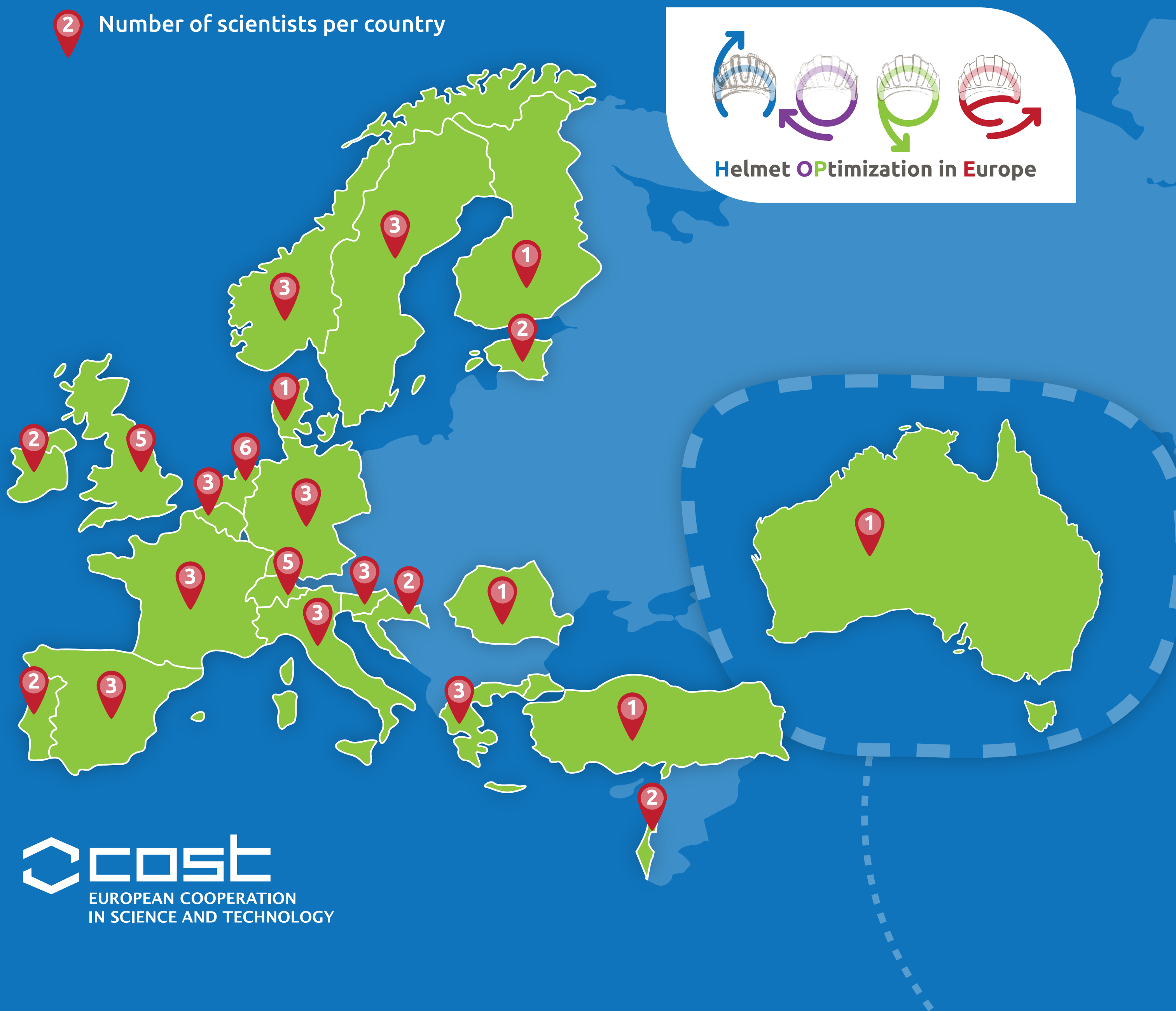
HOPE:

Helmet Optimization in Europe

Final Report of COST Action TU1101



EUROPEAN COOPERATION
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The final report of COST Action TU1101

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- www.bicycle-helmets.eu
- www.cost.eu/domains_actions/tud/Actions/TU1101

This report summarises the work carried out within COST Action TU1101 / HOPE. Additional details can be found in the extensive Working Group reports available from our website (www.bicycle-helmets.eu).

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During the course of our Action, one of our members - Antonietta Stendardo - passed away at far too young an age. We again express our deepest sympathy and condolences to her family, friends, and colleagues.

Contents

Summary

The primary purpose of COST Action TU1101 was to stimulate collaboration and networking amongst European scientists working in the field of bicycle helmet safety and improvement. By gathering together in a single, collective Action, researchers can improve the collection and dissemination of data from across Europe, thereby stimulating and accelerating knowledge.

The Action researchers, Helmet OPtimization in Europe (HOPE), divided into four distinct Working Groups, each addressing the issue from a different perspective, for a period of four years. HOPE explored the various aspects of helmets and wearer behaviour by way of:

- In-depth accident observations and injury statistics;
- Traffic psychology;
- Impact engineering; and
- Ergonomics of thermal effects.

