pp. 401–413.
[5] Miller, R., Huang, Q., “An adaptive peer to peer collision warning system.”, IEEE Veh. Technol. Conf. (2002), Vol. 1, pp. 317-321.

Large cities are “enlargers” of cycling distractions: common technological and non-technological distractions in >300 cities of different sizes

Sergio A. Useche[a]*, Francisco Alonso[a], Aleksey Boyko[b], Polina Buyvol[b], Isaac Castañeda[c], Boris Cendales[d], Arturo Cervantes[c], Tomas Echiburu[e], Mireia Faus[a], Zuleide Feitosa[f], Jozef Gnap[g], Mohd K. Ibrahim[h], Kira H. Janstrup[i], Ignacio Lijarcio[a], Irina Makarova[b], Rich McIlroy[j], Miroslava Mikusova[g], Mette Møller[i], Sylvain G. Ngueuteu-Fouaka[k], Steve O’Hern[l], Mauricio Orozco-Fontalvo[m], Ksenia Shubenkova[b], Felix Siebert[i], Jose Soto[n], Amanda N. Stephens[o], Yonggang Wang[p], Ellias Willberg[q], Phillip Wintersberger[r], Linus Zeuwts[s], Zadir H. Zulkipli[h], Javier Gene-Morales[a]

*Research Institute on Traffic and Road Safety (INTRAS), University of Valencia.
Carrer del Serpis 29, 46022, Valencia, Spain.
email: sergio.useche@uv.es

[a] University of Valencia, Valencia, Spain
[b] Kazan Federal University, Kazan, Russia
[c] Anahuac University, Mexico
[d] El Bosque University, Bogotá, Colombia
[e] Universidad Católica de Chile, Santiago, Chile
[f] Universidade de Brasilia, Brasilia, Brazil
[g] University of Žilina, Briatislava, Slovakia
[h] Malaysian Institute of Road Safety Research, Kajang, Malaysia
[i] Technical University of Denmark, Copenhague, Denmark
[j] University of Southampton, Southampton, England
[k] Université de Dschang, Dschang, Cameroon
[l] Tampere University, Tampere, Finland
[m] Universidade de Lisboa, Lisboa, Portugal
[n] Universidad Tecnológica de Bolívar, Cartagena, Colombia
[o] Monash University, Melbourne, Australia
[p] Chang’an University, Chang’an, China
[q] University of Helsinki, Helsinki, Finland
[r] Technical University of Wien, Wien, Austria
[s] Ghent University, Ghent, Belgium

Keywords: technological distractions, riding behavior, urban cyclists, cycling distractions, city size.

1 INTRODUCTION

Given its several benefits in terms of health, efficiency and sustainability contributions, cycling has acquired a main role for different stakeholders, including urban planners, public health practitioners, and policymakers [1]. Nevertheless, the growing use of bicycles in urban areas has brought with it a notable increase in crash rates in many cities worldwide, which is why the safety of cyclists has turned into a key issue to continue to promote an active, user-beneficial and reasonably safe mode of transportation [2].

Although multifactorial, numerous risky cycling behaviors can increase the chances of a crash and injury (e.g., mobile phone use, and listening to music while riding). Previous research has analyzed the effects of using new technologies on cycling behavior (2,3). However, to the best of our knowledge, no previous research analyzed bicycle riding-related distracting behaviors related to the use of new technologies in relation to city-size patterns.

Therefore, this study aimed to compare the prevalence of common technology-related distracting sources among cyclists riding in cities of different sizes. According to the previous research (mostly retrieved from motor vehicle drivers), the specific traffic settings of larger cities (e.g., higher complexity, greater access to Internet-Connected Technologies – ICTs and app coverage) might increase the presence of technological distractions among road users, including bicycle riders [6,7].

2 METHODS

This cross-sectional study used the information gathered from a sample of cyclists from 18 countries (≥ 300 cities), which were categorized according to their population density in accordance with literature-based criteria, as follows: small city/town (population < 50,000), medium-sized cities (population 50,000 – 200,000), large cities (population 200,000 – 1,000,000), and megacities (population > 1,000,000).

2.1 Participants

The dataset of this study involved a total of 5,705 cyclists (39.7% females; age: 33.79 ± 13.55 years; weekly cycling hours: 5.40 ± 5.54 hours; typical trip length: 46.33 ± 39.50 minutes) from 18 countries on five continents which voluntarily participated in an electronic survey on cycling affairs.

2.2 Survey contents

For this research, participants responded to a set of questions about the use of technological devices while riding. Specifically, they were inquired about their engagement in both headphone and handheld electronic device use, with five possible answers (0= never ---- 4= always). Afterward, a set of third non-technological generic road distractions (i.e., billboards, own thoughts, other users' presence, other users' behaviors, weather, and obstacles) were assessed through a dichotomous (yes/no) 6-item scale [4]. Finally, participants self-reported the number of traffic crashes suffered as a cyclist (regardless of their severity) during the five years before the study.

2.3 Statistical analysis

After basic data curation, descriptive analyses were conducted. The city size-based groups were determined as similar in terms of gender, age, and other sociodemographic parameters. Given that the purposes of riding reported by participants were often not single (e.g., one cyclist could choose both "commuting" and "leisure"), no segregated analyses were made on the basis of this variable. Rather, partial correlation analyses were used, in order to control for cycling intensity when assessing the relationships between city sizes and self-reported distractions. Further, one-way analysis of variance (ANOVA) was used to test the hypothesized differences between the four groups raised according to the cyclist's city size. Effect sizes were assessed with eta partial squared (ηp^2), where $\eta p^2 < .06$ constitutes a small effect, $.06 \leq \eta p^2 \leq .14$ constitutes a medium effect, and $\eta p^2 > .14$ constitutes a large effect. The post hoc testing was applied using the Tukey (HDS) adjustment; this method is especially advisable for non-normal distributions. All the statistical analyses were performed with IBMS SPSS (version 28.0; IBM Corp., Armonk, NY, US).

3 RESULTS

The correlational analysis outcomes are presented in Table 1. Among the most relevant correlations found, there stands out that the higher the city size (i.e., the number of inhabitants), the greater the frequency with which cyclists engage in both headphones and handheld electronic device use. Further, and apart from the aforementioned, cyclists from more extensive urban areas tend to self-report a greater level of cycling distractions of both technological and non-technological nature.

Table 1: Partial correlations between study variables.

Variable		2	3	4	5
1	City size	.086**	.099**	.129**	.036*
2	Headphones (frequency)	1	.375**	.050**	.093**
3	Electronic devices (frequency)	.375**	1	.082**	.156**
4	Generic distracting sources - NT[b]	.050**	.082**	1	.025
5	Self-reported cycling crashes[a]	.093**	.156**	.025	1

Notes: Partial correlations controlled for cycling intensity. [a]The time span used for self-reported crashes was 5 years; [b]NT= Non-technological distracting sources; **The correlation is statistically significant at the level $p < .001$.

Secondly, there was found a set of significant effects of the city size on the three different issues addressed: first, the use of handheld electronic devices (F= 16.56, p < .001, ηp^2= 0.01), headphone-wearing (F= 21.92, p< .001, ηp^2= 0.01), and the overall self-reported exposure to other (i.e., non-technological) generic distracting sources (F= 86.73, p< .001, ηp^2= 0.04). Descriptive statistics and Post Hoc (Tukey HSD) analysis can be found in Table 2, and graphically in Figure 1.

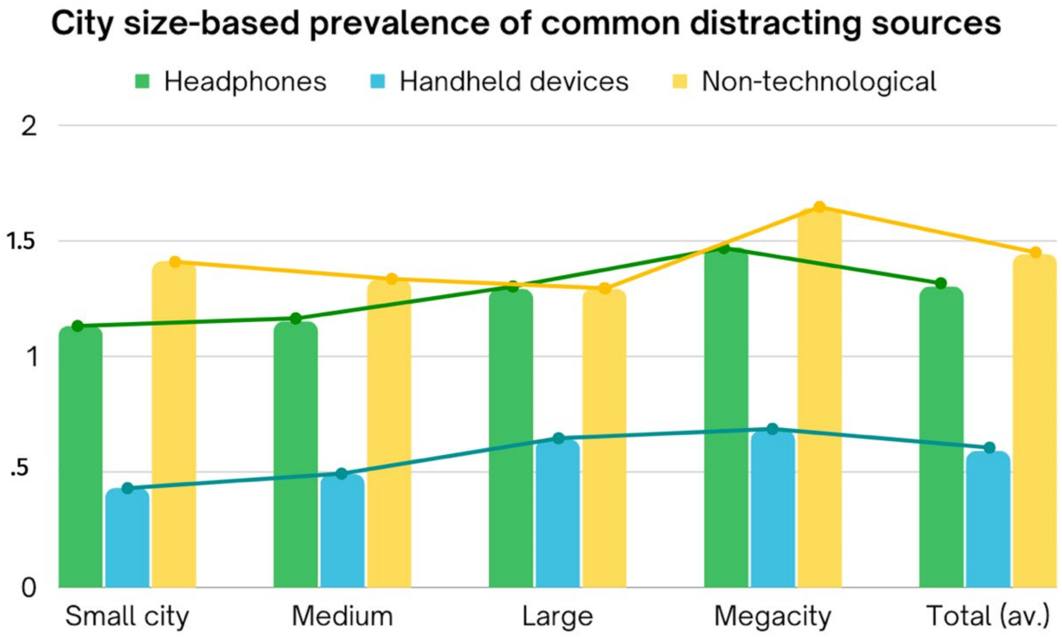


Figure 1: City size-based prevalence of common distracting sources

Table 2: Post-hoc (Tukey) analyses: Results divided per city size.

Variable	**Gr.**	**City Size**	**N**	**Mean**	**Standard Deviation**	**95% CI**	
						Lower	**Upper**
Use of headphones	1	Small	1,100	$1.13^{3,4}$	1.50	1.05	1.23
	2	Medium	1,016	1.15^{4}	1.49	1.06	1.25
	3	Large	1,622	$1.29^{1,4}$	1.54	1.22	1.37
	4	Megacity	1,967	1.47*	1.51	1.41	1.55
		Total	5,705	1.30	1.52	1.27	1.35
Use of handheld electronic devices	1	Small	1,100	$.43^{3,4}$	.79	.39	.48
	2	Medium	1,016	$.49^{3,4}$	.85	.44	.54
	3	Large	1,622	$.64^{1,2}$	1.00	.60	.69
	4	Megacity	1,967	$.68^{1,2}$	.95	.63	.72
		Total	5,705	.59	.93	.56	.61
Non-technological Distractions	1	Small	1,100	1.41*	.72	1.37	1.46
	2	Medium	1,016	$1.33^{,4}$	.69	1.30	1.38
	3	Large	1,622	$1.29^{1,4}$	.67	1.27	1.33
	4	Megacity	1,967	1.64*	.65	1.61	1.66
		Total	5,705	1.44	.69	1.43	1.46

Notes: *Statistically significant differences with all the rest of the groups; ^{1,2,3,4}: statistically significant differences with groups 1,2,3, or 4, respectively; Gr.: Groups being compared; CI: 95% Confidence Interval.

4 CONCLUSIONS

This study aimed at comparing the prevalence of common technological distraction-related factors in urban cycling in accordance with city sizes. The most noteworthy finding was that riders from bigger cities, especially from megacities, uniformly self-reported the greatest use of handheld electronic devices and headphones and the affectation by non-technological common distractions.

Additionally, the exploratory correlational analysis showed positive correlations between self-reported distractions and city sizes, suggesting that technological (but also non-technological) distraction sources, apart from being more present in big cities' social and mobility-related dynamics, could be getting "normalized" in the absence of greater addressing from transport policing.

Although there is a scarce number of previous studies addressing this issue among cyclists, the results of this research show consistency with them, as well as with studies carried out with motor vehicle drivers and pedestrians [5-7]. Further, the outcomes of this study highlight the need for further educational, normative, informative, and law-enforcing actions aimed at discouraging the use of technological distracting sources among cyclists.

REFERENCES

[1] K. L. Young, A. N. Stephens, S. O'Hern, S. Koppel, "Australian cyclists' engagement in secondary tasks", *Journal of Transport and Health* 16 (2020), pp. 100793.
[2] E. S. Wolfe, S. S. Arabian, J. L. Breeze, M. J. Salzler, "Distracted biking: An observational study", *Journal of Trauma Nursing: The Official Journal of the Society of Trauma Nurses* 23 (2016), pp. 65-70.

[3] D. de Waard, P. Schepers, W. Ormel, K. Brookhuis, “Mobile phone use while cycling: Incidence and effects on behaviour and safety”, *Ergonomics* 53 (2010), pp. 30-42.

[4] S. A. Useche, F. Alonso, L. Montoro, C. Esteban, “Distraction of cyclists: How does it influence their risky behaviors and traffic crashes?” *PeerJ* 6 (2018), pp. e5616.

[5] P. L. Jacobsen, D. R. Ragland, C. Komanoff, “Safety in numbers for walkers and bicyclists: Exploring the mechanisms”, *Injury Prevention* 21 (2015), pp. 217-220.

[6] S. García-Herrero, J. D. Febres, W., Boulagouas, J. M. Gutierrez, and M. A. Mariscal, “Assessment of the Influence of Technology-Based Distracted Driving on Drivers' Infractions and Their Subsequent Impact on Traffic Accidents Severity”, *International Journal of Environmental Research and Public Health* 18 (2021), pp. 7155.

[7] D. Stavrinos, C. N. Pope, J Shen, and D. C. Schwebel, “Distracted Walking, Bicycling, and Driving: Systematic Review and Meta-Analysis of Mobile Technology and Youth Crash Risk”, *Child Development* 89(2018), pp. 118-128.

"¡Vamos en Bici!": Exploring the Relationship between Spanish Cyclist Characteristics and Crashes

Sergio A. Useche[*a], Francisco Alonso[a], Mireia Faus[a], Oscar Oviedo-Trespalacios[b]

[*] Research Institute on Traffic and Road Safety (INTRAS)
University of Valencia
Carrer del Serpis 29, 46022, Valencia, Spain
email: sergio.useche@uv.es

[a] University of Valencia, Valencia, Spain
[b] Delft University of Technology, Delft, The Netherlands

Keywords: Cycling behavior, Spain, Performance, Risks, Cycling Crashes

1 INTRODUCTION

In recent years, cycling has gained significant popularity in many countries due to various factors and dynamics. These include a growing environmental awareness, as well as the search for healthier and more convenient transportation options. Indeed, promoting modal shifts towards active transportation is widely recognized as beneficial for the population in terms of health, social and welfare-related aspects [2]. Moreover, the COVID-19 pandemic and the mobility restrictions imposed in some areas have further encouraged cycling as a safe and sustainable alternative for daily trips [1].

The rapidly increasing cycling density has also led to higher involvement rates of cycling crashes in many regions [3]. In the Spanish context, recent studies have highlighted historical issues such as the lack of adequate infrastructure for cycling, inter-user conflicts, and a disregard for traffic rules by both cyclists and other two-wheeled riders, as posing significant threats to cycling safety [4]. Furthermore, especially in urban areas, the lack of experience, knowledge of traffic rules, and risk perception of "new cyclists" (typical in cities with lower degrees of cycling tradition) has been identified as a particularly concerning formula for short- and mid-term cycling safety [5,6].

The primary objective of this study was to examine the association between fundamental user characteristics and self-reported positive and risky cycling behaviors among cyclists in Spain

2 METHOD

In this study, we collected self-reported data from a sample of *n*=335 Spanish cyclists (M=33.71 years; 58% men, 41.8% women; 0.2% other) representing all 17 regions of the country. An online questionnaire was used to gather information on participants' demographic data (e.g., age, gender, experience), cycling patterns (e.g., trip frequency, duration, and most frequent motives), self-rated performance, and cycling behavior measured by the Cycling Behavior Questionnaire (CBQ) [7,8], which measures self-reported traffic violations, errors, and positive behaviors. Risk perception and self-reported cycling rule knowledge were assessed using the Risk Perception and Regulation Scale (RPRS), previously validated in several countries [8]. Additionally, the 12-item version of the Goldberg's General Health Questionnaire (GHQ) [9] was used to measure cyclists' psychological distress. Lastly, participants were asked to report the number of cycling crashes they had experienced in the previous five years.

After data curation, we conducted descriptive analyses, and scale scores were computed as per the authors' instructions. Spearman's rho correlation analysis was used to investigate potential associations between pairs of variables. Furthermore, a logistic regression model (Logit) was employed to estimate the impact of the study variables on the likelihood of experiencing cycling crashes in the past five years, with independent factors log-transformed. All statistical analyses were performed using IBM SPSS software, version 28.

3 RESULTS

In terms of descriptive statistics, the Spanish cyclists included in this study reported a weekly cycling intensity of M=3.6 hours and an average trip duration of M=34.9 minutes. Approximately one-third of the participants (35.2%) reported using their bicycle on a daily basis, while 35.8% used it for sport/fitness purposes. Less than half of the participants (43.6%) reported using their bicycle for specific trips, while approximately 60% reported having cycled in groups at least once. The bicycle was used as a job tool by only a small percentage of participants (5.4%).

Table 1: Bivariate correlations among study variables

Study variable^a		**Mean**	**SD**^{b}	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	**Age**	33.71	14.61	--								
2	**Weekly cycling intensity**	3.60	4.95	.298**	--							
3	**Self-rated performance**	7.34	2.14	.193**	.304**	--						
4	**Traffic rule knowledge**	3.23	.76	.337**	.270**	.315**	--					
5	**Risk Perception**	3.28	.77	.235**	.065	.188**	.562**	--				
6	**Psychological Distress**	1.57	0.54	-.445**	-.169**	-.069	-.327					
Cycling behaviors												
7	**Violations**	.49	.51	-.146**	.248**	.291**	-.057	-.102	-.125	--		
8	**Errors**	.38	.39	.032	.070	.135*	-.091	-.044	.084	.501**	--	
9	**Positive behaviors**	2.92	1.015	.228**	.067	.319**	.470**	.539**	-.223	-.170**	-.086	
Safety outcomes												
10	**Cycling crashes**	.52	1.23	-.52	.107	.135*	-.016	-.102	.110*	.274**	.240**	-.092

Notes for the table: ^{a}Self-reported indicators; ^{b}SD= Standard Deviation; *The correlation (*rho*) is significant at the level .050 (two-tailed); ** The correlation (*rho*) is significant at the level .001 (two-tailed).