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Although the COST Action's primary objective was to encourage cross-European cooperation, HOPE was also able to produce concrete, tangible results, which can already have an impact on regulations and helmet design and manufacturing. These results include:

- Establishment of a Europe-wide database for bicycle accident reporting;
- Development of an international survey on bicycling behaviours, accidents and use of helmets, with more than 8,000 responses to date;
- Proposal of a new bicycle helmet test method, which integrates more realistic impact conditions and pass/fail criteria;
- Specification of design and manufacturing improvements that can significantly reduce discomfort, and thereby increase helmet usage.

In addition, numerous scientific papers and presentations were produced, and – perhaps most importantly – HOPE members received invitations to continue the research in other studies and collaborations.

There is a clear interest in continuing the work started by HOPE, and in continuing to collect and disseminate data amongst researchers throughout Europe. The COST Action was a starting point that created – beyond the actual results – a strong network of experts that will remain active after the lifetime of this COST Action. The network will remain connected through the research projects that already have been granted, and new future projects, for which our members will always find the right experts amongst the members of the COST Action.

Introduction

Most people who regularly ride bicycles agree that wearing a helmet provides additional safety and protection. However, the average European cyclist rarely – or never – wears one. Where is the mismatch? How can manufacturers and legislators come together to increase traffic safety for cyclists? And what role will helmets play in this?

Cycling is not only a healthy and safe form of exercise, it is also a viable alternative form of transportation that reduces carbon emissions and relieves road congestion. As European countries endeavour to increase cycling as an accepted form of transport amongst its citizens, certain factors must be considered in order to optimise safety efforts even further. At present, cyclists represent about 6% of all fatalities (averaged over many western countries).

The bicycle helmet is one of the key pieces of equipment that can increase safety when cycling. However, significant social, psychological, cultural and biological deterrents prevent many cyclists from wearing helmets. Only when all of these deterrents are studied together, can true progress be made. After all, optimising helmets only for one factor – such as physical comfort – does not address the other factors that can so strongly impact a cyclists' decision to wear a helmet or not.

Furthermore, while the helmets currently available on the market are of good quality, they are certified using standards that were developed more than 30 years ago. Recent developments and understanding in biomechanics could be used to help helmet manufacturers further optimise helmet protective properties.

Another issue affecting the speed of progress in this area is the lack of systematic research on the topic, especially on a European level. There is currently no standard for reporting or collecting bicycle accident data, and no European-wide database into which this information can be collected. As scientists and experts in each country make progress in their own investigations, there is little opportunity to share their findings with the broader European community of scientists and researchers. As in many other research areas, the power of collaboration is undeniable: when researchers and scientists come together with a common goal, progress is swifter, scientific understanding is boosted, and results are more easily disseminated and put into practice.

A European Collaboration for Helmet Optimization

In order to facilitate this type of effective collaboration, COST established a unique Action that provided funding to stimulate the creation of an international network, rather than to reach specific research outcomes. COST Action TU1101 focused on improving collaboration amongst European researchers and bringing together the leading researchers in the field of helmet safety and comfort. Through a Europe-wide collaborative effort, the information gathered, discovered and shared can benefit every country equally, and become a stepping-stone for even further research and development, and legislative improvement. The results of the collaboration will not only impact both the helmet industry and current legislation: it will also accelerate development and lead to even safer cycling behaviour. The benefits of the Action, therefore, reach far beyond the parameters of the study – they can actually impact future work for a significant period of time to come.

To effectively execute the COST Action objectives, nearly 60 members, representing 21 countries, came together to create HOPE: Helmet OPtimization in Europe, an Action aimed at working together to address the key issues regarding helmet usage from all of the perspectives that play a role.

HOPE Objectives

As part of the COST Action, HOPE's primary objectives were to:

- Stimulate international collaboration in the field of bicycle traffic safety and helmets;
- Increase scientific knowledge with regards to traffic safety of cyclists;
- Disseminate this knowledge to key stakeholders, including manufacturers, legislators, the scientific community, and of course, the cyclists themselves.

In addition, HOPE aimed to achieve a number of secondary objectives, including:

- Producing state-of-the-art reviews, disseminating knowledge and identifying new areas for research regarding the wide variety of social, psychological, physical and cultural aspects of the decision to wear a helmet;
- Establishing a pan-European database of parameters regarding helmet usage and injury statistics;
- Developing knowledge about cyclist behaviour to enhance cyclists' conspicuity on the road;
- Investigating the protective properties of bicycle helmets in real accident situations in order to improve helmet testing standards;
- Stimulating new research collaborations, preferably on a European level;
- Disseminating information to the public, to the industry and to legislators, in an effort to maximise user comfort and adoption, influence safety and manufacturing standards, and ultimately benefit society.

Working Group Objectives

In order to optimise the efficacy of the 59 researchers that comprise HOPE, these expert scientists split into four Working Groups, each focussing on a specific critical factor related to cycling safety. Through regular meetings and communication, the Working Groups ensured not only their own progress, but also the progress of the Action in its entirety.

- Working Group 1: In-depth Accident Observations and Injury Statistics
  This Working Group focused on the development of a Europe-wide injury and helmet usage database, and the development of acceptance criteria for helmet usage.

- Working Group 2: Traffic Psychology
  This group studied the confounding psychological factors associated with a cyclists' choice of whether or not to wear a helmet, and the conspicuity criteria of helmets.

- Working Group 3: Impact Engineering
  This group reconstructed actual accidents in various countries, and consolidated biomechanical research results, in order to develop new standards for helmets and to improve helmet protection capabilities.

- Working Group 4: Ergonomics of Thermal Aspects of Helmet Usage
  Given that thermal discomfort is one of the primary reasons why cyclists do not wear helmets, this group explored thermal aspects in order to develop guidelines for the optimisation of helmet design for thermal comfort.

During the four-year Action, and certainly as results were collected, each of the four Working Groups made significant efforts to disseminate their findings to experts in the field. Through publications, presentations, meetings and additional research opportunities, HOPE is using the Action outputs to increase scientific knowledge and advance further research in the key areas identified during the Action.

Main Conclusions of the COST Action

HOPE has enabled an unprecedented level of international collaboration, as well as significant output that will help advance developments in the field of bicycle helmets. With the establishment of a Europe-wide database and suggested standards for accident reporting, researchers in various countries can be stimulated to continue collaborating in a way that benefits cyclists across Europe.

The inclusion of psychological and social aspects of helmet usage is crucial in the effective development of both helmet design and legislation. In order to increase and encourage helmet usage, these factors must be taken into consideration. After all, a helmet cannot be effective if it is not worn, and worn properly. The information and guidelines developed by HOPE will help address these issues in a concrete way.

Furthermore, the collection of published research, testing results and accident simulation has identified shortcomings in both current helmet design and test standards. The proposal of a new bicycle helmet test method, which integrates more realistic impact conditions and pass/fail criteria, will likely increase helmet efficacy and reduce the number of serious head injuries as the result of falls or collision with vehicles.

Lastly, the research conducted about thermal comfort resulted in improved techniques for addressing this ever-important factor in cyclist compliance. Through specific design and manufacturing improvements, thermal factors can be addressed in a way that significantly reduces discomfort and thereby increases helmet usage.

One of HOPE's interesting observations is that focussing on the same issues, explored from different perspectives, can produce different results. It therefore follows that, while most of HOPE's findings are comparable to and consistent with each other, there are some findings that seem to contradict each other at first sight, when viewed as a whole. This illustrates the need for further research and investigation to find the right balance, in which the different approaches are integrated even further.

Outlook for Future Development

Despite the wealth of new information and data that HOPE was able to collect and disseminate, perhaps the most crucial outcome for the Action was the bringing together of international experts in the spirit of collaborative thinking. In fact, the bonds formed during the Action were so powerful and beneficial, that many of the participants in the Action will continue their collaboration after the Action activities have been completed. Action members have submitted additional research project proposals, and have also been invited to join other research groups, based upon their work with HOPE.

In addition, further studies, presentations, publications and research opportunities have already been established or are underway. This is a clear indicator of the importance of the Action and the opportunities that HOPE has provided to increase collaborative effort and progress in the field.

Suggestions for Further Study

The strong scientific outcomes of the Action indicate that research funding is best optimised through this type of collaborative effort. While the Action's outputs provided answers to many key questions related to this topic, many additional questions arose as well. All of the specific aspects of helmet safety have not been addressed in full. However, this COST Action has certainly opened the door for more fruitful, effective and directed research that can benefit cyclists across Europe.

Each Working Group has provided a list of suggestions for further research and development, as a direct result of the Action's outputs. These research areas include, but are not limited to:

- Further investigation into the development of a system through which European cycling data and accident information can be more uniformly, accurately, comprehensively and effectively collected, shared and distributed;
- Research into improvements to helmet design and helmet usage standards, customised

for each type of bicycle and optimised against advanced brain injury criteria for typical impact conditions in real-world accidents;

- Studies of the psychological, demographic and sociological aspects that affect helmet usage, such as cyclist age, road types and cyclist perception;
- Exploration of how helmet usage can increase visibility, improve cyclists' visual search behaviour and impact city-sponsored bike lending programmes;
- Achievement of a consensus concerning a six-dimensional global head kinematics model for pass/fail criteria. While Working Group 3 believes that a model-based injury criteria shows the strongest potential, additional work is needed to harmonise different finite element models;
- The improvement of testing methodologies and simulation techniques for more accurate and effective evaluations of helmet efficacy;
- Additional studies of thermal properties and their effect on helmet usage, and the creation of modelling frameworks, simulators and testing standards that will improve the overall design and comfort of cycling helmets, and therefore increase usage and acceptance.

About COST

COST (European Cooperation in Science and Technology) is a pan-European intergovernmental framework. Its mission is to enable break-through scientific and technological developments leading to new concepts and products and thereby contribute to strengthening Europe's research and innovation capacities.