The relationships between the continuous study variables were evaluated using bivariate analyses, which are fully presented in Table 1. The results show positive and significant associations between several bicycle user characteristics and their road risk-related behaviors. Notably, there was a negative correlation between cyclists' age and traffic violations, but a positive correlation between age and protective behaviors. Additionally, a greater weekly cycling intensity was associated with a higher frequency of traffic violations. Conversely, cyclists who had a greater perception of risk and cycling rule knowledge exhibited positive behaviors more frequently.

Regarding self-reported cycling crashes, the study found a positive association between a higher self-rated cycling performance (i.e., cyclists' perception of their own riding skills) and the frequency of riding errors and traffic violations. Furthermore, a logistic regression model was used to predict the likelihood of self-reported cycling crashes based on the study variables. The model had an overall accuracy of 76.3%, a -2 log likelihood of 331.456, and a Nagelkerke's R2 coefficient of .242, explaining 24.2% of the variance. The results showed that self-rated performance, psychological distress, traffic violations, and riding errors (with a greater magnitude) were significant positive predictors of cyclists' involvement in crashes. These variables increased the odds ratios. Conversely, risk perception decreased the odds ratios. See Table 2 for more details on the logistic regression analysis.

Table 2: Logistic regression model to predict self-reported cycling crash involvement (dichotomous) based on individual factors and riding behaviors.

Variable	B	SE[b]	Wald	Sig.[c]	Exp(B)	95% CI EXP(B)[d]	
						Lower	Upper
Constant	-4.255	1.225	12.071	***	.014		
Individual user features							
Age	.006	.012	.279	.598	1.006	.984	1.029
Gender[a]	.112	.309	.126	.723	1.116	.609	2.047
Cycling weekly hours	.047	.032	2.141	.143	1.048	.984	1.115
Typical trip length	.002	.004	.288	.592	1.002	.994	1.011
Self-rated performance	.203	.091	4.98	*	1.225	1.025	1.464
Traffic norm knowledge	.188	.249	.57	.450	1.207	.741	1.968
Risk Perception	-.127	.066	3.52	*	.881	.774	1.002
Psychological distress	.653	.301	4.73	**	1.921	1.067	3.459
Cycling behavior							
Traffic Violations	.595	.381	7.761	*	1.781	.934	3.453
Riding Errors	1.17	.390	8.986	*	3.221	1.499	6.921
Positive Behaviors	-.227	.188	1.454	.228	.797	.551	1.152

Notes: [a]Categorical variable. Reference= Male cyclists; [b]SE= Standard Error; [c]p-value; [d]Confidence Interval at the 95% level; *Significant at the level < .050; **Significant at the level < .010; ***Significant at the level < .001.

4 CONCLUSIONS

In conclusion, this study sheds light on the relationships between the characteristics of Spanish bicycle users, their cycling behaviors, and the crashes they get involved in. The results reveal that both violations and errors of Spanish cyclists significantly contribute to the crashes they suffer, highlighting the need for effective strategies to promote safer cycling practices. Additionally, there is a positive link between self-rated cycling performance and crash involvement, which raises concerns about cyclist overconfidence and greater risk assumptions, particularly in countries with a 'young' cycling tradition.

Moreover, the study highlights the role of mental health issues and risk perception in self-reported crash involvement, underscoring the need to consider these factors in potential interventions. These findings can be of significant value for public policy decision-makers and urban infrastructure designers to develop more effective strategies to prevent and reduce cycling crashes. By addressing the identified factors related to cycling crashes, such as promoting safe cycling practices, addressing mental health concerns, and improving risk perception, policymakers and designers can help create a safer and more sustainable cycling environment for everyone. Overall, this study provides valuable insights into the relationship between cycling behaviors and crashes, highlighting the importance of promoting safe cycling practices and developing evidence-based interventions.

REFERENCES

[1] R. Buehler, and J. Pucher. “COVID-19 impacts on cycling, 2019–2020”. *Transport Reviews* 41(2021), pp. 393-400.

[2] P. Oja, S. Titze, A. Bauman, B. de Geus, P. Krenn, B. Reger-Nash, and T. Kohlberger, “Health benefits of cycling: a systematic review”. *Scandinavian Journal of Medicine & Science in Sports*, 21(2011), pp. 496-509.

[3] P. Schepers, N. Agerholm, E. Amoros, R. Benington, T. Bjørnskau, S. Dhondt, A. Niska. “An international review of the frequency of single-bicycle crashes (SBCs) and their relation to bicycle modal share”. *Injury prevention*, 21(e1) (2015), pp. e138-e143.

[4] S.A. Useche, S. O’Hern, A. Gonzalez-Marin, J. Gene, F. Alonso, and A. Stephens, “Unsafety on two wheels, or social prejudice? Proxying behavioral reports on bicycle and e-scooter riding safety – a mixed-methods study”. *Transportation Research Part F: Traffic Psychology and Behaviour*, 89(2022), 168-182.

[5] R. Cordovil, C. Mercê, M. Branco, et al. “Learning to Cycle: A Cross-Cultural and Cross-Generational Comparison”, *Frontiers in Public Health*, 10(2022), pp. 861390.

[6] R. Aldred, T. Watson, R. Lovelace, and J. Woodcock, “Barriers to investing in cycling: Stakeholder views from England”, *Transportation Research Part A: Policy and Practice*, 128(2019), pp. 149-159.

[7] S. A. Useche, L. Montoro, J. M. Tomas, B. Cendales, “Validation of the Cycling Behavior Questionnaire: A tool for measuring cyclists' road behaviors”. *Transportation Research Part F: Traffic Psychology and Behaviour* 58 (2018), pp. 1021-1030.

[8] S. A. Useche et al., “Cross-culturally approaching the cycling behaviour questionnaire (CBQ): Evidence from 19 countries”. *Transportation Research Part F: Traffic Psychology and Behaviour* 91(2022), pp. 386-400.

[9] D. Goldberg, *General Health Questionnaire (GHQ-12)*, NFER-Nelson, Windsor. 1992.

Comparison of emergency response records with police collision reports for improving cyclist safety

Niamh O'Reilly*, Brian Caulfield†, Mark Mulville*

*School of Surveying and Construction Innovation
Technological University Dublin
Bolton Street, Dublin 1, D01 K822, Ireland
email: niamh.oreilly@tudublin.ie

† Department of Civil, Structural &
Environmental Engineering
Trinity College Dublin, Dublin 2, Ireland
email: brian.caulfield@tcd.ie

Keywords: cycling safety, underreporting, cyclist collisions, emergency response records, GIS.

1 INTRODUCTION

Underreporting of cyclist collisions in official police road safety reports poses a problem when compiling road safety statistics, particularly for single bicycle collisions (SBCs) where no third party is involved, and those collisions resulting in minor injuries. The extent of underreporting of cyclists injured in SBC's requiring hospital treatment (admitted or attending an emergency department) is estimated between 2% and 4% [1–3]. The consequences is that unreported cyclist collisions are excluded from road safety statistics used to identify road safety measures designed to reduce risk for cyclists and prioritise areas where improvements are required [4]. It is necessary to identify supplementary cyclist collision data sources to provide a more complete picture of the overall road safety problem for cyclists. Alternative data sources used to supplement these include hospital records [5, 6]. While hospital records provide details about the injuries sustained, they rely on retrospective surveys circulated to injured cyclists to establish details about the contributory factors associated with the collision circumstances. However these surveys are subject to patient memory recall issues [7] and may exclude patients with severe head or spinal injuries [8]. Only a few of these studies[5] examine the actual route and location where a collision occurred. Knowledge about the geographic location where collisions occur in the road network including their proximity to intersections, bike lanes, and other road infrastructure is essential for understanding the road safety problem for cyclists [3]. There is a need to identify alternative collision data sources that provide both details about the injuries sustained and the location where the collision occurred.

This study evaluates how effective emergency response records (ERRs) of injured cyclists attended by the Emergency Ambulance Services (EASs) in Dublin are for supplementing Police Collision Reports (PCRs). Unlike hospital records ERRs are georeferenced to assist the EAS respond quickly to the injured party. The study uses the georeferenced information to integrate ERRs with other road environment data using spatial tools in a Geographical Information System (GIS) to establish details about the road environment. The study compares the collisions and contributory factors from the ERRs with PCRs to determine how effective they are for addressing the underreporting issue in PCRs.

2 DATA AND METHOD

This study compares PCRs with ERRs of cyclist collisions that occurred in Dublin City between 2006 and 2016. Data was provided from the Road Safety Authority and Dublin Fire Brigade and used for this analysis. In total, 2299 cyclist collisions were reported to the police, and the EAS attended 1821 cyclist incidents in Dublin City between 2006 and 2016. Of the 2299 PCRs, 1876 (81.6%) involved a motorised vehicle and 257 (11.2%) were SBCs. In contrast, of the 1821 ERRs, 1577 (86.6%) were SBCs and 118 (6.5%) involved a motorised vehicle.

Both datasets included demographic and temporal information about each case. Georeferenced information was also provided for each case which enabled them to be examined and compared spatially in a GIS. Details about the road environment contributory factors were not included in the ERRs but were established by integrating them with road environment datasets using spatial tools in a GIS. The roads dataset was provided from the national mapping agency and included road classification and intersection types. which enabled these details to be assigned to each record. For intersections, collision within a 25m proximity to a road intersection were assigned a junction value, otherwise they were treated as midblock collisions. Other datasets used were the cycle network, bus lanes, traffic lights, tram lines and lane use.

Descriptive statistics were undertaken to describe the characteristics of both datasets and to determine how effective ERRs are for supplementing PCRs. Pearson's chi-squared tests (χ^2) were performed to identify if there is a statistically significant difference between ERRs and PCRs in relation to collision type, age, time of day and the road environment where they occurred. Unadjusted odds ratios were computed to compare the probability of emergency services attending specific collision types, demographic, and temporal factors to the probability of collisions being reported to the police.

3 RESULTS

Most collisions attended by emergency services are SBCs where there are no other third parties involved. SBCs are 53 times more likely to be attended by the EASs (unadjusted OR: 53.10, 95% CI: 43.99, 64.11, P = 0.000), whereas BMV's are more likely to be reported to the police (unadjusted OR: 0.16, 95% CI: 0.13, 0.20, P = 0.000). Cramer's V indicates a strong degree of association with the type of collision attended by EASs more likely to be SBCs (χ^2 = 2362, $p < 0.001$, φ_C 0.76) while BMV's (χ^2 =2293, $p < 0.001$, φ_C 0.75) have a strong association with being reported to the police.

Children under 12 and those over 65 are most likely to be attended by emergency services. Cramer's V indicates a low association between under 12s and over 65's (0.193 and 0.105 respectively) attended by EASs. However, EASs are 6 times more likely to attend children aged under 12 (unadjusted OR: 6.35, 95% CI: 4.57, 8.83, P = 0.000) and almost 4 times more likely to attend over 65 years old's (unadjusted OR: 3.73, 95% CI: 2.48, 5.50, P = 0.000).

EASs are most likely times to attend cyclist victims at night-time (unadjusted OR: 1.53 95% CI: 1.30, 1.80, P = 0.000). The month of the year is also a factor, with the EASs more likely to attend injured cyclists during the summer month of June, July and August. emergency services attend twice as many incidents in August (unadjusted OR: 1.50, 95% CI: 1.21, 1.85, P = 0.000), whereas more collisions are reported to the police in some winter months including January (unadjusted OR: 0.77, 95% CI: 0.59, 1.00, P = 0.000) and November (unadjusted OR: 0.78, 95% CI: 0.63, 0,98, P = 0.000).

EASs attend more collisions located on midblock road sections (unadjusted OR: 2.18, 95% CI: 1.92, 2.48, P = 0.000) that do not have any cycle infrastructure (unadjusted OR: 0.29, 95% CI: 0.25, 0.33, P = 0.000). EASs are less likely to attend collisions at intersections (unadjusted OR: 0.21, 95% CI: 0.19-0.24, P = 0.000). However, when junction types are analysed, the results indicate that emergency services are twice as likely to attend collisions at T junctions than those reported to the Police (unadjusted OR: 1.91, 95% CI: 1.58, 1.84, P = 0.000). In contrast, emergency services are less likely to attend collisions at crossroads or roundabouts (unadjusted OR: 0.48, 95% CI: 0.38, 0.61, P = 0.000) (unadjusted OR: 0.47, 95% CI: 0.25, 0.88, P = 0.000) respectively, which suggests cyclists are more likely to be involved in collisions with motorised vehicles at these types of junctions.

Emergency services were less likely to attend incidents on second-class roads (unadjusted OR: 0.23, 95% CI: 0.20, 0.27, P = 0.000), whereas they are over 5 times more likely to attend incidents on fourth class, residential roads (unadjusted OR: 5.10, 95% CI: 4.01, 6.47, P = 0.000).

4 DISCUSSION AND CONCLUSIONS

The study demonstrates the effectiveness of using emergency ambulance data for supplementing police collision reports. Unlike PCRs that capture mainly cyclist collisions involving motorised vehicles, most collisions attended by EAS are SBCs. This study has shown how integrating ERRs with other road environment datasets in a GIS, it is possible to gain insight into different types of collisions particularly SBCs that are not reported to the police. Knowledge about the location in the road network where collisions occur including their proximity to intersections, bike lanes, and other road infrastructure is essential for understanding the road safety problem for cyclists and can guide policy makers about where interventions in the road network must be implemented to reduce these risks in the future.

While ERRs do have some limitations related to their locational accuracy data, this study demonstrates their benefits for supplementing police collision reports. It must be acknowledged that emergency response data was never collected specifically to supplement official police collision reports, however the results presented in this research compare favorably with those using retrospective hospital-based analysis. Given that ERR data is collected in real-time on a continual basis, this study highlights the potential of using ERRs to supplement PCRs when compiling road safety statistics. Their inclusion can help inform policy makers on where to targeted interventions aimed at improving cyclist safety that are would otherwise be excluded from PCRs.

ACKNOWLEDGEMENTS

The authors thank the Irish Road Safety Authority (RSA), which is funding this PhD research under the RSA Helena Winters Scholarship for Studies in Road Safety.

REFERENCES

[1] S. Boufous, T. Senserrick, R. Ivers, D. Richardson, and L. De Rome, “Circumstances of on-road single-vehicle cyclist crashes in the Australian Capital Territory,” 2014. [Online]. Available: https://trid.trb.org/view.aspx?id=1343699

[2] C. Juhra *et al.*, “Bicycle accidents - Do we only see the tip of the iceberg?: A prospective multi-centre study in a large German city combining medical and police data,” *Injury*, vol. 43, no. 12, pp. 2026–2034, 2012, doi: 10.1016/j.injury.2011.10.016.

[3] R. Elvik, “A transport policy whose injury impacts may go unnoticed: More walking, cycling and use of public transport,” *Int. J. Environ. Res. Public Health*, vol. 16, no. 19, Oct. 2019, doi: 10.3390/ijerph16193668.

[4] F. Wegman, F. Zhang, and A. Dijkstra, “How to make more cycling good for road safety?,” *Accid. Anal. Prev.*, vol. 44, no. 1, pp. 19–29, 2012, doi: 10.1016/j.aap.2010.11.010.

[5] K. Teschke *et al.*, “Route infrastructure and the risk of injuries to bicyclists: A case-crossover study,” *Am. J. Public Health*, vol. 102, no. 12, pp. 2336–2343, Dec. 2012, doi: 10.2105/AJPH.2012.300762.

[6] J. Foley *et al.*, “Cycling related major trauma in Ireland,” *Injury*, vol. 51, no. 5, pp. 1158–1163, May 2020, doi: 10.1016/j.injury.2019.11.025.

[7] L. B. Meuleners, M. Fraser, M. Johnson, M. R. Stevenson, G. Rose, and J. Oxley, “Characteristics of the Road Infrastructure and Injurious Cyclist Crashes Resulting in a Hospitalisation,” *Accid. Anal. Prev.*, vol. 136, Mar. 2020, [Online]. Available: https://doi.org/10.1016/j.aap.2019.105407

[8] L. De Rome, S. Boufous, T. Georgeson, T. Senserrick, D. Richardson, and R. Ivers, “Bicycle Crashes in Different Riding Environments in the Australian Capital Territory,” *Traffic Inj. Prev.*, vol. 15, no. 1, pp. 81–88, Jan. 2014, doi: 10.1080/15389588.2013.781591.

Mental workload of cyclists in different urban road layouts : towards a study with a bicycle simulator

K. LI*, S. SAUDRAIS*, L. DESIRE†, B. BARBEDETTE*, C. MOREL*

* ESTACA'Lab
Parc universitaire Laval-Changé, 53000, Laval, France
email : kuotian.li@estaca.fr
email : sebastien.saudrais@estaca.fr
email : bertrand.barbedette@estaca.fr
email : cristina.morel@estaca.fr

†CEREMA
Research team PsyCAP, 5 rue Jules Vallès, F-22015, Saint-Brieuc, France
email : lara.desire@cerema.fr

Keywords: mental workload, bicycle, virtual reality, urban road design, road safety

1 INTRODUCTION

Mental workload of cyclists in real traffic is higher in complex traffic situation, such as intersections in mixed traffic, than in simple ones, such as secluded bicycle paths [1]. To avoid overload in those complex situations, cyclists may engage in inappropriate behaviors [2]. Road design may help to reduce mental workload of cyclists at intersections or in mixed traffic situations. Because investigation of different road layouts in real traffic is expensive and would be unsafe in real complex situations, bicycling simulator would be a more appropriate tool to investigate mental workload and behavior of cyclists [1]. Our research project aims to investigate mental workload of cyclists in complex road traffic situations such as intersections or in mixed lanes with different road layouts using a bicycle simulator composed of a virtual reality headset with embedded eye-tracking. Mental workload assessment will rely on different measures, i.e perceived mental workload measured with a standardized subjective scale, the secondary-task technique and physiological parameters based on eye-tracking measures. A preliminary study was conducted to test the possibility to use the eye-tracker embedded in the headset to measure blink rate and pupil diameter to evaluate cyclists' mental workload.

2 MATERIALS AND METHODS

8 participants (one female) were recruited. Data were excluded for one participant who was unable to ride in a straight line. The seven remaining participants (one female) were between 25 and 34 years old.

The experiment was conducted using the bicycle simulator under development at ESTACA'Lab. It was composed of a virtual reality headset with a built-in eye-tracker and a bicycle fixed on a home trainer through the rear wheel. To get the unprocessed eye-tracking data directly, some modifications to the original Unreal Engine based plugin were needed to create a dedicated interface for eye-tracking in the bike simulator.