It allows researchers, engineers and scholars to jointly develop their own ideas and take new initiatives across all fields of science and technology, while promoting multi- and interdisciplinary approaches. COST aims at fostering a better integration of less research-intensive countries to the knowledge hubs of the European Research Area. The COST Association, an International not-for profit Association under Belgian Law, integrates all management, governing and administrative functions necessary for the operation of the framework. The COST Association has currently 36 Member Countries. www.cost.eu

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Working Group 1:
In-depth Accident Observations and Injury Statistics

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Additional details on the work carried out by Working Group 1 in their final report: Otte D, Jänsch M, Morandi A, Orsi C, Stendardo A, Bogerd CP, Tzamalouca G, Papadakaki M, Chliaoutakis J, Parkkari K, Dias J, Weber T. (2015). Final report of Working Group 1: In-depth accident observations and injury statistics. COST Action TU1101 / HOPE, Brussels, Belgium.

Introduction

According to the recent survey by Working Group 1, most bicyclists in Europe recognise the increased safety of wearing a helmet. However, they provide an extensive list of reasons why they still do not do so, including thermal discomfort. Working Group 2 found similar results in their survey.

In addition, the lack of sufficient and consistent data about cycling accidents in different European countries makes it difficult to pinpoint exactly how beneficial bicycle helmets are, or how effective they are in preventing serious injury. In an attempt to collect and expand Europe-wide research on this topic, and provide recommendations for further improvements, Working Group 1 examined injury data from 20 European countries, conducted accident research and performed field studies of cyclists' attitudes and behaviours regarding helmet usage. The primary goal was to offer advice and insight into improvements still yet to be made on a European level to make cycling even safer.

Starting with publications from the International Traffic Safety Data and Analysis Group (IRTAD), the Citizens Consular Assistance Regulation in Europe (CARE) and the European Road Safety Observatory (ERSO), Working Group 1 assembled as much data as was available. In particular, ERSO's annual statistics reports, DaCoTa, provided data up to and including 2010. The largest German In-depth Accident Study Report (GIDAS) was also analysed, as it provided information on helmet efficacy in regard to head injury. Further research and field studies were then conducted to provide insight and information that could propel helmet safety standards to higher levels, and encourage helmet usage among cyclists.

Working Group Focus

In relation to COST Action TU1101, the primary focus of Working Group 1 was to:

- Provide a report on Europe-wide bicyclist injuries in traffic accidents, with a focus on helmet usage;
- Conduct an in-depth analysis of head injuries, and the effectiveness of bicycle helmets in real accident situations;
- Examine the habits of cyclists in regard to helmet usage, with a particular focus on comfort, temperature and adjustments for climate;
- Identify the influences of seating geometry, posture and helmet position on bicycle safety.

Overall Result

The primary conclusion of this Working Group is that the full potential of bicycle helmets has not yet been fully exhausted. In fact, helmets could even provide additional benefits, when protection is extended further on the lateral side. This extension to helmet protection has shown to be useful in preventing or reducing severe head injury.

Working Group 1 is confident in its recommendation that increased usage of bicycle helmets can reduce the number and severity of head injuries. In addition, the Working Group recommends the optimisation of helmet design as a means of providing more head protection upon bicycle accident impact. Furthermore, additional design modifications, based upon real accident data, can help improve overall protection factors. While literature varies on the overall effectiveness of bicycle helmets, the inconsistent usage and lack of data mean that absolute conclusions cannot yet be drawn about the overall impact of bicycle helmets on safety.

In addition, Working Group 1's output indicates that design improvements and regulatory changes that focus on specific bicycle types (city bikes, racing bikes, mountain bike, e-bikes, etc.) can positively influence accident outcomes. Safety factors can also be increased when the helmet is properly positioned on the head, and when helmets are customised to fit the specific needs of different cyclists. Depending upon the type of bicycle used, the cyclists' upper body is in a more upright or forward-leaning position. If the cyclist adjusts the position of the helmet to accommodate these different positions, he can strongly improve his visual acuity. Improvements here can also contribute to an optimised helmet position in the event of impact with the road or a vehicle.

Implications for Industry

Helmet design can have a tremendous impact on the prevention of bicyclist injuries or the reduction of their severity. In particular, the optimisation of helmet design on the lateral part of the helmet, and modification of the helmet standards set forth in CEN EN 1078 guidelines can improve protection zone and impact conditions, based on data gathered from actual accidents.

Furthermore, both helmet design and usage guidelines should be adjusted according to the types of bicycles (city bikes, mountain bikes, racing bikes, touring bikes, e-bikes, etc.), and clarity about the best helmet position and cyclist posture can also have a positive affect on overall bicyclist safety. This can lead to improved helmet usage amongst cyclists with these specific types of bicycles.

Implications for Legislators

One of the key implications for legislators in regard to Working Group 1's investigations was the call for a more centralised, accurate and comprehensive reporting structure for bicycle-related accidents and injuries. Each country examined had different levels of reporting available (some none at all) and data was retrieved from a variety of sources. A more effective reporting structure for bicycle and helmet use, and the monitoring of data from hospitals, government and infrastructure, as well as the standardisation of injury severity measurements, would provide a better overall view of the European challenges and opportunities for cyclists. Moreover, statistical reliability and consistency could be greatly improved if police reports at the scene of bicycle accidents also included accurate injury data.

In addition, as the output of the investigation clearly indicates that the number and severity of head injuries are reduced by helmet usage, legislators should take this all-important factor into consideration in any discussion of helmet legislation.

Report on Europe-wide Bicyclist Injuries in Traffic Accidents, with a Focus on Helmet Usage

Although the amount and quality of bicycle-related accident data varies greatly per country, Working Group 1 was able to draw a number of important conclusions. Using DaCoTa Fact Sheets to assemble data up to and including 2012, it appears that cyclists represent about 5% of all fatalities in IRTAD countries, and the trend has been increasing since 2010. In the 20 EU countries covered by the data, bicycle fatalities made up about 6.8% of the total road accident fatalities reported.

In general, cyclist fatalities decreased between 2001 and 2010, but statistics vary greatly from country to country. For example, the fatality rate for cyclists in Ireland is about one per every one million inhabitants, while in the Netherlands, Romania and Hungary, about eight out of every one million inhabitants dies in a bicycle accident. In Denmark, an estimated 75% of cyclist fatalities occur in urban areas, while in Spain, only 26% of fatalities take place in urban settings. Obviously, exposure (time spent bicycling or distance covered by the bicycle) plays a key role in this. Working Group 2 quantified these factors for the first time for many countries.

The severity of non-fatal injuries is also difficult to pinpoint, as different countries have different definitions of what constitutes a 'slight' or 'severe' injury. In addition, the usage of helmets also varies greatly per country, with 3% of cyclists using them in Italy, as compared to more than 50% in Norway. The highest helmet usage rates can typically be found amongst children, as several countries have mandatory helmet usage laws in place for young bicyclists. However, other countries have stated that they do not intend to enact helmet mandates, because doing so might lead to a reduction in cycling activities.

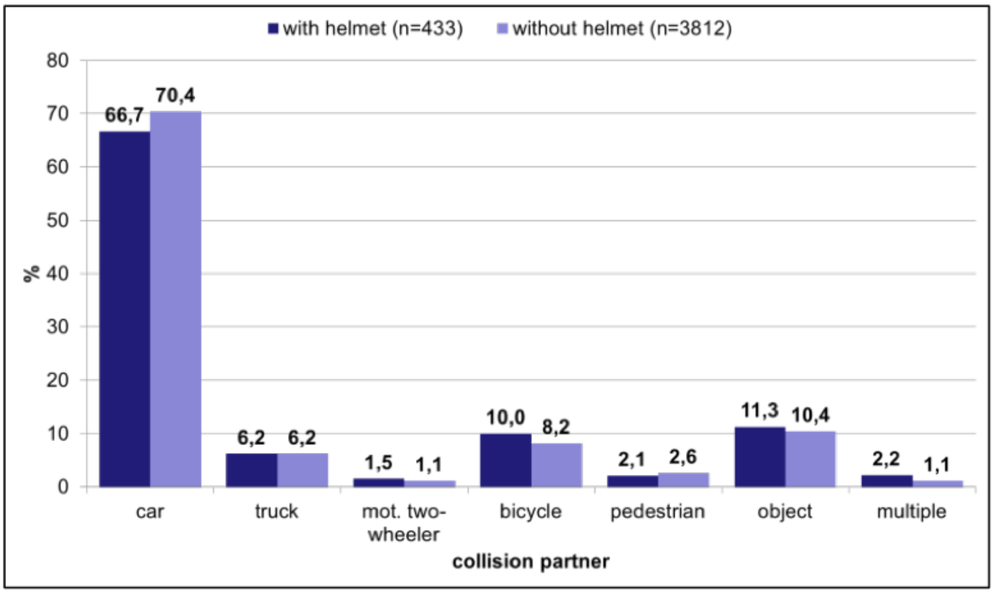
Bicycling and alcohol consumption

An in-depth study in Germany measured the effect that alcohol consumption can have on both the perception and outcome of bicycle accidents. Alcohol has been tied directly to both an increase in cyclists' fault for traffic accidents, and the decrease in helmet usage rates. Cyclists who had consumed alcohol were less likely to wear a helmet. Cyclists who were not deemed responsible for an accident were also less likely to have consumed alcohol than those who were held partially responsible for accidents. Overall, the greatest risk of head injury did not occur in collisions with other vehicles, but rather in accidents related to falls.

Accidents among e-bikers in Switzerland

Accident investigation of the users of electronic bicycles (e-bikes) in Switzerland shows that e-bikers who were involved in accidents tended to be older than most bicyclists involved in accidents. The investigation also indicates that e-bikers tended to be involved in accidents that did not involve collision with another vehicle. It was also concluded that both bicyclists and riders of e-bikes over the age of 40 are at a higher risks of sustaining severe injuries in an accident than bicyclists and e-bikers aged 39 and younger.

In-depth Analysis of Head Injuries, and the Effectiveness of Bicycle Helmets in Real Accident Situations



Percentage distribution of the collision partners of injured cyclists with and without helmet.

In Germany, a database of head injuries sustained in accidents, the German In-depth Accident Study (GIDAS), revealed that overall, helmet usage rates are increasing in Germany. However, the number of cyclists who currently wear a helmet is about 10% - still extremely low.