The virtual reality environment was developed with Unreal Engine (version 4.26). The simulated route was a two-way urban road consisting of distinct straight sections of 300 m each, a bike lane was present only in one out of two sections. Each section contains a T-junction in which the participant had priority and traveled straight through without turning.

All the participants filled out an informed consent form. Then, they were installed on the bicycle simulator, and they were equipped with the headset. After the completion of the calibration, the procedure consisted of one familiarization session with the bicycle simulator and one experimental session. During this session, all participants traveled through two sections but depending on their starting position in the virtual environment, they encountered the section with the bike lane in first or second. Participants were randomly assigned to the two different groups with the restriction that each group contains four participants. Finally, participants filled out a form to gather demographic information and two standardized questionnaires to gather respectively, their perceived sense of presence [3] and their perceived sense of simulator sickness [4].

Pupil diameter and the occurrence of eye blink were recorded for each section to analyze the mental workload of cyclists depending on the presence of a bike lane, as they are recognized indicators of mental workload [5, 6]. Because the work is in progress, only descriptive statistical analysis for blink rate is available.

3 RESULTS

Blink rate (the number of blinks per minute) for each participant in the section without bike lane versus with bike lane are available in Table 1.

Percentage of change in blink rate based on situation without bike lane was calculated for each participant and are reported in the last column in Table 1. According to previous research, the higher the mental workload, the lower the blink rate. Thus, it can be concluded that if the values about percentage of change in blink rate in Table 1 are positive, it means that participants have a lower mental workload on roads containing bike lanes; if they are negative, it means that participants have a lower mental workload on roads that do not contain bike lanes. The results in Table 1 show that one participant (id: 5) may have experienced similar workload in the presence and in the absence of a bike lane, three participants (id: 3, 6, 7) may have experienced lower workload in the presence of a bike lane and three participants (id: 1, 2, 4) may have experienced lower workload in the absence of a bike lane.

Table 1 : Blink rate in section without a bike lane versus with a bike lane for each participant.

	SECTION WITHOUT BIKE LANE			**SECTION WITH BIKE LANE**			
ID	**Duration (s)**	**Number of blinks**	**Blink rate**	**Duration (s)**	**Number of blinks**	**Blink rate**	**% of change in blink rate**
1	120	21	10.5	120	14	7.0	-33
2	132	45	20.5	134	36	16.1	-21
3	142	11	4.6	124	29	14.0	202
4	148	86	34.9	120	46	23.0	-34
5	124	99	47.9	142	115	48.6	1
6	126	35	16.7	121	51	25.3	52
7	166	2	0.7	166	10	3.6	400

4 CONCLUSIONS AND FUTURE WORKS

The preliminary analysis of the blink rate suggests that it may change depending on the road environment. Nevertheless, those results merit further investigation with a larger number of participants and with a larger set of trials. Furthermore, we must consider other indicators of mental workload such as the perceived mental effort, the performance to a secondary task such as the detection-reaction task [7] and other psychological indicators as the pupil diameter before to make assumptions about the mental workload of cyclists in different traffic situations. Further work is planned to measure those different indicators of mental workload in an extended experiment to study the effect of different road layout in more complex traffic situations and with cyclists with different levels of expertise.

ACKNOWLEDGMENTS

Funding for this study was provided in part through the French Ministry of the Interior and Overseas-funded CharMent-Vélos project. The views and conclusions expressed are those of the autohors and may not necessarily reflect those of the consortium members.

Many thanks to T. Gohier for the creation of the virtual environment and his assistance during the experiment.

REFERENCES

[1] W. P. Vlakveld et al., « Speed choice and mental workload of elderly cyclists on e-bikes in simple and complex traffic situations: A field experiment », Accident Analysis & Prevention, vol. 74, p. 97-106, janv. 2015, doi: 10.1016/j.aap.2014.10.018.
[2] R. Elvik, A. Høye, T. Vaa, et M. Sørensen, « 1.6 Roundabouts », in The Handbook of Road Safety Measures, 2e éd.Bingley, UK: Emerald Group Publishing, 2009, p. 185-190.
[3] T. Schubert, F. Friedmann, et H. Regenbrecht, « The experience of presence: factor analytic insights », Presence: Teleoper. Virtual Environ., vol. 10, n° 3, p. 266-281, juin 2001, doi: 10.1162/105474601300343603.
[4] R. S. Kennedy, N. E. Lane, K. S. Berbaum, et M. G. Lilienthal, « Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness », International Journal of Aviation Psychology, vol. 3, n° 3, p. 203, juill. 1993.
[5] Beatty et B. Lucero-Wagoner, « The pupillary system », in Handbook of psychophysiology, 2nd ed, New York, NY, US: Cambridge University Press, 2000, p. 142-162.
[6] J. A. Stern, L. C. Walrath, et R. Goldstein, « The endogenous eyeblink », Psychophysiology, vol. 21, n° 1, p. 22-33, janv. 1984.
[7] « ISO 17488:2016 - Road vehicles - Transport information and control systems - Detection-response task (DRT) for assessing attentional effects of cognitive load in driving », AFNOR, Paris, France, ISO 17488:2016, 2016.

Digital Support Systems for Cyclists: Early Hazard Notifications and their Implementation Challenges

Tamara von Sawitzky*#, Thomas Grauschopf*, Andreas Riener*

* Technische Hochschule Ingolstadt
Esplanade 10, 85049 Ingolstadt, Germany
Tamaravon.Sawitzky@carissma.eu
Thomas.Grauschopf@thi.de
Andreas.Riener@thi.de

Johannes Kepler University Linz
Altenberger Straße 69, 4040 Linz, Austria

Keywords: Connected Traffic, Cyclist Safety, Digital Support Systems, Hazard Notifications.

1 MOTIVATION

Cyclists are exposed to a high risk of injury in road accidents [1]. Various approaches are being explored to create a safer environment for cyclists, such as dedicated lanes or the separation of motorized and non-motorized traffic [2]. As infrastructural solutions are not possible everywhere, alternative options should also be considered. For example, technology-based support could make drivers aware of cyclists, e.g., when turning right [3], when overtaking [4], or to prevent dooring [5, 6].

We believe it is equally valuable to provide cyclists with tools to identify hazards they may not notice or easily overlook. There are some approaches to assist cyclists in potentially dangerous situations through on-bike systems, e.g., [7, 8]. In our view, the main benefit of hazard notifications is to make cyclists aware of potential hazards. They could enable them to react deliberately when a hazard appears, instead of being surprised.

2 HAZARD NOTIFICATION SYSTEMS FOR CYCLISTS: POTENTIAL AND CHALLENGES

Based on the findings of three user studies (N=77) that we conducted in simulated situations (mixed reality and on a test track), we outline how hazard messages could be presented to cyclists and the challenges to implementing digital support for cyclists. Two studies were focused on potential dooring situations and one on hazards from overtaking vehicles [9, 10]. Participants experienced rides with and without awareness messages of potential hazards. This work is intended to provide a framework for further research on early hazard notifications directed at cyclists.

2.1 Hazard Detection

Information about the cyclist's surroundings and other road users is required to detect hazards. Due to the limited range covered by on-bike sensors [7, 8], we considered using connected traffic technologies [11] to cover a wider area. In addition, technological advances, such as 5G, connected traffic, and related technologies [11, 12], could enable real-time hazard detection. In combination with powerful smartphones, cyclists could be effectively supported. In our user studies, messages were generated based on a few pieces of information: Position of the cyclist and hazard, direction, speed, and, in dooring situations, vehicle occupancy. Implementation challenges include the distribution of necessary sensors for data collection and the prediction (accuracy) of potential hazards.

2.2 Provision and Communication of Hazard Notifications to Cyclists

Adequate timing of hazard notifications is important. The time frame provided should allow for (1) noticing an incoming message, (2) becoming aware of the current situation, (3) making a decision, and (4) taking action if necessary. In conditional automated driving, where the driver may be asked to regain control of the vehicle, 7 seconds to complete these steps were considered appropriate [13]. We provided notifications 9 seconds in advance of a potential hazard, which was perceived as adequate by most of our participants to assess the situation and prepare for it.

However, some hazards may not be identified at this early stage. It is an open question whether this time frame can be met for most potential hazards. Warnings should be used in situations where hazards can only be detected just before they occur. It must also be ensured that the messages are displayed in real time.

Hazard notifications should be easy-to-understand and non-distracting. Related work has contributed insights such as which modalities work best to use in a cycling context [14]. As part of our research, we were able to deduce that a combination of visual cues with a supporting cue should be used to alert cyclists to potential hazards at an early stage. A head-worn device with a see-through display, audio output, and/or integrated tactile motors could therefore be suitable for conveying feedback. In this way, unlike other approaches, the messages could be received at all times regardless of the direction of gaze or hand contact with the handlebars [15]. Furthermore, we concluded that hazard notifications should inform the user of the elapsed time (indicates the approach to the hazard), the hazard type, and its relative position to the cyclist. Our participants responded positively to the information provided. They also preferred either auditory (about 60%) or tactile (about 30%) feedback as a supporting cue. These additional modalities should be used to make cyclists aware of an incoming notification and update them about closing in on a hazard (redundancy).

A major challenge is the simultaneous presence of multiple hazards. Prioritization must be performed here. In addition, it is essential to provide precise time and direction information, which depends heavily on localization accuracy; an accuracy of 1-2 meters is already achievable with smartphones.

2.3 Using Hazard Notifications

Most of our participants (about 90%) found hazard notifications helpful. We saw a significant increase in perceived safety while cycling compared to unassisted rides. In addition, they also reported that hazard alerts while cycling were highly usable and intuitive.

On the user side, we could derive a major challenge that needs to be addressed in future work: users could over-rely on hazard messages, which could lead to inattention to other hazards. Road users should always be vigilant, but the use of assistance systems can easily lead to a false sense of security. As a countermeasure, we suggest an initial phase where users can learn about the notification system and how to use it properly, i.e., as a support, not a substitute for their own attention.

Although our participants' acceptance of the use of hazard alerts about potential hazards was relatively high, it is unclear how they would deal with "false positives". After all, receiving a hazard notification does not necessarily imply that the hazard will occur. In addition, it is important to examine how users would respond to repeated notifications when no hazard has occurred. With higher traffic density, the number of notifications is likely to increase.

Our participants responded well to using a head-mounted device. However, they should be lightweight, so they don't cause headaches or weigh down the head (our mock-up, a Microsoft HoloLens2, was quite heavy). As a result, the technical components required for the processing of hazard notifications cannot be installed there. Therefore, a companion device, such as a smartphone, must handle the data processing. Current devices with transparent displays also have the problem that the contrast and brightness of the visual content projected onto the viewing surface are too low, making it difficult to recognize the content.

3 CONCLUSION

Hazard notifications for bicyclists could be a potential measure to improve cyclist safety. However, connected traffic technologies would be required to provide feedback on a wide range of potential hazards. Implementing such technology is challenging in itself and therefore a limitation of our approach. We have highlighted several issues that need to be considered when providing hazard information to cyclists. Future work will need to address how such support can be implemented in a real-world system and how the challenges can be overcome.

4 REFERENCES

[1] Destatis - Statistisches Bundesamt, "Verkehrsunfälle - Kraftrad- und Fahrradunfälle im Straßenverkehr (2018)," 2019.

[2] J. H. van Petegem, P. Schepers, and G. J. Wijlhuizen, "The safety of physically separated cycle tracks compared to marked cycle lanes and mixed traffic conditions in Amsterdam," *European Journal of Transport and Infrastructure Research*, vol. 21, no. 3, pp. 19–37, 2021, doi: 10.18757/ejtir.2021.21.3.5283.

[3] J. Warner, D. S. Hurwitz, C. M. Monsere, and K. Fleskes, "A simulator-based analysis of engineering treatments for right-hook bicycle crashes at signalized intersections," *Accident; analysis and prevention*, vol. 104, pp. 46–57, 2017, doi: 10.1016/j.aap.2017.04.021.

[4] T. Brijs, F. Mauriello, A. Montella, F. Galante, K. Brijs, and V. Ross, "Studying the effects of an advanced driver-assistance system to improve safety of cyclists overtaking," *Accident; analysis and prevention*, vol. 174, p. 106763, 2022, doi: 10.1016/j.aap.2022.106763.

[5] C. Scharfenberger, S. Chakraborty, and G. Färber, "Robust Image Processing for an Omnidirectional Camera-based Smart Car Door," *ACM Trans. Embed. Comput. Syst.*, vol. 11, no. 4, pp. 1–28, 2012, doi: 10.1145/2362336.2362354.

[6] M. Zhu, L. Han, F. Liang, C. Xi, L. Wu, and Z. Zhang, "A Novel Vehicle Open Door Safety System Based on Cyclist Detection Using Fisheye Camera and Improved Deep Convolutional Generative Adversarial Nets," in *IV*, Paris, France, 2019, pp. 2195–2201. Accessed: Feb. 5 2021.

[7] W. Jin *et al.,* "CycleGuard: A Smartphone-based Assistive Tool for Cyclist Safety Using Acoustic Ranging," *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, vol. 5, no. 4, pp. 1–30, 2021, doi: 10.1145/3494992.

[8] Garmin Ltd., *Varia™ RTL516.* [Online]. Available: https://buy.garmin.com/de-DE/DE/p/698001#overview (accessed: Jan. 20 2024).

[9] T. von Sawitzky, T. Grauschopf, and A. Riener, "Hazard Notifications for Cyclists: Comparison of Awareness Message Modalities in a Mixed Reality Study," in *27th International Conference on Intelligent User Interfaces (IUI '22)*, Helsinki, Finland, 2022, pp. 310–322.

[10] T. von Sawitzky, T. Grauschopf, and A. Riener, "“Attention! A Door Could Open.”—Introducing Awareness Messages for Cyclists to Safely Evade Potential Hazards," *MTI*, vol. 6, no. 1, p. 24, 2022, doi: 10.3390/mti6010003.

[11] M. Jenkins, D. Duggan, and A. Negri, "Towards a connected bicycle to communicate with vehicles and infrastructure," in *2017 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA 2017): Savannah, Georgia, USA, 27-31 March 2017*, Savannah, GA, USA, 2017, pp. 1–3.

[12] M. Baqer and A. Krings, "On the Reliability of VANET Safety Applications for Bicycles," in *2019 IEEE ICCVE: The 8th IEEE International Conference on Connected Vehicles and Expo (ICCVE) : 2019 conference proceedings : November 4-8, 2019*, Graz, Austria, 2019, pp. 1–6.

[13] C. Gold, M. Körber, C. Hohenberger, D. Lechner, and K. Bengler, "Trust in Automation – Before and After the Experience of Take-over Scenarios in a Highly Automated Vehicle," *Procedia Manufacturing*, vol. 3, pp. 3025–3032, 2015, doi: 10.1016/j.promfg.2015.07.847.

[14] E.-H. Erdei, J. Steinmann, and C. Hagemeister, "Which signal modalities do cyclists prefer based on experiences in road traffic?," *Traffic injury prevention*, vol. 22, no. 8, pp. 640–645, 2021, doi: 10.1080/15389588.2021.1985113.

[15] I. Kreißig, S. Springer, and J. F. Krems, "Cycling Safety at the Fore - Evaluation of a Cyclist Warning System from a User Perspective," in *HCI International 2022 Posters*, 2022, pp. 223–230.

Sickness absence and disability pension among bicyclist after an accident, a nationwide register-based study comparing bicyclist with other road user groups with matched references

L. Kjeldgård*, H. Stigson#, K. Farrants†, E. Friberg‡

*Department of Clinical Neuroscience
Karolinska Institutet
171 77, Stockholm, Sweden
email: linnea.kjeldgard@ki.se

#Department of Clinical Neuroscience
Karolinska Institutet
171 77, Stockholm, Sweden
email: Helena.stigson@ki.se

†Department of Clinical Neuroscience
Karolinska Institutet
171 77, Stockholm, Sweden
email: Kristin.farrants@ki.se

‡Department of Clinical Neuroscience
Karolinska Institutet
171 77, Stockholm, Sweden
email: emilie.friberg@ki.se

Keywords: sick leave, road user groups, traffic injury.

1 INTRODUCTION

Globally, road traffic injuries contribute to 1.3 million deaths per year [1]. In addition, between 20 and 50 million individuals suffer non-fatal injuries which could lead to disability [1]. Bicyclists are the road user group with the highest number of severe injuries in Sweden and in all EU[2, 3]. Being injured in a road traffic accident may affect the individual's work ability and lead to sickness absence (SA) and disability pension (DP). Previous research on pedestrians and bicyclists has shown that about a fifth of individuals injured in a road traffic accident have a new SA spell in connection with an accident [4, 5], and about a tenth among injured car occupants[6]. Moreover, in the long-term, studies have found heterogeneity in duration, reoccurrence, and diagnosis of SA and DP during the years following the accident [7-9]. However, SA and DP after a road traffic accident have not been studied in relation to the general population.

The aim was to estimate excess diagnosis-specific SA and DP among bicyclists and other road user groups injured in a road traffic accident compared to matched references without such injury.

2 METHODS

A nationwide register-based study, including all working individuals aged 20-59 years and living in Sweden who in 2015 had in- or specialized outpatient healthcare after a new traffic-related injury (n=20,177) and population-based matched references (matched on: sex, age, level of education, country of birth, living in cities) without traffic-related injuries during 2014-2015 (n=100,885). Annual diagnosis specific (injury and other diagnoses) net days of SA and DP were assessed during 5 years, one year before (Y_{-1}) and four years after (Y_{+4}) the date of the injury (T_0) and was compared to non-injured matched references. Mean SA and DP net days/year for each road user group and mean differences of (excess) SA and DP net days/year compared with their matched references were calculated with independent t-tests with bootstrapped 95% confidence intervals (CIs).

3 RESULTS

There were 20,177 working individuals with in- or specialized outpatient healthcare due to a new traffic accident including fall accidents in 2015 aged 20-59 years and 100,885 matched references. A third of the injured road users were bicyclists, 31% car occupants, 16% pedestrians (including fall accidents), and 19% were other road users (of which most were motorcycle/moped, 82% of other road users). Pedestrians and other road users were the groups with the highest mean number of SA days during the first year following the accident (51 and 49 days/year respectively). In the second year, car occupants had the highest mean number of SA days (26 days/year). The matched references had between 8 and 13 SA days/year throughout the study period (Figure 1).