However, the GIDAS study also shows a strong tie between helmet usage and the reduction in both the frequency and severity of head injuries. Helmets provide a significant protection against skull fractures, severe brain injuries, and skull base fractures alike. About 40% of cyclists who did not wear a helmet suffered head injuries as the result of accidents. In 13% of those cases, the head was the only body part to be injured, and in 23% of cases, the head was the most severe of injuries sustained to multiple body parts.

Bicycle helmets can also be considered to be particularly effective for older adults, especially those over 50 years of age. In this age group, a significant increase in severe head injuries could be observed, attributed to the much lower biomechanical load limits for older persons.

Helmets and facial injuries

Since the lower parts of the face are not included as part of the helmet protection area of the head, the use of helmets had virtually no influence on facial fracture statistics. Scientific literature also does not indicate a reduction in facial injury through the use of helmets. However, the use of helmets did show protective effects for the upper and middle parts of the face, due to the protruding frontal part of the helmet structure. And of course, helmets are already very beneficial for protection of the head itself.

Optimisation of helmet design based on accident observations

Working Group 1's investigations showed that optimising helmet design, particularly on the sides and edges of the helmet, could have a positive effect on the reduction of severe injury. In terms of shock absorption, extending the protection zone currently identified in the existing standard CEN EN 1078 would be appropriate. Impacts on the side of the helmet appear to result in greater injury severity than impacts at the top of the helmet. Enlarging the protection zone and optimising helmet design would result in further optimisation of shock absorption capabilities and overall protection, both during impact with flat surfaces, and impact with edgy surfaces, such as collisions with the edgy parts of cars and trucks. However, extending the surface covered by a helmet may also increase (thermal) discomfort. Future efforts should continue the multidisciplinary approach initiated in the present network.

The Habits of Cyclists in Regard to Helmet Usage

To analyse helmet usage and practices in Europe, Working Group 1 developed a questionnaire to collect relevant information by means of a field study carried out from 2010 to 2014.

Despite some limitations and boundary conditions, the results of the survey did indicate that helmet usage varies, depending upon the country and the type of bicycle. Cyclists in Finland tend to wear helmets more often than in other countries, for example. And those who ride racing bikes are more likely to wear helmets than riders of other types of bikes.

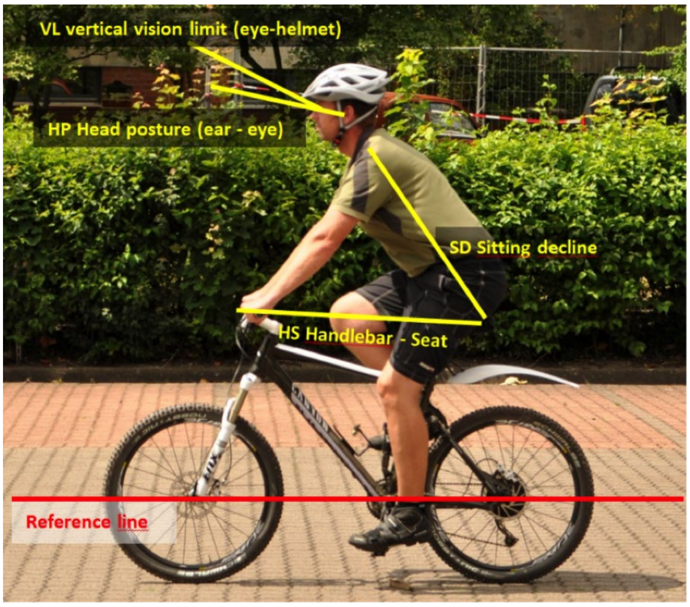
The survey also provided insight into cyclists' perceived safety. In general, those interviewed thought that riding a bicycle was more dangerous than walking or driving a car, whether cyclists wore a helmet or not.

Cyclists seem to be aware of the dangers of biking in general, and most believe that helmets increase cycling safety even more, and also increase the cyclists' overall feeling of safety. However, a litany of reasons was given for why bikers nevertheless choose not to wear them. From carelessness to short biking distances, from warm temperatures to inconvenience, bikers tend to go without protective headgear. Even a lack of a place to put the helmet when arriving at their destination was a reason given for not wearing one. Physical complaints like excessive sweating, headaches, or a narrow field of vision were also among the reasons.

Most remarkable from the survey was that 48% of the respondents indicated that they had been involved in a serious fall from a bike, and 26% reported a collision with a car while cycling. Collisions were rarely reported to the police, and primary impact zones were given as the sides and front of the head/helmet. In this way, the survey substantiates the conclusions drawn from earlier research, and supports the recommendation to modify helmet designs to further protect these impact areas.

The Influences of Seating Geometry, Posture and Helmet Position on Bicycle Safety

In another field study, Working Group 1 took pictures of bicyclists in all age ranges and bicycle types, in order to evaluate posture, head position and helmet position. From these pictures, different angles were identified in order to assess helmet position and body posture while cycling. The incline of the line between the handlebars and the seat can indicate the degree to which the handlebars are raised above the seat. Combining these measurements with an approximation of the cyclist's age provided data about posture and head positioning.