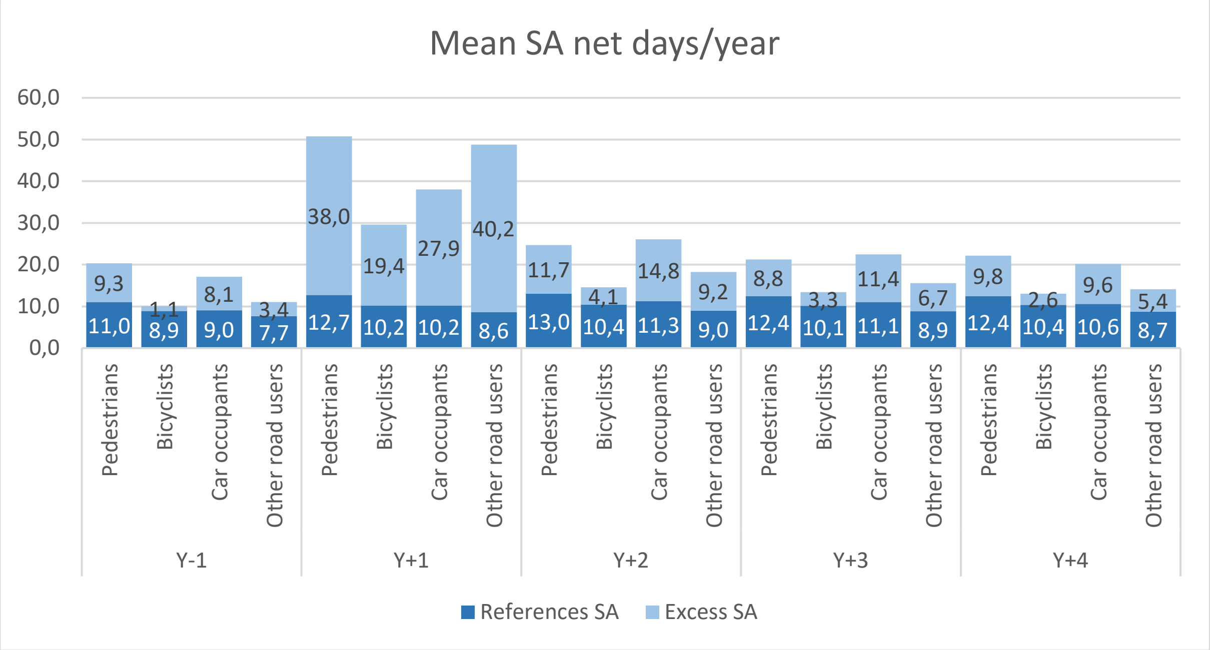


Figure 1: Average net days/year of sickness absence (SA) for the references and excess SA for the injured in the different road user groups.

The excess SA days/year were elevated for all road user groups all five studied years. Excess SA due to injury diagnoses was 15-35 days/year during the first year following the accident (Figure 2). Excess SA due to diagnoses other than injuries were about eight days/year during the whole study period for pedestrians and car occupants and about zero for the bicyclists.

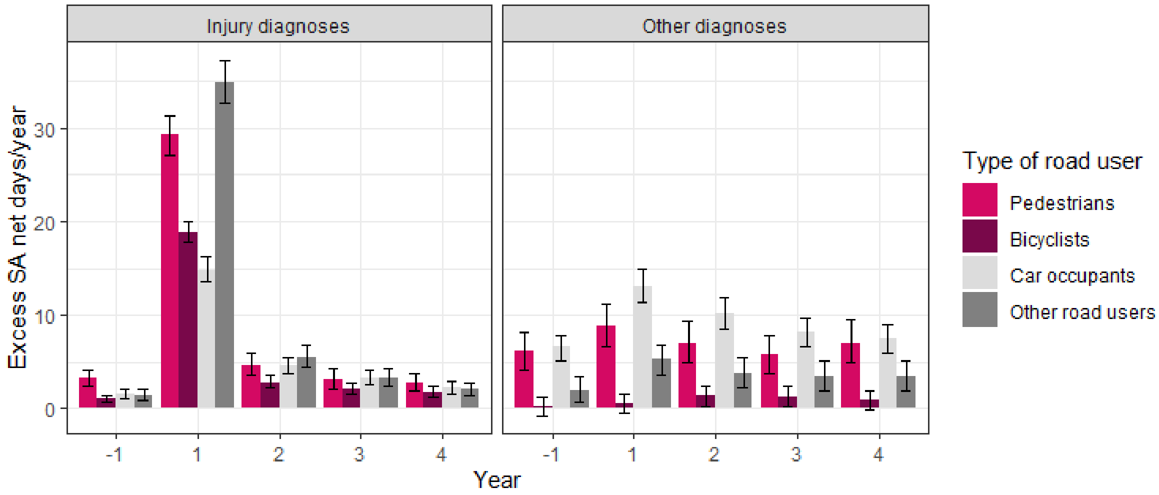


Figure 2: Excess sickness absence (SA) net days/year due to injury diagnoses and other diagnoses before and after the accident compared to their matched references and 95% bootstrapped confidence intervals.

The excess DP was low, although it increased every year after the accident for pedestrians and car occupants; for bicyclists no excess DP was seen (Figure 3).

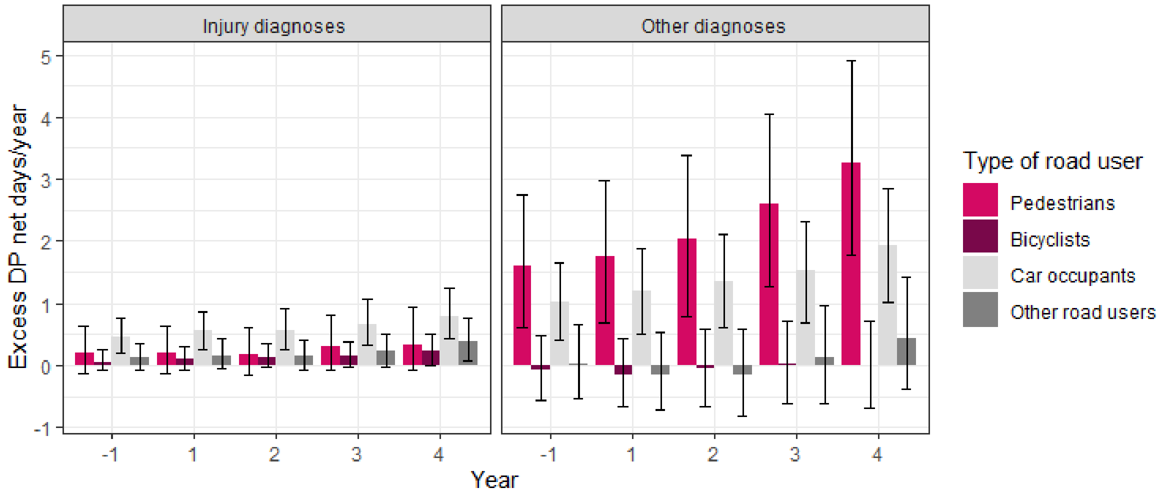


Figure 3: Excess disability pension (DP) net days/year due to injury diagnoses and other diagnoses before and after the accident compared to their matched references and 95% bootstrapped confidence intervals.

4 CONCLUSIONS

Higher levels of SA due to injury diagnoses were seen among all road user groups during the first year after the accident compared to their references. Pedestrians and car occupants had more excess SA due to other diagnoses and more excess DP throughout the study period, while bicyclists had no such excess SA or DP compared to their references.

REFERENCES

1. Global Status Report on Road Safety 2018 [https://apps.who.int/iris/handle/10665/277370]
2. Traffic Safety Basic Facts 2018 - Cyclists [https://road-safety.transport.ec.europa.eu/system/files/2021-07/bfs20xx_cyclists.pdf]
3. Analysis of Road Safety Trends 2018 - Management by objectives for road safety work towards the 2020 interim targets [http://trafikverket.diva-portal.org/smash/get/diva2:1389250/FULLTEXT01.pdf]
4. Kjeldgård L, Stigson H, Klingegard M, Alexanderson K, Friberg E: Sickness absence and disability pension among injured working-aged pedestrians - a population-based Swedish register study. *BMC Public Health* 2021, 21(1):2279.
5. Kjeldgård L, Ohlin M, Elrud R, Stigson H, Alexanderson K, Friberg E: Bicycle crashes and sickness absence - a population-based Swedish register study of all individuals of working ages. *BMC Public Health* 2019, 19(1):943.
6. Elrud R, Stigson H, Ohlin M, Alexanderson K, Kjeldgård L, Friberg E: Sickness Absence among Passenger Car Occupants following a Crash. In: *IRCOBI Conference Proceedings.* 2017: IRC-17-18, s 79-90, ISSN 2235-3151.
7. Kjeldgård L, Stigson H, Alexanderson K, Friberg E: Sequence analysis of sickness absence and disability pension in the year before and the three years following a bicycle crash; a nationwide longitudinal cohort study of 6353 injured individuals. *BMC Public Health* 2020, 20(1):1710.
8. Elrud R, Friberg E, Alexanderson K, Stigson H: Sickness absence, disability pension and permanent medical impairment among 64 000 injured car occupants of working ages: A two-year prospective cohort study. *Accid Anal Prev* 2019, 127:35-41.
9. Kjeldgård L, Stigson H, Bergsten EL, Farrants K, Friberg E: Diagnosis-specific sickness absence among injured working-aged pedestrians: a sequence analysis. *BMC Public Health* 2023, 23(1):367.

Bicycle crashes with curbs

V. Zuser[*]

[*] Austrian Road Safety Board (KFV)
Schleiergasse 18, 1100 Vienna, Austria
e-mail: veronika.zuser@kfv.at

Keywords: single-bicycle crashes, infrastructure, curb.

1 INTRODUCTION

Overall, cycle crashes are characterized by a high proportion of single-bicycle crashes, with various factors relating to the road surface and – in addition to rails – curbs being an important factor in such crashes. Various studies have already investigated the significance of the problem. Primarily, these studies have so far been conducted in Sweden, Denmark, the Netherlands, and Germany. After several serious crashes involving curbs in the city of Salzburg, the relevance of the topic is now being investigated in Austria for the first time.

2 ACCIDENT ANALYSIS

The IDB Austria (Injury Database Austria) was used as the data source for an accident analysis. The IDB is based on interviews with injured persons in selected hospitals throughout Austria, in which detailed facts about the person involved, products involved, causes of the accident and accident severity are collected. Together with the accident description, this results in a unique data basis for accident prevention. Trained interviewers guarantee high quality data.

A total of 259 interviews from 2017 to 2021 could be analyzed in which, according to the accident description, a curb was accident-causal or played a role in the course of the accident. For all accidents, an analysis of the textual description of how the accident occurred was conducted. Accidents with curbs that did not occur while driving (e.g., tripping over a curb while pushing the bicycle) were not included in the further analysis (n=10). Thus, a total of 249 accidents could be analyzed in more detail. The proportion of accidents involving curbs in all accidents included in the IDB was higher for e-bikes (12.4%) than for muscle-powered bicycles (8.7%).

Table 1: Sample size of interviews about crashes with curbs in the IDB database (2017-2021).

Type of bicycle	Number of crashes with curbs	Number of curb crashes as share of total number of crashes [%]
muscle-powered bicycle	199	8.7%
e-bike/pedelec	50	12.4%
total	249	

From the analysis of the textual description of the accident it was possible to distinguish between the following types of curb contact: (1) Deliberate driving up or down the curb, e.g. to change from the sidewalk or bike track to the road or vice versa. (2) Unintentional contact with the curb. (3) The curb was only relevant to the accident in the course of the fall, but the contact with the curb did not cause the accident. (4) Descriptions from which it was clear that a curb was involved, but it was not clear in what form. The majority of curb crashes were accidents with unintentional contact (67% bicycle, 80% e-bike); deliberate driving up or down the curb was the trigger for one in four bicycle accidents (25%) and one in five e-bike accidents (18%).

The majority of curb crashes were single-bicycle crashes (bicycle 89%, e-bike 88%). In 1 out of 10 crashes (bicycle: 10%, e-bike: 12%) other road users were involved, the interaction with them was accident-causal, but without a collision with any other vehicle/person, e.g. swerving, which ended in a fall. Only one single crash involving a curb was a collision with another road user and 1 person was a passenger on a bicycle. The majority of curb crashes occurred on roadways in mixed traffic, the share of roadways was higher for e-bikes than for bicycles (82% vs. 64%), bicycle tracks had a share of 14% (bicycle) and 12% (e-bike).

The most frequent cause of curb crashes is misjudgment; for bicycles it is responsible for more than one third (37%), for e-bikes even for more than half (56%) of the analyzed crashes. In second place comes inattention or lack of concentration and distraction due to external circumstances (32% bicycle, 22% e-bike), followed by the condition of the ground, and here above all slipping on rolling gravel, which is in the same order of magnitude for bicycles and e-bikes (19% and 18% respectively). Thus, three quarters of the causes of curb crashes of bicycles and four fifths of curb crashes of e-bikes are related to the behavior of the cyclist (misjudgment, inattention, distraction, stress, impairment, etc.).

What stands out about curb crash victims is the high proportion of older crash victims: Nearly half of the curbside crashes in the database involved e-bike riders aged 65 and older (48%). For all e-bike accidents recorded in the IDB during this period, the proportion of older people was about 10% lower (39%). Thus, curb crashes affect older e-bike riders disproportionately often. This can also be observed for normal bicycles, but at a lower level (18% vs. 13%).

3 COMPARISON WITH RESULTS OF INTERNATIONAL STUDIES

Schepers & Klein Wolt [1] investigated a total of 669 single-bicycle crashes in the Netherlands. 14% of these crashes were due to curb collisions. In most cases the cyclists hit the curb with the front wheel, in a few cases the cyclists kept too little distance to the curb and hit the curb with one of the pedals. Specifically for accidents involving elderly cyclists (50 years and older) in the Netherlands, Davidse et al [2] concluded that 15% to 27% of the total 136 investigated crashes involving elderly cyclists were due to colliding with the curb or unintentionally touching the curb.

Møller et al. [3]analyzed a total of 5,313 accidents involving cyclists that occurred in Denmark from 2010 to 2015 based on hospital records and police accident data. An accident factor could be identified in 2,931 accidents. Curbs were causal in 231 accidents, or 8% of the accidents. Olesen et al [4] conducted an in-depth analysis of a total of 349 self-reported single-bicycle crashes in Denmark. In 12.9% of the accidents, a curb was an accident contributing factor.

For Sweden, Algurén & Rizzi [5] studied a total of 616 single-bicycle crashes from 2013 to 2017 of which 8% involved curbs. The proportion of crashes involving curbs was slightly higher for cyclists aged 65 years and older (10%) than for persons aged 50 years and younger (6%). Niska & Eriksson [6] analyzed accident data from 2,848 single-bicycle crashes between 2007 and 2012 in Sweden. A total of 11% of these crashes were due to curbs or sharp edges. The study by Nseya [7] investigated the causes of single-bicycle accidents from 2010 to 2016 in Stockholm. 2,845 crashes were analyzed using data from the Swedish Accident Database. In about 4% of these crashes, curbs or a collision with a curb were the cause of the accident. Ohlin et al. [8] studied 947 Swedish crashes, in which curbs or a collision with a curb was the main cause in 7%.

For Ireland, Gildea et al. [9], studying a total of 295 single-bicycle crashes, found that curbs or curb collisions were a contributing factor in 21% of the crashes. In many cases, crashes involving curbs had no other causes and mostly occurred when cyclists were trying to move from the roadway to the cycle track. In some cases, crashes involving curbs were also due to avoidance maneuvers. Crashes involving curbs most frequently resulted in the cyclists toppling over.

A study by Utrainen [10] analyzed the circumstances of 3,448 single-bicycle crashes of commuters in Finland. 62.9% of the crashes were related to infrastructure. Among them, in 144 of the total 3,448 crashes (4.2%), the cyclists collided with a curb with their front wheel and fell.

The study by Fountas et al [11] examined crash data from 350 single-bicycle crashes and 6,483 cyclist-vehicle collisions that occurred in Scotland between 2018 and 2020. Among other aspects, they analyzed whether cyclists struck an object on the roadway at the time of the crash. In 5.54% of single-bicycle crashes, cyclists struck curbs. In collisions with motor vehicles, this was the case in only 0.29%.

In summary, the proportion of crashes related to curbs among all bicycle crashes is about 5% to 8%, or even lower in isolated studies; looking at single-bicycle crashes alone tends to show higher proportions of 4% to 14%. For pedelecs and e-bikes, the literature review shows a significantly higher proportion of crashes involving curbs, ranging from 18% to 23% for single-bicycle crashes.

4 CONCLUSIONS AND OUTLOOK

The relevance of curbs in bicycle crashes is clearly shown by the analysis of international studies and of the Austrian data in the accident database IDB. In a second part of the study, which is not yet completed, the analysis will be complemented by a survey among cyclists. Finally, recommendations for measures to prevent accidents with curbs will be developed.

REFERENCES

[1] Schepers, P. and Klein Wolt, “Single-bicycle crash types and characteristics”, *Cycling Research International 2*, S. 119-135, 2012.
[2] Davidse, R., van Duijvenvoorde, K., Louwerse, R., Boele-Vos, M., Stelling-Kończak, A. and Algera, A.J., *Scootmobielongevalle. Hoe ontstaan ze en hoe zijn ze te voorkomen?* R-2018-15, SWOV, Den Haag, 2018.
[3] Møller, M., Janstrup, K. H. and Pilegaard, N., “Improving knowledge of cyclist crashes based on hospital data including crash descriptions from open text fields”, *Journal of safety research*, 76, S. 36-43, 2021.
[4] Olesen, A.V., Osmann Madsen, T.K., Hels, T., Hosseinpour, M. and Lahrmann, H.S., “Single-bicycle crashes: An in-depth analysis of self-reported crashes and estimation of attributable hospital cost.” *Accident Analysis & Prevention 161*, 106353, 2021.
[5] Algurén, B. and Rizzi, M., “In-depth understanding of single bicycle crashes in Sweden - Crash characteristics, injury types and health outcomes differentiated by gender and age-groups”, *Journal of Transport & Health 24*, 101320, 2022
[6] Niska,A. and Eriksson, J., “Statistik över cyklisters olyckor. Faktaunderlag till gemensam strategi för säker cycling”, Vti, 2013.
[7] Nseya, C., *Bicycle accidents: An analysis of the causes of single bicycle accidents in Stockholm*. Master thesis University Uppsala. Uppsala, Sweden, 2018.
[8] Ohlin, M., Algurén, B. and Lie, A., “Analysis of bicycle crashes in Sweden involving injuries with high risk of health loss”, *Traffic Injury Prevention 20* (6), p. 613-618, 2019.
[9] Gildea, K., Hall, D. and Simms, C., “Configurations of underreported cyclist-motorised vehicle and single cyclist collisions: Analysis of a self-reported survey.” *Accident Analysis & Prevention 159*, 106264, 2021.
[10]Utrainen, R., “Characteristics of Commuters’ Single-Bicycle Crashes in Insurance Data”, *Safety,* 2020, 6, 13. S. 1-12, 2020.
[11]Fountas, G., Fonzone, A., Olowosegun, A. and McTigue, C., “Addressing unobserved heterogeneity in the analysis of bicycle crash injuries in Scotland: A correlated random parameters ordered probit approach with heterogeneity in means.”, *Analytic methods in accident research*, 32, 100181, 2021.

Proactive Safety Assessment for Single Bicycle Crashes: A Dynamics-Informed Cyclist Tracking Approach

K. Gildea[*], **A. Laureshyn**

Department of Technology & Society
Faculty of Engineering
Lund University
Sweden
email: kevin.gildea@tft.lth.se

Keywords: Single bicycle crashes, Surrogate measures of safety, Computer vision, Artificial intelligence.

1 INTRODUCTION

Single bicycle crashes (SBCs), i.e., falls from bicycles, are a significantly underestimated road safety problem. In Sweden, SBCs comprise roughly 80% of serious injuries to cyclists [1,2]. Cyclist-motorised vehicle collisions comprise the largest share among fatalities, however, among serious injury cases, SBCs dominate. Throughout Europe, significant road safety improvements have been achieved through targeted decreases in fatality/injury rates by focusing on collision/injury prevention strategies for cyclist-motorised vehicle collisions. However, SBCs have received relatively little attention. Therefore, towards Vision Zero [3], there is a significant potential for serious injury rate reductions through targeted measures addressing SBCs.

The Safe System approach [4] takes a proactive stance on targeting and treating road safety risks, i.e., to target and treat collision risk before any occur. However, while proactivity is ideally preferred, road safety analysts are often constrained to performing reactive analyses of historical collision data, and justifying infrastructural interventions based on collision hot-spots. While this can be effective in some cases, its application for SBCs is limited by several factors. One primary challenge is that SBCs often go unreported [5,17,18]. Studying traffic conflicts and near-misses for Surrogate Measures of Safety (SMoS) can provide valuable safety insights by allowing for proactive identification of potential safety issues, i.e., the paradigm illustrated by Hydens safety pyramid [6]. As discussed by Johnsson, Laureshyn, et al. (2018) [8], due to underreporting, traffic conflict analysis may be particularly important for addressing collisions involving VRUs. However, few SMoS studies focus on VRUs, i.e., pedestrians and cyclists, and fewer again consider SMoS for SBCs. A recent International Transport Forum round table highlighted the potential utility of using computer vision (CV), and artificial intelligence (AI) to acquire relevant information for crash risks in a proactive safety assessment framework [7]. It is expected that these technologies will play an increasingly important role in the future of transportation safety. However, industry experience in recent years has highlighted that AI solutions should be thoughtfully tailored to specific applications. Therefore, this project is adopting an application-led approach, using domain knowledge to improve effectiveness.

2 METHODS

The project is structured into five stages:

2.1 Literature Review & Knowledge Gathering

A comprehensive review of existing literature on SBCs, proactive safety assessment approaches, SMoS technologies, and knowledge gathering from experts will be conducted.

2.2 Figures and Tables

This project aims to go beyond the state-of-the-art for cyclist detection and tracking by integrating novel concepts and approaches that address existing limitations. For practical purposes, monocular methods are more practically useful for safety assessments, however work is required to overcome the flatness problem associated with relating detections in 2D space to 3D space. One common approach to addressing this is to use multiple cameras or sensors that capture different views of the same road user, however, this complicates the data collection process. Another approach which may allow for monocular collection is to incorporate additional information about the object/road user, such as its size, shape, or motion characteristics to help constrain its possible 3D configuration, e.g., Generalized Urban Traffic Surveillance (GUTS) [18], the further inclusion of semantic segmentation, e.g., Segment Anything (SAM), along with cyclist-specific motion characteristics [12] may help with this for more robust tracking. Furthermore, since cyclists are uncovered by vehicle structures, incorporating human pose estimation into these models may allow for better understanding of behaviours and fall risk. For example, our recent work has applied human pose estimation to infer injury outcomes from video footage of cyclist falls [9, 10, 11]. Towards a proactive safety assessment framework for SBCs, work is needed to establish both dynamics-informed SMoS and tracking techniques for these cases. Therefore, a dynamics-informed cyclist tracking algorithm will be developed, combining CV and AI techniques with bicycle/rider dynamics knowledge (Figure 1).

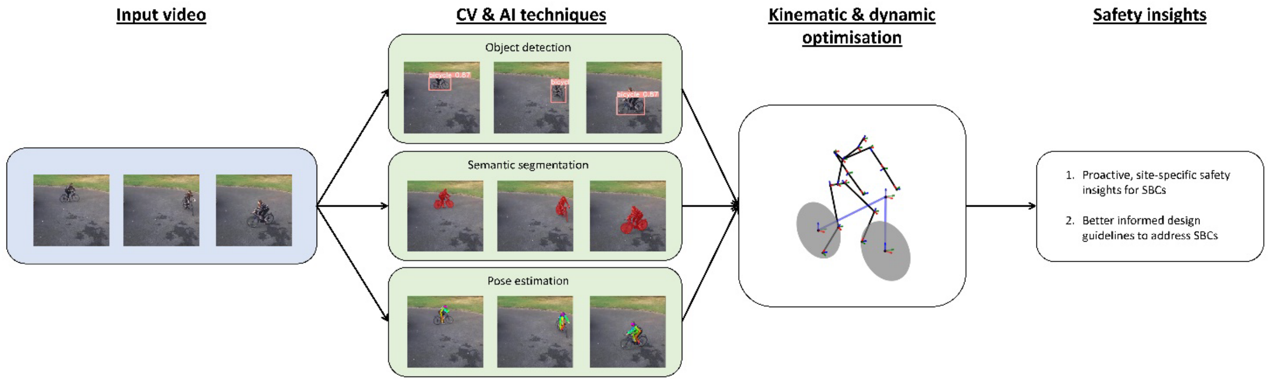


Figure 1: Proposed framework for obtaining Surrogate Measures of Safety (SMoS) for Single Bicycle Crashes (SBCs).

2.3 Data Collection and Algorithm Fine-Tuning

Video footage will be collected from cyclists in a controlled experimental environment, using bicycles and riders fitted with Inertial Measurement Units (IMU). The purpose of this data collection is to obtain measures for fine-tuning the bicycle/rider model used in optimal control [12]. This will include specific control parameters to account for special interest cyclist groups such as the elderly or mobility impaired.

2.4 Pilot Testing and Further Model Refinement

The developed algorithm will be pilot tested in real-world environments, with the goal of refining the model based on observed results.

2.5 Data Analysis

The data collected from the pilot testing and supplementary data for risky locations/infrastructural scenarios of interest will be analysed.

3 CONCLUSIONS

This abstract outlines the development of a novel proactive safety assessment pipeline aimed at addressing the significant road safety issue of SBCs. By utilizing video-based SMoS in combination with CV and AI technologies, we propose a dynamics-informed cyclist tracking algorithm to identify high-risk scenarios and locations for SBCs. Ultimately, our approach has the potential to provide valuable insights into road factors that contribute to cyclist falls and inform design guidelines for safer cycling infrastructure. The expected outcomes of this work include the identification of specific road features or environmental factors that increase the risk of SBCs, the development of proactive safety assessment strategies, and the reduction of the number of serious injuries resulting from SBCs. The authors expect to have preliminary results to present at ICSC 2023.

REFERENCES

[1] Eriksson, J., Henriksson, P., & Rizzi, M. (2022). Oskyddade trafikanters inblandning i olyckor och deras skadeutfall.
[2] Niska, A., Gustafsson, S., Nyberg, J., & Eriksson, J. (2013). Cyklisters singelolyckor Analys av olycks-och skadedata samt djupintervjuer.
[3] Björnberg, K. E., Hansson, S. O., Belin, M.-Å., & Tingvall, C. (2023). The Vision Zero Handbook: Theory, Technology and Management for a Zero Casualty Policy. Springer Nature.
[4] International Transport Forum. (2016). Zero road deaths and serious injuries: Leading a paradigm shift to a safe system. OECD Publishing.
[5] Madsen, T., Várhelyi, A., Polders, E., Reumers, S., Hosta, P., Bibiloni, D. J., Ramellini, A., Agerholm, N., & Lahrmann, H. (2018). Assessment of Safety of VRUs Based on Self-Reporting of Accidents and Near-Accidents.
[6] Hydén, C. (1987). The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Bulletin Lund Institute of Technology, Department, 70.
[7] International Transport Forum. (2021). Artificial Intelligence in Proactive Road Infrastructure Safety Management.
[8] Johnsson, C., Laureshyn, A., & Ceunynck, T. De. (2018). In search of surrogate safety indicators for vulnerable road users: a review of surrogate safety indicators. Transport Reviews, 38(6), 765 785.
[9] Gildea, K., Mercadal-Baudart, C., Blythman, R., Smolic, A., & Simms, C. (2022). KinePose: A temporally optimized inverse kinematics technique for 6DOF human pose estimation with biomechanical constraints. Irish Machine Vision & Image Processing Conference (IMVIP).
[10] Gildea, K., & Simms, C. (2022). Towards computational modelling of active response in cyclist falls from in-the-wild footage. Congress of the European Society of Biomechanics (ESB).
[11] Gildea, K. (2023). A biomechanical analysis of cyclist collisions in Ireland [Trinity College Dublin].
[12] Åström, K. J., Klein, R. E., Lennartsson (2005). Bicycle dynamics and control: adapted bicycles for education and research; Bicycle dynamics and control: adapted bicycles for education and research. IEEE Control Systems, 25.
[13] Johnsson, C., Norén, H., Laureshyn, A., & Ivina, D. (2018). InDev Deliverable 6.1: T-Analyst - semi-automated tool for traffic conflict analysis.
[14] Bornø Jensen, M., Ahrnbom, M., Kruithof, M., Åström, K., Nilsson, M., Ardö, H., Laureshyn, A., Johnsson, C., & Moeslund, T. (2019, January). A Framework for Automated Traffic Safety Analysis from Video Using Modern Computer Vision. Transportation Research Board Annual Meeting 2019.
[15] Laureshyn, A., Svensson, Å., & Hydén, C. (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. Accident Analysis & Prevention, 42(6), 1637 1646.
[16] Ali, Y., Haque, M. M., & Mannering, F. (2023). A Bayesian generalised extreme value model to estimate real-time pedestrian crash risks at signalised intersections using artificial intelligence-based video analytics. Analytic Methods in Accident Research, 38, 100264.
[17] Gildea, K. & Simms, C. "Characteristics of cyclist collisions in Ireland: Analysis of a self-reported survey," Accident Analysis & Prevention, vol. 151, p. 105948, mar 2021.
[18] M. Ahrnbom, I. Persson, H. Ardo, and M. Nilsson, "Generalized urban traffic surveillance (GUTS): World-coordinate tracking for traffic safety applications," vol. 2022-October, pp. 3813–3818, IEEE.

Impact of road safety to enhance cycling culture in Sub-Saharan Africa

Azeb T. Legese *, Prof. Angela Francke **, Prof. Mitullah Winnie#
Feleke Gebremariam##, Namakula Hidayahβ

*Cycling and local mobility University of Kassel
Mönchebergstraße 7
34125 Kassel, Kassel, Germany
email: azeb.tesfaye@uni-kassel.de

** Cycling and local mobility University of Kassel
Mönchebergstraße 7
34125 Kassel, Kassel, Germany
email: angela.francke@uni-kassel.de

Institute for Development Studies
University of Nairobi,
30197-00100 Nairobi, Kenya
email: mitullahwinnie@gmail.com

Ethiopia institute of technology
Mekelle University
231, Mekelle, Ethiopia
email: gmariamster@gmail.com

β Makerere University,
College of Engineering, Design, Art and Technology
7062 Kampala, Uganda
email: namakulahidayah@gmail.com

Keywords: Cycling safety, infrastructure, cycling culture, mobility behavior, Sub-Saharan Africa

1 INTRODUCTION

Mobility is a necessity for the social, economic, and environmental progress of any city; and getting around by any means of transportation is a core part and a dynamic experience of everyday life in cities. It is not just about getting from A to B efficiently, rather it means being able to access living, working, and leisure spaces using safe, swift, environmentally friendly, and affordable transport options [1]. Active mobility is the most preferable option regarding sustainability. Despite the widespread use of active mobility modes, transport planning and the provision of infrastructure in most of the cities in Africa have become car centered. The infrastructure financing also overlooked the needs of active mobility users` and focused more on constructing roads for cars neglecting the importance of cycling and walking.

More than one-third of Africans use active mobility as a daily mode [2]. Many are dependent on walking and cycling as primary means of transport, not by choice but as a necessity. This high modal share of active mobility in Africa could be an opportunity to maintain sustainable mobility within the continent. However, active mobility in most African cities is unsafe and one of the riskiest modes of mobility. According to WHO`s status report on road safety [3], the African region has 26.6 deaths per 100,000 population, which renders it the highest among all regions. Unfortunately, in most cases, the victims of traffic casualties are primarily pedestrians and cyclists who made no contribution to the accident, e.g. Kenya 37% pedestrians / 2.4% cyclists: Uganda 40% pedestrians / 6% cyclists, Ethiopia 37% pedestrians/ 2.9% cyclists [3]. Much of that is linked to the neglect of the infrastructure needs for pedestrians' and cyclists' safety. Walking and cycling in most African cities are not only unsafe, but also extremely uncomfortable due to the poor quality of infrastructure. Cyclists in particular are often forced to share space with pedestrians, street vendors, and with vehicles moving at very high speeds. The lack of adequate facilities exposes people to a high risk of injury or death. Unlike all the mobility challenges, there are various local initiatives around the continent that promote cycling, such as car-free days, place-making, Open Streets, and Critical Mass campaigns to inspire citizens to reimagine and reinvent their streets to be accessible for all.

The focus of the session will be to present the results on cyclists` safety, motivating factors, and obstacles for cycling based on the quantitative mobility survey done for a collaborative mobility project, Collaboration on Active Mobility Africa (CAMA), that is being conducted among three sub–Saharan African universities (University of Nairobi-Kenya, Mekelle University-Ethiopia, Makerere University-Uganda) and two universities in Germany (University of Kassel and Hochschule Karlsruhe University of Applied Sciences). CAMA is a five-year sustainable mobility project funded by DAAD and BMBF. This project intends to promote walking and cycling in sub–Saharan African countries through research, continuous education, and real-life experiments.

2 OBJECTIVE

The project’s main aim is to combine scientific goals to better understand the cyclists’ perceptions, preferences, daily experience, and individual barriers while cycling in the three African cities’ context. This could help us to develop tailor-made strategies for promoting safe cycling and encouraging cycling culture in urban areas in Ethiopia, Kenya, and Uganda by capturing the needs and preferences of cyclists.

3 METHODOLOGY

A mixed research methodology is utilized to achieve the goal of the project. Survey questionnaires, bike lane safety audits, mapping tools, and key informant interviews were instrumented as data collection tools. A quantitative survey in each of the three case cities (Kampala, Nairobi, and Mekelle) with more than 420 data sets per city was spread. The survey contained four main parts: sociodemographic data, users` daily experience, preference for safe cycling, perception towards active mobility, and users’ recommendation to create a safe cycling environment. The surveys were set up together with all project partners and tailored to the local circumstances to give a first deep understanding of the mobility conditions and needs in those areas. A comparative analysis will be conducted to understand the cycling safety barriers and enabling factors and to understand the culture of cycling in the 3 Sub-Saharan countries context.

4 CONCLUSION

The research findings will help us understand the user`s mobility behavior, preferences for the choice of route, the subjective feeling of safety, and the general attitude and socialization towards cycling. In addition, motivators, and obstacles for or against cycling are also evaluated. The first analysis already showed that the lack of subjective safety is a main barrier, unfair space allocation and computation of space within the urban fabric, also intensified by the lack of law enforcement, as the severity of pedestrian and cyclist crashes, is strongly dependent on the speed of traffic.

REFERENCES

[1] Gerike, R., Dean, M., Koszowski, C., Schröter, B., Wittwer, R., Weber, J. and Jones, P. (2019), “*Urban Corridor Road Design: Guides, Objectives and Performance Indicators”*, Deliverable D1.2, Multimodal Optimisation of Roadspace in Europe, 2019

[2] E. Sumper and M. Barker,” *Sustainable Urban Transport: Improving Mobility Conditions for Vulnerable Road Users in Sub-Saharan Africa*”, in: W . Leal Filho, S. Belay, J. Kalangu, W. Menas, P. Munishi, K. Musiyiwa (eds) Climate Change Adaptation in Africa. Climate Change Management. Springer, Cham. H. B. Pacejka, Tyre and Vehicle Dynamics, Butterworth and Heinemann, Oxford, 2002.

[3] WHO, *Global status report on road safety*, World Health Organization, 2018, 26 pp

Investigating the Safety Behaviour of Cyclists in Construction Sites

Marie Klosterkamp[*], **Eike Rothauge**[#], **Paul Papendieck**[+], **Angela Francke**[†]

[*]Faculty of Cycling and Sustainable Mobility
University of Kassel
Mönchebergstraße 7, 34125, Kassel, Germany
email: marie.klosterkamp@uni-kassel.de

[#] Faculty of Cycling and Sustainable Mobility
University of Kassel
Mönchebergstraße 7, 34125, Kassel, Germany
email: eike.rothauge@uni-kassel.de

[+] Faculty of Cycling and Sustainable Mobility
University of Kassel
Mönchebergstraße 7, 34125, Kassel, Germany
email: paul.papendieck@uni-kassel.de

[†] Faculty of Cycling and Sustainable Mobility
University of Kassel
Mönchebergstraße 7, 34125, Kassel, Germany
email: angela.francke@uni-kassel.de

Keywords: road construction, safety, cyclists, traffic counting, behaviour.

1 INTRODUCTION

Research on the safety of pedestrians and cyclists in construction site situations has been relatively neglected, despite the increased conflict situations resulting from reduced space for traffic management at work sites during road construction.