Establishment of angels relevant for seating geometry and vision limits

Of course, the type of bike had a major influence on handlebar positioning. Racing bikes often have handlebars that rest below the level of the seat, while mountain bikes and city bikes do not. Helmeted riders held their heads slightly lower than those who did not wear a helmet. The limitation of vision, mostly due to the helmets sun shade, varied from 0 degrees (horizontal line from the eye to the sun shade) to 75 degrees upwards. Age appeared to have no impact on posture or head positioning. However, older riders who wore helmets tended to wear them lower on their faces, which could possibly affect vertical vision limitations.

Further Research

Overall, the studies begun by Working Group 1 in some European countries could be carried out for all of Europe. The primary area in need of further investigation is in the development of a Europe-wide system through which European cycling data, accident information and data about helmet usage could be continuously collected. Such data can be more uniformly, accurately, comprehensively and effectively collected, shared and distributed. Only then can we analyse and interpret Europe-wide data in order to evaluate the true influence of helmets on increasing bicycle safety.

In addition, improvements to helmet design and helmet usage standards, customised for each type of bicycle, can increase helmet effectiveness and the likelihood that cyclists will actually wear protective headgear. Further research can support the need for improved protection zones and side-impact panels.

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Traffic Psychology

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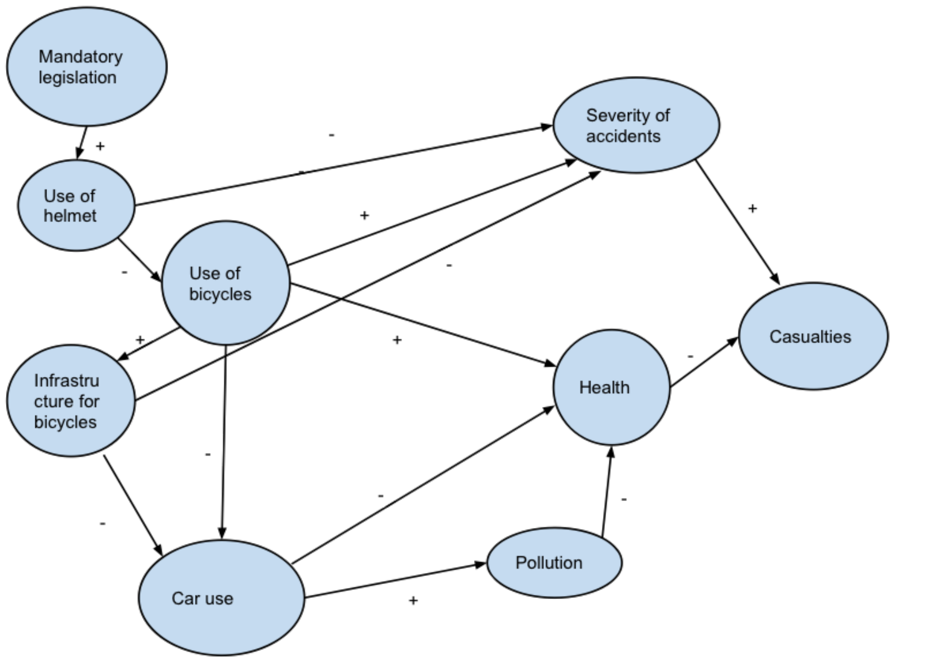
Additional details on the work carried out by Working Group 2 in their final report: Shinar D, Bogerd CP, Chliaoutakis J, Cavallo V, Crundall D, Dias J, Haworth N, Holt N, Houtenbos M, Kuklane K, Lajunen T, Morandi A, Oron-Gilad T, Orsi C, Papadakaki M, Parkkari K, Rus D, Saplioglu M, Tzamalouka G, Valero-Mora P, Walker I, Wardlow M, Weber T (2015). Final report of Working Group 2: Traffic psychology. COST Action TU1101 / HOPE, Brussels, Belgium.

Introduction

There are significant social, behavioural and perceptual aspects that play an important role in whether cyclists choose to wear helmets. The decision depends upon many factors – which could act as either barriers or facilitators – including cultural norms, the perceived level of danger or benefits, and social pressure for conformity. In addition, the types of bicycles, the cycling conditions, the age of the cyclists, and other biographical and contextual conditions play an important role.



One possible arrangement of variables influencing helmet use.

Working Group Focus

Working Group 2 had four primary objectives during the course of their investigations. First, to collect information about research related to the psychological aspects of helmet usage, and share it with those currently working in this field. For this, both existing research and the group's own investigations played key roles. Second, to develop recommendations for new research on, and evaluation of, the design of bicycle helmets. Third, to conduct an international survey of cycling exposure, cyclist riding habits and attitudes, and crash involvement. Fourth, to examine options for further networking and funding of such research within the individual frameworks of the participants, and also at the EU level.

The study also:

- Identified national and regional needs in terms of prevention and management;
- Produced up-to-date evidence on the current situation and assisted in prioritising road safety targets; and
- Guided national and local policy based on local needs.

Overall Result

In addition to discussion sessions and Scientific Research Meetings, as well as data collection and analysis, the Working Group formulated a major cooperative study to be jointly conducted in a variety of cultures and environments across most of the countries involved in this COST Action. Furthermore, the group developed research proposals to be submitted to funding organisations in both government and industry settings. The group also promoted research in this area among graduate students and PhD candidates, and cooperated with other researchers at other institutions.