Existing research has primarily treated guidance for bicycle and pedestrian traffic along construction sites as a sub-aspect in accident research reports. Teschke et al. (2012) and Alrutz et al. (2009) analyzed accident data for cyclists and categorized it by road type. Teschke et al. (2012) surveyed 690 cyclists involved in accidents in Toronto and Vancouver, while Alrutz et al. (2009) analyzed 1,100 accidents and the rule-compliant street use of 39,000 cyclists in Germany and conducted interviews. Teschke et al. (2012) found that construction sites almost double the likelihood of accidents for cyclists in comparison to infrastructure without ongoing construction. The researchers also observed that construction work was more frequent on shared lanes, multi-use paths, and bike paths compared to cycle tracks, sidewalks, and streets without bicycle infrastructure. Alrutz et al. (2009) further found that 48% of interviewed cyclists reported that construction sites negatively affect their riding comfort. The researchers also observed that construction sites often lead to the abandonment of bike lanes that are subject to mandatory use. Interestingly, more women were found to avoid the construction site via the walkway, while men were more likely to detour by way of the roadway.

Therefore, it is crucial to further investigate the behavior and preference of cyclists in construction sites. In response to this need, the "BRAVOUR" research project has been initiated, which is funded by the German Federal Ministry of Digital and Transport and aims to improve the safety of cyclists to contribute to the goal of the National Cycling Plan 3.0. The goal of the current study is to gain an understanding for the factors influencing the path choice of the cyclists by observing their interactions with and also their avoidances of other road users. Hence, this submission aims to investigate the specific safety preferences of cyclists in construction site situations and to identify potential conflict situations that may arise.

By addressing these issues, the research will contribute to enhancing public health and improving the overall quality of life by improving safety for cyclists.

2 METHOD

During the spring and summer of 2023, a variety of construction sites in the city of Hamburg will be investigated in regards to the cyclists' behavior resulting from the design of the construction sites. For this, three categories of study setup will be utilized:

Firstly, non-complex construction sites will be equipped with traffic counting systems of the company Eco Counter GmbH to gain inside into the choice preference of cyclists. These systems are utilized to evaluate whether the cyclists chose the safer option of joining the pedestrians on the sidewalk or join in with the mixed traffic on the shared lane. The traffic counting systems will be deployed in situations where cyclists can only choose from one of two options (sidewalk or a shared lane with vehicles) for cycling past the construction (see figure 1). Each of these pathways will be equipped with a system consisting of two tubes, which are able to differentiate between the transportation mode (vehicle vs. bicycle) rolling over the tubes. However, since these tubes are not able to count pedestrians, a pedestrian-specific counter is also utilized for the walkway.

Figure 1 Set-up of the traffic counting system. Yellow - pedestrian and cyclist counting on the sidewalk. Blue - vehicle and cycling counting on the shared lane.

Secondly, for some of these construction sites the counting systems will be complemented with camera systems to investigate the interaction of the road users along the construction as well as to compare the effectiveness of both measures on counting traffic volumes.

Thirdly, at rather complex construction sites cameras will solely be used to investigate choice processes of cyclists, the interaction behavior with other road users as well as to record the trajectories of the road users.

3 IMPLICATION

The results are expected to further the understanding of the cyclists' preferences for safe pathways through construction site situations. Furthermore, the specific factors will be identified that influence the cyclists' path choice. Likewise, the perceived safety as well as utility, in terms of the cyclists speed, of this choice preference are going to be evaluated.

Another expected result is the comparison of the effectiveness of traffic counting systems and camera systems in capturing the traffic volumes. This will help to evaluate the advantages and limitations of each method and to optimize future data collection processes.

The proposed submission will provide valuable insights into the safety preferences and behaviors of cyclists in construction site situations. The results will help to identify potential factors influencing conflict situations as well as informing design solutions that can reduce the risk of accidents and injuries. By addressing these issues, the research will support the promotion of active modes of transport and improve the safety of cyclists and pedestrians.

REFERENCES

[1] Alrutz, D. (ed.). (2009). *Unfallrisiko und Regelakzeptanz von Fahrradfahrern: Bericht zum Forschungsprojekt FE 82.262*: *Unfallrisiko, Konfliktpotenzial und Akzeptanz der Verkehrsregelungen von Fahrradfahrern*. Wirtschaftsverlag NW, Verlag für neue Wiss.

[2] Teschke, K., Harris, M. A., Reynolds, C. C. O., Winters, M., Babul, S., Chipman, M., Cusimano, M. D., Brubacher, J. R., Hunte, G. S., Friedman, S. M., Monro, M., Shen, H., Vernich, L., & Cripton, P. A. (2012). Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study. *American Journal of Public Health*, *102*(12), 2336–2343. https://doi.org/10.2105/ajph.2012.300762

Development of a VR bicycle simulator for assessment of a new ADAS in interaction with vehicles and cyclists: departing intention case study.

Meysam IMANIPOUR, Alexandre BARBIER, Sebastien SAUDRAIS, Bertrand BARBEDETTE
ESTACA LAB
Parc universitaire Laval-Changé, 53000, Laval, France
email: meysam.imanipour@estaca.fr (*surname.name@estaca.fr)*

Keywords: Bike simulator, Virtual reality, Cycling safety in urban situation, deparking car phase, Communication-oriented ADAS.

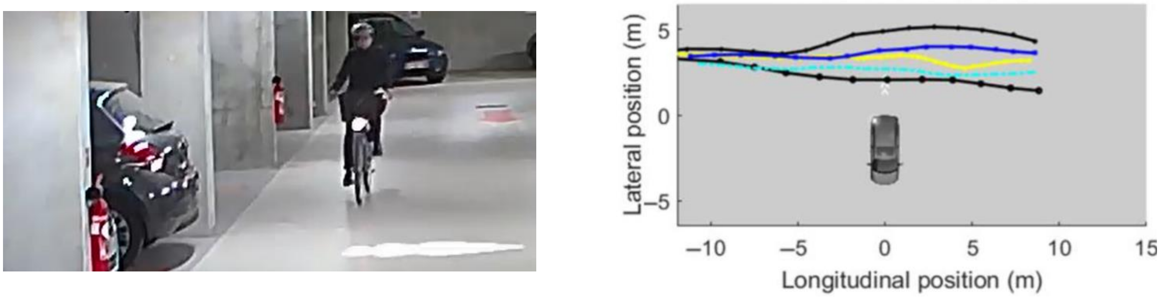
1 INTRODUCTION

Cycling is a sustainable and active means of transport [1][2], which increases physical activity [3] and has positive impact on health [2]. Urban planning designers shift more toward using this type of transport [4]. Despite these advantages, due to the dangers of cycling, the use of bicycles in transport is still low [3]. Wintersberger *et al.* [5] argued that cyclists are still involved increasingly in accidents. Brijs *et al.* [1] explained that due to higher speed of cyclists comparing to pedestrians there is more risk of injury when interacting with motorized vehicles. Alongside these safety limitations, Advanced Driving Assistance Systems (ADAS) and Autonomous Vehicle (AV) have been promising and various studies show the improvement of road safety, when using them. Existing ADAS systems and AV can detect potential crashes and alert the driver or take a prevention action to avoid the upcoming hazard. For example**,** there are ADAS systems that detect the cyclists and alert the driver to avoid crashes [8], but for further enhancement of the road users' safety, especially the cyclists, it is also important to be aware of vehicle movement. New communication-oriented ADAS systems, like on-road light projection, give a visual information to vulnerable road users, and will reduce the risk of crash. However, the challenges that designers of the new ADAS system are facing are high complexity of the traffic and different road conditions [7] which make the assessment of an ADAS system in real experiments very expensive and difficult [6]. Beside of these complexities, the risk of performing real life experiments is high. To overcome these challenges, especially in context of car-bicycle interactions, researchers proposed the use of bicycle simulator which performs different experiments in cost efficient manner and under safe laboratory conditions. In addition to the advantages, the behavior of cyclists can study and finally to improve ADAS systems. The main objective of this study is to develop a bike simulator in Virtual Reality (VR) environment to assess the impact of future communication-oriented ADAS on safety of cyclists in urban situations. Azouigui *et al.* [9] presented a real experiment testing this new ADAS on democar projecting on the road a light signal in a departing situation to prevent other road users, like cyclists. Based on this previous study investigating the safety impact on cycling, this paper deals with the validation of this VR bike simulator and the cyclist feeling in virtual reality. A first virtual environment is based on urban situations with different on-road cyclist marks. Secondly with the same new ADAS tested in real world [9], upcoming results in virtual world will be compared to results of cycling in reality.

2 METHODOLOGY AND MATERIALS

To evaluate the future proposed ADAS system, it is required to ensure the validity of the VR bike simulator and to confirm that results of cycling in virtual reality are comparable to results of cycling in reality. To this end, the departing scenario was considered in [9] and a new virtual environment was designed. In this way, the comparison between VR bike simulator results and real cycling results can be ensured. Then to achieve the main objective of this study, the new ADAS system will be evaluated via the VR bike simulator (only in

Virtual Reality). For this, cyclists will ride the VR bike simulator and pass from behind or side of vehicles equipped, or not, with communication-oriented ADAS. The departing intention of parked cars will be signaled by the on-road projection new ADAS, or simply by the reverse or turn indicator of classical car. Via comparing the behavior changes of cyclists in these two conditions, the safety impact of this system on cycling safety will be evaluated. After these experiments, the cyclists will fill out a questionnaire about the comprehension of ADAS system and its meaning, since they will not be informed about the ADAS system. Figure 1 shows the experiment in reality and cyclists behavior result when interacting with this ADAS system.



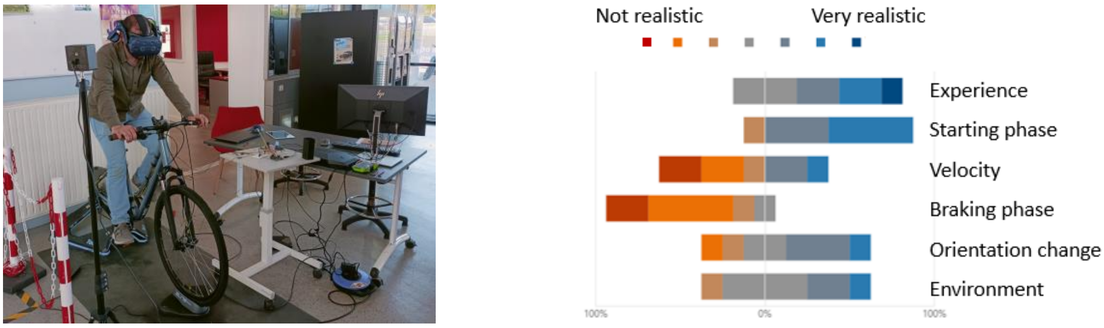
a) Cyclist passing behind ADAS on-road projection *b) Trajectories for 5 cyclists*

Figure 1: Experiment in real context presented in [9]

The materials used in the development of VR bike simulator are a direct home trainer (Tacx neo 2T), Vive headset mounted display, Vive tracker, pressure sensors, Arduino and rotary encoder. The bike is installed on the home trainer. The trainer supports reading speed and power of the bike as well as writing resistance to the bike trainer to simulate brake. It supports ANT+ and Bluetooth low energy communication. One of the limitation of these two communication protocols is that they do not transfer data at high frequency, which will result in considerable delay in the simulation. To avoid this limitation, a rotary encoder placed on inertia wheel of the home trainer was used to measure the position, and the speed of the bike trainer was proceeded by Arduino microcontroller and send it to the simulator software via serial communication. The Vive tracker was installed on the handlebar of the bike to measure rotation of handlebar. Two pressure sensors were positioned inside the front and rear disk brake to send the braking amount via Arduino to the simulator software. Figure 2a shows the VR bike simulator and different components of it. The virtual environment software was developed on Unreal Engine (Version 4.28).

3 FISRT RESULTS AND ANALYSIS

In the first version of our VR bike simulator, we conducted an experiment with a small population of 8 persons (7 males / 1 female) to evaluate subjectively the VR bike simulator and see how much it is similar to real cycling. For this different factors of cycling were considered in the questionnaire, such as speed, braking, steering, etc. The population of this first experiment were between 25 and 34 years old and had experience in riding bicycle since their childhood. 5 people among the participants, have regular use of bicycle riding between 100km and 1000 km per year. The participants also were asked if they had experience with virtual reality. 5 participants indicated the experience with virtual reality where 2 of them had frequent experience 5 times and more. Regarding the symptoms of virtual reality, one participant indicated a slight feeling of discomfort after the virtual cycling, and another felt vertigo, but the rest did not mention discomfort feelings. At the end, the participants were asked to rank how much their experience felt like real life cycling and they also rank the level of immersion of different cycling factors (speed, steering, starting phase, brake) and the environment (Figure 2a). As it can be seen in figure 2b, five of them expressed good feelings, and among these 5 people, 2 participants indicate quasi realistic experience. Among cycling factors, speed and brake were ranked as not realistic at all, while steering and starting phase felt more realistic by participants.



a) VR Bike simulator setup *b) Feeling on VR bike simulator experience*

Figure 2: Experimental setup and first feeling results.

4 CONCLUSIONS AND FUTURE WORKS

Based on the first experiments with 8 participants, 5 people had good experience in their virtual cycling (like real cycling) and among them only two participants felt a slight discomfort, which can indicate the potential of this VR bike simulator to be used in our research study. Since this work is in progress, further improvement of VR bike simulator is being considered, especially for braking and speed simulation. For future work, we consider improving the VR bike simulator to ensure the comparability of it with real cycling experience, and then perform different experiments in the virtual environment of the parking lot, to investigate the behavior changes of cyclists when interacting with communication-oriented ADAS system and evaluate the impact of this new ADAS on safety of cyclists.

REFERENCES

[1] Brijs, T., Mauriello, F., Montella, A., Galante, F., Brijs, K., & Ross, V. (2022). Studying the effects of an advanced driver-assistance system to improve safety of cyclists overtaking. *Accident Analysis & Prevention*, *174*, 106763.

[2] Lieze, M., Benedicte, D., Mario, M., & Van Dyck, D. (2020). Using virtual reality to investigate physical environmental factors related to cycling in older adults: A comparison between two methodologies. *Journal of Transport & Health*, *19*, 100921.

[3] van Paridon, K., Timmis, M. A., & Sadeghi Esfahlani, S. (2021). Development and evaluation of a virtual environment to assess cycling hazard perception skills. *Sensors*, *21*(16), 5499.

[4] Schramka, F., Arisona, S., Joos, M., & Erath, A. (2017). Development of virtual reality cycling simulator. *Arbeitsberichte Verkehrs-und Raumplanung*, *1244*.

[5] Wintersberger, P., Matviienko, A., Schweidler, A., & Michahelles, F. (2022). Development and Evaluation of a Motion-based VR Bicycle Simulator. *Proceedings of the ACM on Human-Computer Interaction*, *6*(MHCI), 1-19.

[6] Siebke, C., Bäumler, M., Blenz, K., Lehmann, M., Ringhand, M., Mai, M., & Prokop, G. (2023). Predicting the impact on road safety of an intersection AEB at urban intersections. Using a novel virtual test field for the assessment of conflict prevention between cyclists/pedelecs and cars. *Transportation Research Interdisciplinary Perspectives*, *17*, 100728.

[7] Huemer, A. K., Rosenboom, L. M., Naujoks, M., & Banach, E. (2022). Testing cycling infrastructure layout in virtual environments: An examination from a bicycle rider's perspective in simulation and online. *Transportation research interdisciplinary perspectives*, *14*, 100586.

[8] A. Mohammadi, G. Bianchi Piccinini, M. Dozza, Understanding the interaction between cyclists and automated vehicles: Results from a cycling simulator study, ICSC22, Dresden, Germany

[9] Azouigui, S., Saudrais, S., Barbedette, B., Bordel, S., Delauzun, S., Khatir, B., ... & Jaillette, P. (2021). *Road Projections: Impact on Road Users and Potential to Enhance Awareness of Backing Situation in Parking Lots* (No. 2021-01-5078). SAE Technical Paper.

An Investigation into the Road Interactions Experienced by Bicycle Food Delivery Riders with Other Road Users

O. Oviedo-Trespalacios[a], L. Martinez-Buelvas[b], N. Haworth[b]

[a]Faculty of Technology, Policy & Management
Delft University of Technology
Jaffalaan 5, 2628 BX, Delft
email: O.OviedoTrespalacios@tudelft.nl

[b]Centre for Accident Research and Road Safety-Queensland (CARRS-Q)
Queensland University of Technology
130 Victoria Park Rd., 4059, Kelvin Grove, Australia
email: l.martinezbuelvas@qut.edu.a;
n.haworth@qut.edu.au

Keywords: Gig Economy, Road Safety, Vulnerable Road Users, Bicycle Food Delivery, Driver Behavior, Cyclist Safety

1 INTRODUCTION

The rapid growth of the gig economy, together with a rising preference for home delivery of meals due to the COVID-19 pandemic, has led to a significant surge in the number of bicycle food delivery riders (BFDRs) worldwide. International studies have identified that job pressure can lead to risky on-road behaviors such as running red lights, riding while fatigued, and using their phones while riding (1-2). However, very little information is available about how BFDRs interact with other road users. To close this gap, this research study aims to further explore the road conflicts experienced by BFDRs in Australia to better understand the impact of the gig economy on traffic safety, health, and sustainability.

2 METHOD

2.1 Study Design

For this study, we employed a qualitative research method using semi-structured interviews with BFDRs to explore their experiences while working in Brisbane, Queensland, Australia. The interviews were designed to elicit participants' perspectives on their interactions with various road users, including cars, pedestrians, e-scooters, motorcyclists, and other cyclists. The interviews provided rich, contextual data that allowed us to gain a deeper understanding of the challenges and nuances these workers face daily. To analyze the data collected from the interviews, we used a reflective thematic analysis approach.

2.2 Participants

This study included 23 BFDRs from various companies: UberEats (n=12), Doordash (n=5), Deliveroo (n=1), and multiple companies (n=5). Participants' ages ranged from 20 to 40 (M = 27.5, SD = 5.0), with 17 males, five females, and one non-binary individual. Thirteen participants reported experiencing at least one safety-critical event, such as collisions or near misses. Of these events, only two were near misses, while the remaining 11 involved collisions.

3 RESULTS

3.1 BFDRs Interactions with Car Drivers

With regard to cars, BFDRs expressed ambivalence, noting that drivers often seem unaware of their presence. This lack of acknowledgment is particularly concerning given that Australia has limited dedicated infrastructure for cyclists. Consequently, this poses a significant safety risk as car drivers may not actively watch for cyclists, potentially overlooking them on the road. In addition to being unnoticed by drivers, cyclists also emphasized the absence of effective communication channels with drivers, which can lead to substantial risks as well.

> *"Bikes do not have horns like cars, so you cannot tell someone to give way or some. If you're driving, you cannot tell someone you're coming at the back through the horn or something like that because they could just pull out the door and you could get hit" [M, 24]*

Some BFDRs reported that they experienced intimidation from drivers in certain circumstances, such as driving extremely close or engaging in aggressive behaviors like altering lights. Participants mentioned that this behavior seemed more prevalent among young male drivers. Additionally, the speed differential when sharing the road was cited as a triggering factor by several participants.

> *"Well, in some cases, I have felt that some people try to intimidate a little, like young drivers, especially. When I ride my bike, they always flash their lights, make noise, or even say (abusive) words" [M, 30]*

In a limited number of situations, BFDRs reported experiencing physical and sexual harassment. These incidents not only pose a threat to the riders' safety and well-being but also create a hostile work environment, potentially impacting their job performance and mental health.

> *"He used this car, locked the road, came down, and grab me by my shirt, and it was trying to say he was gonna beat me up and all of that." [M, 25]*

3.2 BFDRs Interactions with Pedestrians

BFDRs frequently described their interactions with pedestrians as generally reasonable, although some individuals occasionally acted obstructively. A recurring observation was that pedestrians often ignored the ringing of bicycle bells, making it challenging for riders to navigate through footpaths. In response, some delivery riders acquired louder bells, but this did not seem to yield a significant improvement. A critical factor contributing to conflicts with pedestrians was their preoccupation with using their phones or listening to music, preventing them from effectively negotiating situations with the riders.

> *"People are very distracted with their phones, a lot. I don't know if they're taking photos, but they're glued to their phones. They're walking, and they don't even realize it, even when they hear the bike bell. They don't even cross at the lights." [M, 32]*

Some BFDRs noted that certain pedestrians exhibited hostility towards them. In a few cases, these individuals even attempted to knock or grab the riders off their bicycles, compromising their safety and well-being.

> *"He had to move aside, but instead, he stopped in front of me, grabbed my handlebars, and started saying a thousand things." [F, 33]*

BFDRs working near nightclub areas reported being targets for attackers, including those with racially motivated intentions. The proximity to nightlife establishments may increase the likelihood of encountering intoxicated or aggressive individuals, exacerbating the risks faced by these riders.

> *"Pedestrians sit pretty bad sometimes because they don't like the cyclists sometimes, or if they are rude or racist, especially on the nights when everyone is going for clubbing. And if you are doing that*

> *for your living, they're just because everyone mostly is drunk, so they just pass the racial comments and stuff." [M, 35]*

3.3 BFDRs Interactions with E-scooters

BFDRs felt that e-scooter riders were unpredictable and inconsistent in their behaviour on the road, resembling both cyclists and pedestrians at different times. This made it hard for BFDRs to stay safe as e-scooters could act unpredictably. Additionally, shared e-scooter users leave scooters scattered across footpaths, which poses safety hazards for BFDRs. This group is among the most problematic when it comes to ensuring BFDRs' safety.

3.4 BFDRs Interactions with Motorcycles

No major issues were reported in interactions with motorcyclists, which could be attributed to their smaller numbers in Australia.

3.5 BFDRs Interactions with Bicycles

No major issues were reported in interactions with cyclists, which could be attributed to their smaller numbers in Australia. Interestingly, some on-road competition seemed to exist among BFDRs in terms of speed, with a few even engaging in impromptu races while working.

> *"They tend to bring in competition, especially from other food delivery companies. They tend to bring it to come along the road, but I see that it is a distraction." [F, 23]*

4 CONCLUSIONS

In conclusion, this study highlights the challenges faced by bicycle food delivery riders (BFDRs) when interacting with different road users in Australia. Car drivers' aggressive behavior poses a significant safety risk, especially as there is limited infrastructure for cyclists. Additionally, pedestrians and e-scooter users can be unpredictable, further complicating safety concerns for BFDRs. To ensure a safer working environment for BFDRs, there is a need for improved infrastructure and better communication channels between road users. Increased awareness and education about the unique challenges faced by BFDRs could also foster a more respectful and cooperative atmosphere on the road. Ultimately, addressing these safety concerns is essential for the well-being of food delivery riders and the success of the gig economy.

REFERENCES

[1] Christie, N., & Ward, H. (2019). The health and safety risks for people who drive for work in the gig economy. *Journal of Transport & Health*, 13, 115-127. https://doi.org/10.1016/j.jth.2019.02.007

[2] Oviedo-Trespalacios, O., Rubie, E., & Haworth, N. (2022). Risky business: Comparing the riding behaviours of food delivery and private bicycle riders. *Accident Analysis & Prevention,* 177, 106820. https://doi.org/10.1016/j.aap.2022.106820

Trends in US Bicycle Crash Geometries and Cyclist Age

D.H. Good[†]

[†]O'Neill School of Public and Environmental Affairs
Indiana University
Bloomington, Indiana 47405, USA
email: good@indiana.edu

Keywords: cycling crash geometries, older cyclists, trends and policy recommendations

1 INTRODUCTION

Over the last few decades vehicle engineers and local planners have devoted considerable effort into improving the safety of vulnerable road users: pedestrians and cyclists. In the US these efforts have included the introduction of driver assistance technologies (ADAS) such as pedestrian and cyclist detection, blind spot and cross traffic detection. Planners, with the assistance of billions of dollars of US Department of Transportation funding have adopted stop-as-yield laws and constructed walking/biking trails along with specific bike lanes; most recently through the RAISE program. Yet over this period from 2010 through 2022 the number of traffic fatalities in the US has increased from approximately 31,000 to an estimated 46,000. Vulnerable road users have not been particularly affected with a pedestrian and cyclist fatality growth from 4,302 to 7,308 and 623 to 966 over the period from 2010 to 2021–a 70% and 55% increase. Cyclist fatalities reached the highest total since 1975.

There is considerable disagreement about the primary factors of these increases. Chief among them is distraction by both the cyclist and vehicle drivers, not using proper safety equipment, and impairment with alcohol, drugs or both. In this paper less often describe details of the crash the gross geometry of how the vehicle and cycle interact, and details of the cyclist, predominately age may constitute contributing risks and hazards.

The findings show that as people age, they experience both increased hazards and risks associated with fatality. On a gross level, one of the findings is that mean age of the cyclists killed continues to increase from 42 years old in 2010 to nearly 50 by 2021. As a conclusion, most of the dramatic increase in cyclist fatalities can be attributed to cyclist aging as more and more older Americans turn to cycling as a means of staying active and fit. This suggests two potential efforts to reduce cyclist fatalities: education programs targeted toward the over-50 cyclists, potentially through Area Agencies on Aging and non-profit organizations such as AARP.

2 RESEARCH PLAN

In this initial analysis, attention is focused on relatively simple single vehicle/single cyclist crashes involving light vehicles (cars, light trucks, and utility vehicles built either on a truck or car chassis) over the period from 2010 through 2021 a period of relative stability in federal fatality crash reporting. When analyzing these data, it is always worthwhile to remember why and how these data are collected and that some information is likely more reliable than other information.

2.1 Crash Geometry

To that end, a three tier approach is used to identify the crash geometry. Understanding these crash geometries, and particularly how they change over time, can offer some insights into how engineering and planning efforts have been in enhancing safety. These tiers are associated with the reliability of information on police crash reports. Tier one describes, the gross geometry and whether the vehicle and bicycle are on parallel or crossing paths (Classified as PP: or CP:). Tier two describes vehicle actions and whether it is traveling straight or turning left or right and whether it is overtaking or head-on (VLT, VRT and whether it is overtaking or facing the cyclist head-on VOT, VHO). Tier three describes characteristics of the crash that are often incompletely described in crash reports. This includes the bicyclists actions relative to those of the vehicle and often incorporates more fine detail about relationships to the vehicle. The end result of this is characterized in Figure 1.

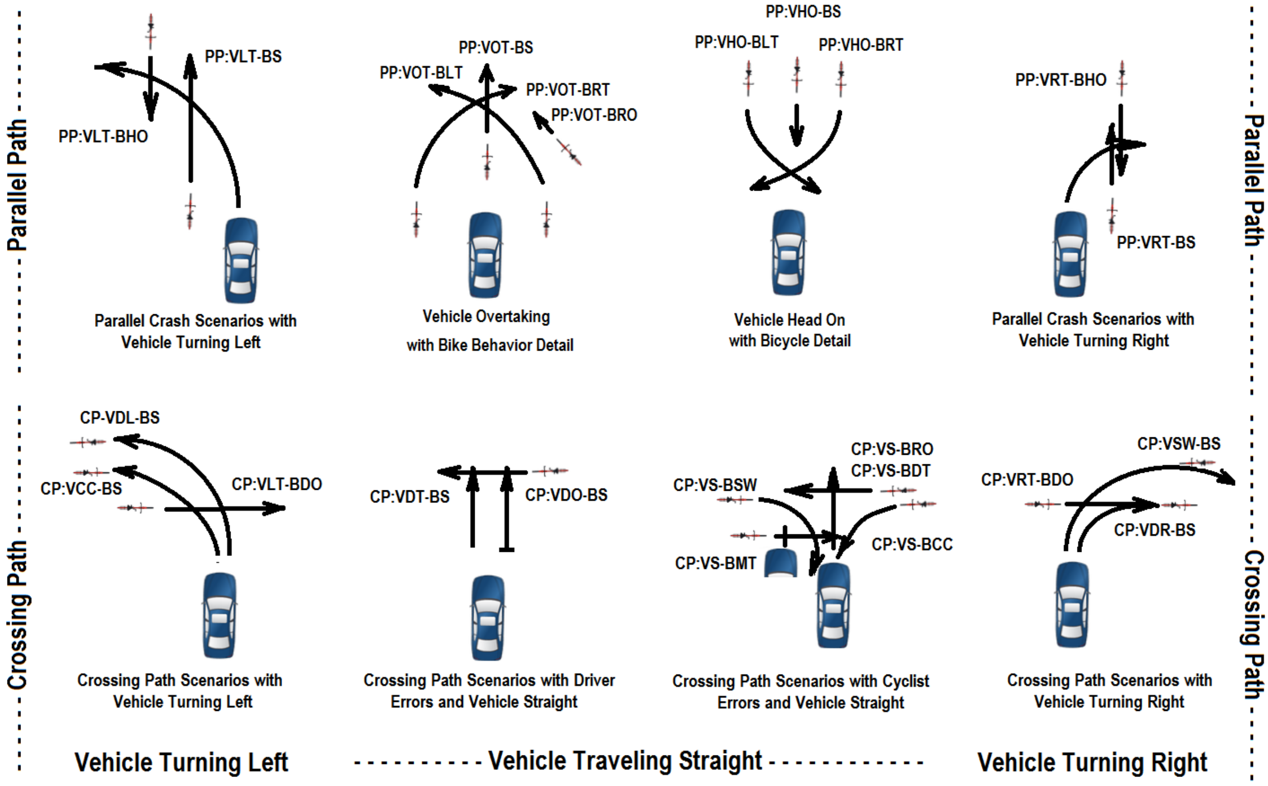


Figure 1. Three Tiered Classification of Cyclist Crash Geometries

It is useful to note that some ADAS are directly relevant for some crash geometries but not all. For example BLIS might offer some useful driver information to help prevent PP:VRT-BS or PP:VLT-BS crashes. Other crash configurations are more dependent on cyclists being able to correctly identify gaps.

2.2 Trends in Cyclist Demographics

Over the study period from 2010 through 2021, some cyclist characteristics have changed, while others have not. Data for this period is based on NHTSA [1,2]. Most older Americans ride purely as a form of exercise rather than as mobility *per se* [3]. Raw exposure information is derived from the National Household Travel Survey [4]. The fraction of cyclists killed who are male remains relatively flat at about 86%. Age however tells a different story. In Figure 2, the changing trend in the age of cyclists involved in crashes and the cyclists killed in crashes is presented. The first is based on a sampling of crashes in the US and the second a census of fatal crashes over the same period. Both show dramatic increases in average age. The relative risk of age as a factor in crash outcome is summarized in Figure 3 with a lowess model. When compared to a 20 year old, a 60 year old is 4.5 times more likely to be killed and an 80 year old is over 7 times more likely to be killed in the crash.

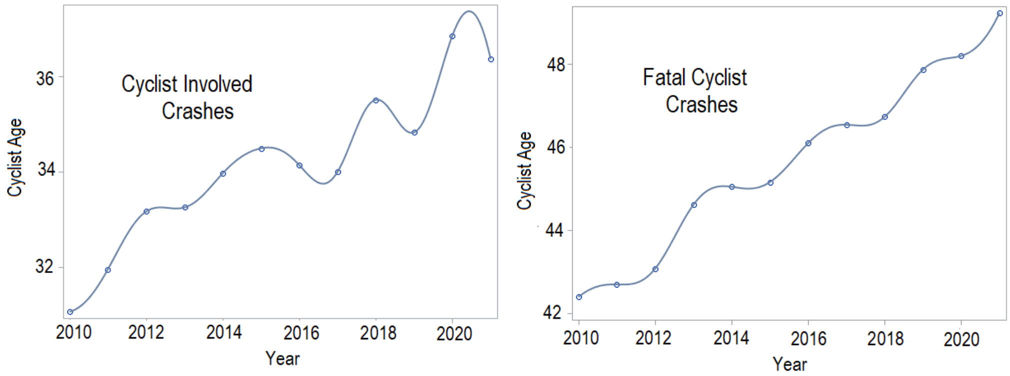


Figure 2 A comparison of the Average Age pf Cyclist Involved And Fatal Crashes Over Time

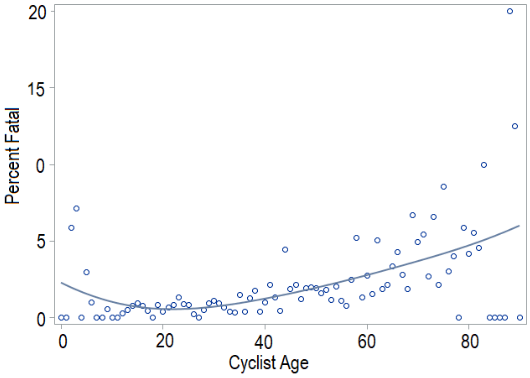


Figure 3 Relative Risk of Age as a Factor in Cyclist Fatality

Of course there are factors other than frailty in identifying the effects of aging. As one ages, balance is impaired as is vision and rapid cognitive processing in the judgement about the adequacy of gaps. These will increase the likelihood of older cyclists being involved in crashes. These will be incorporated into the work presented again using a relative risk approach.

3 CONCLUSIONS

It is tempting to think of cycling as an important mode for mobility. This is appropriate for a large part of the population. However, there have been large increases in mobility as a means of exercise. Unfortunately, this is more prevalent among older Americans than ever before. Older riders are more likely to turn to cycling, more likely to be involved in crashes, and once involved, more likely to die as a result of frailty. This research suggests that prior to embarking on cycling as an exercise regimen, that older Americans evaluate their fitness to the task. Programs implemented by trusted organizations that serve this community should develop testing and education campaigns can eliminate much of this tragedy.

REFERENCES

[1] United States. National Highway Traffic Safety Administration NHTSA. Fatal Accident Reporting System 2010 through 2021.

[2] United States. National Highway Traffic Safety Administration NHTSA. Generalized Estimates System 2010 through 2014 and Crash Report Sampling System 2015 through 2021.

[3] Carol Kachadoorian, dblTilde Collaborative. 50+ Cycling Survey for American Association of Retired Persons, 2020.

[4] United States. Federal Highway Administration. National Household Travel Survey 2009 and 2017.

Near-misses Involving Cyclists – A Neglected Problem?

L. Bhaskaran-Kenny, A.P. Morris, and L. Brown

Transport Safety Research Centre, Loughborough University, UK
email: a.p.morris@lboro.ac.uk

Keywords: Near-miss; time and location, driver attitudes, reporting

1 INTRODUCTION

The aim of this study was to highlight the types of near-miss events experienced by cyclists when out on public roads, and, to emphasise their importance for inclusion in the implementation of safety countermeasures. Near-miss events are relatively frequent on UK roads. The UK-led "Near Miss Project" found that nearly 4000 incidences of 'near-miss' events occurred on the roads during 2015, and the study also established that the experience of a 'near-miss' can adversely influence and determine the behaviour of cyclists - altering their cycling patterns, affecting their confidence and enjoyment of the activity (Aldred, 2015). A study of over 1000 regular cyclists also found that there was a statistically significant difference between genders. Despite covering a quarter of the distance of male cyclists in a given week (DfT, 2020), female cyclists experienced a higher rate of near misses per mile (0.42 and 0.24 respectively - Aldred, 2015). A study of over 400 cyclists in San Francisco, established that the fear and potential threat of injury attributed to road traffic presented a significant barrier to cycling acceptance in both a recreational/commuter capacity for potential and occasional cyclists (Sanders, 2015). This statistic further substantiates similar findings from the UK National Transport Survey, whereby 24% of respondents indicated that general road traffic was a barrier to cycling acceptance (DfT, 2020). Of the cyclists surveyed for Sander's study, 20% of respondents had experienced a physical collision and 86% had experienced some form of a 'near miss' event (Sanders, 2015). The common types of near-misses recorded in that study included almost being struck by the opening of a vehicle door, being almost struck by a vehicle whilst turning, and almost being struck by a vehicle merging with traffic (39%, 33% and 27% respectively). Both studies also explored deliberate acts of aggressive behaviour perpetrated by vehicle occupants. Aggressive behaviour included the sounding of horns, passing too closely, and tailgating as an act of punishment towards the cyclist. This behaviour tactic is pervasive; in a qualitative study carried out by Prato and Kaplan (2013), aggressive and confrontational behaviour between vehicle occupants and cyclists was a frequent occurrence on the road. The study found that motorists' perception of road user (cyclists) violations, combined with a lack of understanding or misinterpretation of the highway laws, acted as justification for their behaviour. The results also indicated that the absence of continuity of the cycling infrastructure in the area was a source of confusion, with vehicle occupants assuming that as there was infrastructure available, it should therefore preclude cyclists from utilising the highways. However, the infrastructure at the time was deemed insufficient for the travel patterns of cyclists due to the fragmentary way in which it was designed i.e., incomplete networks and "sporadic" cycling projects that were not fully integrated or implemented into the wider travel infrastructure.

2 METHODOLOGY

An online survey was conducted to ascertain the prevalence and types of cycling-related near-miss events experienced by the public. A total of 92 individuals volunteered to participate in the study. Of the 92 participants, 79 had experienced a near-miss event, of which, 87% had experienced one within the last 6 months. The sample group comprised 20% (n=16) females and 80% (n=63) males. Of the respondents, 8% were aged between 19-24, 19% were aged 25-34, 25% were aged 35-44, 30% were aged 45-54, 13% were aged 55-64 and 5% were aged over 65 years. The participants primarily engaged in the activity of cycling for leisure purposes (51%) and leisure/commuting purposes (47%). 92% of the sample group had knowledge of the UK Highway Code via the ownership of a UK driving license.

3 RESULTS

3.1 Safety Equipment Usage

Cycle helmets were the most popular type of safety equipment, with 89% of all participants stating that they used one. This was followed by visible or reflective clothing (81%) and then a substantial drop-off in bike light usage, with only 57% stating that they used bike lights. Usage of helmets and visible/reflective clothing was comparable between men and women (88% and 81% respectively), however, there was a difference in light usage, with 60% of men using lights compared to 44% of women. Most participants (94%) stated that they used at least one type of safety equipment 'all of the time', with only 5% stating that they would 'sometimes' use equipment and only one participant out of 79 stating that they would not use any.

3.2 Activity Engagement

51% of the participants stated that their primary cycling purpose was for leisure activities, followed by 47% who cycled for leisure and commuting purposes. Only 31 out of the 79 participants stated that their cycling was exclusively for commuting only. Most participants (59 of 79, 75%) cycled between Monday and Sunday, while only 15 (19%) cycled at weekends and 4 (5%) cycled only on weekdays.

3.3 Near Miss Events by Time of Occurrence

Approximately a quarter of participants reported that a near-miss had occurred in the last 7 days prior to them completing the survey. 52% of the participants had experienced a near miss within the last month, and for all incidents that occurred within the last 3 months, this increased to 70%.

3.4 Near Miss Events by Location

53 of the incidents (67%) took place in urban locations, with the remaining 26 incidents (33%) occurring in rural locations. Almost two-thirds of the participant cohort reported that their near-miss incident occurred on a straight road (63%), followed by 18% (n=14) that took place on a roundabout. 62% of the events that took place on a straight road occurred in urban environments, compared to 38% that occurred in rural locations. The urban/rural split for incidents that occurred at roundabouts was more heavily weighted to urban locations (71% and 29% respectively).

3.5 Near Miss Events by Environmental Conditions

Most near-miss incidents occurred in dry, sunny, or clear conditions (71 out of 79, 90%), with the remaining 10% occurring in wet conditions (6 in slight rain, 2 in rain). Grouping the weather conditions into two categories – Dry (i.e.: dry, sunny, or clear) and Wet (i.e.: Slight Rain or Rain), 88% of the incidents that occurred on a straight oad were in dry conditions, and all of the incidents at roundabouts occurred in dry conditions. Dry weather also accounted for most incidents that occurred at a T-Junction (90%).

3.6 Near Miss Events by Time of Day

Over half (57%) of all incidents occurred in daylight morning hours, followed by afternoon (19%) and daylight evening hours (19%). Four out of 79 incidents (5%) occurred in dark conditions. Grouping the Time of Day into two categories – Light (i.e., Morning (daylight), Afternoon and Evening (daylight)) and Dark (i.e., Evening (dark) and Morning (Dark)), 96% of the incidents that occurred on a straight road took place during daylight hours, and a similar proportion was also reported for Roundabout and T-Junction incidents (93% and 90% respectively). Of the five incidents that occurred at either a Pedestrian/Cycle Crossing, a Crossroad or a Side Turning, all of them took place during daylight hours.

3.7 Near Miss Events by Primary at Fault

70 of 79 incidents (89%) were caused because of vehicle driver error, and the most common road layout that these 70 events occurred on was a straight road. Only 4% of all incidents were stated as Cyclist errors. 90%

of the incidents that occurred on a straight road were caused by vehicle drivers. This proportion increased to 100% for roundabouts and decreased to 80% for T Junctions.

3.8 Near Miss Events by Event Description

The most frequently occurring reason given to describe the 79 near-miss events was ‘vehicle driver overtook took closely’ (this accounted for 35 out of 79 incidents, 44% of the total). This was followed by ‘vehicle driver did not give way’ (16 of 79, 20%); ‘vehicle driver did not see cyclist (9 of 79, 11%); and ‘vehicle driver did not signal when making a manoeuvre’ (6 of 79, 8%).

3.9 Event Descriptions by Road Layout

All 35 of the reported cases of ‘vehicle occupant overtook too closely’ occurred on Straight Roads. Of the 16 cases reported of ‘Vehicle occupant did not give way’, 50% occurred at a Roundabout and 38% occurred at a T-Junction (the remaining two incidents occurred at a crossroad). ‘Vehicle driver did not see cyclist’ was reported to have occurred nine times at four different road layouts (the highest spread of all road layouts in the survey) – five on a straight road; two on a roundabout; and one each at a T Junction and a Pedestrian/Cycle Crossing. Focusing on the 35 incidents that were ‘Vehicle driver overtook too closely’ (all of which occurred on straight roads), 97% took place during daylight hours and 91% took place in dry conditions. However, the distribution between urban and rural locations was more even (51% to 49% respectively).

3.10 Near Miss Incident Reporting

Only two out of 79 participants reported their incidents to the police (3%). The primary reason given for not reporting to the police was ‘It didn’t seem important at the time’, (23 incidents, 30%), followed by participants not being aware that near-miss incidents could be reported to the police (22 occurrences, 29%). 12 cases of non-reporting were due to the incident occurring too quickly (16%). Two participants were at fault, and another two had not captured the required details to make a report. 52 participants (66%) responded that they would consider reporting a near miss in the future, although this would be dependent on the severity of the event. 13 participants (16%) responded that they would report in the future, and another 13 participants stated that they would not consider reporting future near-misses.

4 CONCLUSIONS

Of the very small number of safety strategies that have been implemented, there is still a long way to go to change the behaviours and attitudes of vehicle drivers. This is especially pertinent for near misses that involve close passes, particularly on straight roads. Close passes accounted for 44% of all near-miss events in this study. Furthermore, other research suggests that near-misses are not only a common occurrence for cyclists, but they are also preventable had the other parties involved taken different actions. Under-reporting of near-miss events also poses a significant problem. Both systemic and social reform are required to change the narrative and attitude of cyclists in the future and reinforce the value and importance of reporting near-misses to relevant authorities. This study aims to highlight the prevalence of near-misses and support the argument that near-miss data should be analysed in conjunction with reported accidents to ascertain a true representation of the dangers faced by cyclists when out on public roads.

REFERENCES

[1] Aldred, R. and Crosweller, S., 2015. Investigating the rates and impacts of near misses and related incidents among UK cyclists. Journal of Transport & Health, [online] 2(3), pp.379-393.
[2] Department for Transport, Office for Zero Emission Vehicles, Office for Low Emission Vehicles and Shapps, G., 2020. £2 billion package to create new era for cycling and walking. [online] GOV.UK.
[3] Kaplan, S. and Prato, C., 2014. “Them or Us”: Perceptions, cognitions, emotions, and overt behaviour associated with cyclists and motorists sharing the road. International Journal of Sustainable Transportation, 10(3), pp.193-200.
[4] Sanders, R., 2015. Perceived traffic risk for cyclists: The impact of near miss and collision experiences. Accident Analysis & Prevention, 75, pp.26-34.

Essential safety elements concerning infrastructure of cycle paths; a risk based approach in cycling safety

G. J. Wijlhuizen[*], **E. de Kievit**[#],

[*]Department of Infrastructure and Traffic
SWOV Institute for Road Safety Research
Henri Faasdreef 312, 2492 JP, The Hague,
The Netherlands
email: gert.jan.wijlhuizen@swov.nl

[#]Knowledge Network for the Strategic Road Safety,
CROW
Horaplantsoen 18, 6717 LT, Ede,
The Netherlands
email: eric.dekievit@crow.nl

†

Keywords: Risk based approach, Safety performance indicators, cycling infrastructure, essential safety elements, evidence based.

1 INTRODUCTION

In 2022 in total 737 road deaths were registered in The Netherlands [1]. Most fatalities occurred among cyclists (39%; n=287). In 2021 about 5000 cyclists were seriously injured (MAIS3+) due to crashes. Among these about 80% are crashes without involvement of motorized traffic [2]. The number of cycling fatalities and serious injuries is increasing in the past years [1,2]. This requires more attention in order to reach the Dutch policy aims to reduce the number of road deaths and injuries with an ambition of zero casualties in 2050.

In 2018, the Dutch Ministry of Infrastructure and Water Management together with the boards of regional and local authorities launched the Strategic Road Safety Plan 2030. The Ministry established the Knowledge Network for the Strategic Road Safety[1], which is a cooperation between the Dutch knowledge center directed at infrastructure, traffic, and safety (CROW) and the Dutch institute for road safety research (SWOV).

One of the key elements in this initiative is the implementation of a ‘risk-based’ approach, which means that crash statistics are not the primary source for road safety policy, but indicators that provide information on hazards in road traffic: the risk-indicators, also known as road Safety Performance Indicators (SPIs) [3]. One of these SPIs is focused on improving the safety of infrastructure; including cycling infrastructure. The SPI for cycling infrastructure is defined as the proportion of cyclists that cycle on infrastructure that is qualified as sufficiently safe. As a first part of the operationalization of what is called ‘sufficiently safe’ cycling infrastructure, SWOV selected essential safety elements of a specific part of the cycling infrastructure, namely the cycle paths (not including intersections).

---

1. https://www.kennisnetwerkspv.nl/

2 ESSENTIAL SAFETY ELEMENTS OF CYCLE PATHS

The essential safety elements of cycle paths are defined as those elements for which evidence is available that they have impact of level of safety of the cycling infrastructure. SWOV conducted a review on international literature in order to identify those elements that appeared to have an impact on crash risk. Most of the literature was based on Dutch studies and reports.

From literature it appears that a large majority of cycling crashes resulting in serious injuries happen without involvement of motor vehicles [4,5]. They may collide with other cyclists, pedestrians or mopeds on the cycle paths, but also with infrastructure elements like obstacles on, or near the pavement [4,5]. Loosing balance and falling due to for instance swerving or strong breaking may also result in serious injuries [6]. It is estimated that in about 50% of these cycling crashes infrastructural factors play a role [4,5]. Amongst them, the following scenarios were reported, for instance slippery surface (29%), curbs (23%), unsafe shoulder (12%), fixed obstacles on the pavement (12%) and bumps, pits and clutter on the pavement (10%).

Following from these crash scenario's, two general design principles for sufficiently safe cycle paths are formulated (Figure 1). These cycle paths should:

1. enable cyclists to maintain their balance and be wide enough to enable cyclists to overtake or pass other cyclists;
2. be provided with forgiving shoulders.

In order to give substance to these design principles the following elements of cycle path infrastructure were identified from literature that appeared to have an evidence based safety impact; the essential safety elements 1a-d, 2a,b; Figure 1.

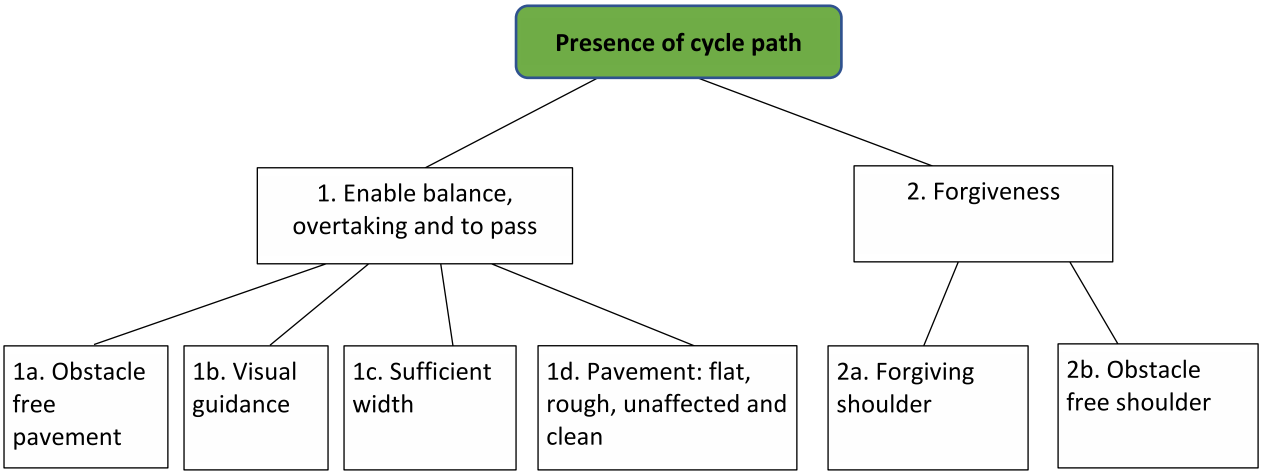


Figure 1: Design principles and essential safety elements for sufficiently safe cycle paths

1a Obstacle free pavement

Putting obstacles on the pavement of the cyclepath is generally seen as an unsafe element for cyclists [7,8]. Fixed obstacles on the pavement were involved in 12% of cycling crashes involving infrastructure elements [4,5].

1b Visual guidance

Safe passing of vehicles at high speeds requires high level of visual guidance. Especially older cyclists and people with visual limitations report a higher experienced safety when clear visual guidance is present [10]. In depth studies showed that at cycling crash locations visual guidance of the edge of the cycle path was deteriorated [9]. In an experimental study [10] it was found that steering behaviour of cyclists deteriorates as the visual guidance of edges of the cyclepath and obstacles is less clear.

1c. Sufficient width

The design of a cyclepath should accomodate safe overtaking and passing of cyclists. In a recent study [11], van Weelderen found an increased risk of cycling crashes on cycle paths with lower widths.
De Goede [12] found a reduction in serious traffic conflicts between cyclists as the width of a cyclepath increased.

1d. Pavement: flat, rough, unaffected and clean

In about 40% of all cycling crashes involving infrastructure elements [4,5] slippery surface or bumps, pits and clutter on the pavement were involved.

2a. Forgiving shoulder

In general, cyclists keep a distance of one meter to the curb if it concerns a substantial difference in level [13,14]. Nevertheless it appears that almost 25% of all cycling crashes involving infrastructure elements involves a crash with a curb [4,5]. This might be the result of for instance an evasive action of a cyclist requiring more space then is available. If the shoulder appears to have a level difference the cyclist will be brought out of balance and fall.

2b Obstacle free shoulder

In a recent study [11], van Weelderen found an increased risk of cycling crashes on cycle paths by increased number of obstacles per 100 meters in the shoulder of the cyclepath. The distance of the relevant obstacles to the edge of the cycle path surface was less than two meters.

The six essential infrastructure elements of safe cycle paths are formulated as follows:
A cycle path is qualified as sufficiently safe as each of the following essential elements are present:

1. The pavement is obstacle free;
2. Visual guidance is available;
3. The width of the cyclepath is according to the design guide cycling infrastructure 2016 [8];
4. The pavement of the cycle path is flat, rough, unaffected and clean;
5. The shoulder is forgiving (no vertical difference in level);
6. The shoulder is free of obstacles.

The level of safety of the cycle path is in accordance with the number of essential elements that are present per unit of length.

3 INTENDED USE OF ESSENTIAL SAFETY ELEMENTS

The intention is that for each cyclepath in The Netherlands the level of safety will be established based on the the number of essential elements that are present. These safety level scores will be an important indicator for setting priorities for improving the safety of cyclepaths.

The Knowledge Network for the Strategic Road Safety enhances the processes to obtain the required data and to monitor future improvements of the safety of cycle paths. The data that are obtained will be made available for all policymakers (central, regional and local) and other stakeholders by means of a national dashboard.

REFERENCES

[1] SWOV, *Verkeersdoden in Nederland.* SWOV-factsheet. SWOV, Den Haag, 2023.
[2] SWOV, *Serious road injuries in the Netherlands*. SWOV fact sheet. SWOV, The Hague, 2022.
[3] L.T. Aarts, *Prestatie-indicatoren voor verkeersveiligheid (SPI's); Overzicht van beschikbare kennis over SPI's als basis voor risicogestuurd beleid*; R-2018-19. SWOV, Den Haag 2018.
[4] CROW-Fietsberaad (2011). Grip op enkelvoudige ongevallen; Fietsberaadpublicatie 19a. Fietsberaad, Utrecht.
[5] Schepers (2013). A safer road environment for cyclists. Technische Universiteit Delft, Delft.
[6] Davidse, R.J., Duijvenvoorde, K. van, Boele, M.J., Doumen et al. (2014). Fietsongevallen van 50-plussers: Karakteristieken en ongevalsscenario's van enkelvoudige ongevallen en botsingen met overig langzaam verkeer; R-2014-3A. SWOV, Den Haag.
[7] CROW-Fietsberaad (2014). Keuzeschema sanering palen op fietspaden. Fietsberaad, Utrecht.
[8] CROW (2016). Ontwerpwijzer fietsverkeer. CROW, Ede.
[9] Schepers, P. & Brinker, B. den (2011). What do cyclists need to see to avoid single-bicycle crashes? Ergonomics, 54(4), 315.
[10] Fabriek, E., Waard, D. de & Schepers, P. (2012). Improving the visibility of bicycle infrastructure. International journal of human factors and ergonomics, 1(1), 98-115.
[11] G. van Weelderen, *Relations between the obstacle space of cycling infrastructure and bicycle crashes; An analysis of Amsterdam.* Master thesis Transport, Infrastructure and Logistics. TU Delft, 2020.
[12] Goede, M. de, Obdeijn, C. & Horst, A.R.A. van der (2013). Conflicten op fietspaden - fase 2. TNO, Soesterberg.
[13] Westerhuis, F. & Waard, D. de (2014b). Onderzoek naar het effect van ingrepen aan de rand van een fietspad op gedrag, zichtbaarheid & acceptatie. Rijksuniversiteit Groningen, Groningen.
[14] Janssen, B., Schepers, P., Farah, H. & Hagenzieker, M. (2018). Behaviour of cyclists and pedestrians near right angled, sloped and levelled kerb types: Do risks associated to height differences of kerbs weigh up against other factors? European Journal of Transport and Infrastructure Research, 18(4).

SWOV Institute for Road Safety Research
The Hague, November 2023