The primary resulting output was a 17-country, 118-item survey of bicycle use, cyclist attitudes and crash experience, which was completed by more than 8,500 adult cyclists. In addition, Scientific Research Meetings and presentations were held to communicate the initial findings, and technical reports and scientific papers were published about bicycle safety and helmet usage. Working Group 2 also established a list of potential applications and implementations for the data that is being collected.

Implications for Industry

In addition to the long-term, positive implications of a standardised survey about cyclist psychology and its effect on helmet usage, the research conducted by Working Group 2 also has immediate implications for the industry. Most notably, the advice to improve cyclist visibility through the use of smart lighting systems that link helmet and bicycle lights in a pattern that is more noticeable than standard lighting systems.

The study, conducted by David Shinar, illustrates how the utilisation of the helmet-bicycle system and the well-known phi-phenomenon (of apparent movement) can be exploited for the enhancement of cyclist visibility in marginal conditions, such as dusk and dawn. The system uses alternating flashing lights (AFL) on the handlebars and the helmet, creating a vertical apparent movement effect. The results showed that the AFL system improved both cyclist conspicuity and visibility, especially at dusk.

Implications for Legislators

Working Group 2's investigations identified gaps in legislation at the country level. The results of the international survey provide relevant exposure data and can highlight norms and acceptability of various controls, needs for infrastructure and aspects of bicyclist culture. The survey and its results are therefore useful tools for the development of legislation and regulation, both on a European level and within individual countries.

International Survey of Bicycle Use, Attitudes and Safety, with an Emphasis on Helmet Use

Both Working Group 1 and Working Group 2 encountered similar challenges in the collection of existing Europe-wide data regarding cycling, helmet usage and accident information. Simply stated, a lack of a standardised reporting structure made comparisons between countries extremely difficult. After a comprehensive review of literature already available on this topic, Working Group 2 developed an international, multi-lingual survey to collect data across countries, cultures and demographic groups.

A standardised, web-based questionnaire was developed based on a previous Australian study and was distributed among participants in 17 countries: Australia, Belgium, Brazil, Croatia, Estonia, France, Germany, Greece, Italy, Israel, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and Turkey.

The survey comprised 118 questions related to 1) biographical data, 2) frequency and amount of cycling activity in different environments for different purposes, 3) frequency and circumstance for use and non-use of helmets, and the attitudes and reasons behind these decisions, and 4) crash involvement and level of reporting to the police.

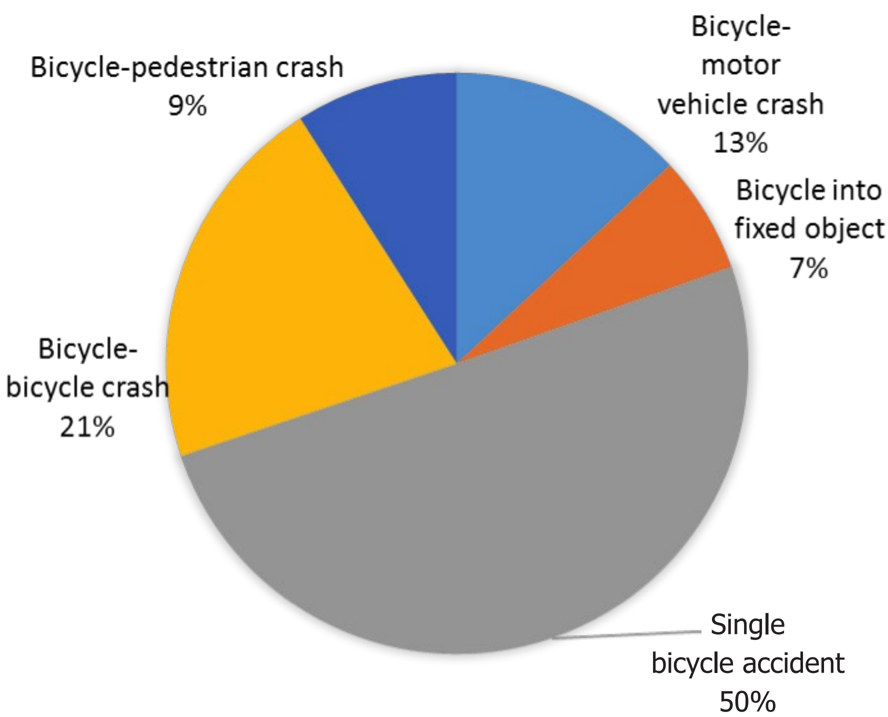
Preparation, publication and survey pilot

Beginning with a pilot survey in Israel, Working Group 2 collected data and used it to further refine the overall survey. In addition, two scientific papers were published, outlining the rationale, method and approach, and initial partial results of the international survey. This exposure brought the topic and issues surrounding bicycle helmet usage to the forefront, and helped disseminate knowledge, information and the current challenges in this field of study.

Initial survey results

Whilst the bulk of the insights and products of the survey will be published after the COST Action has been completed, some preliminary results are provided now. As was expected, the data gathered from survey participants in different countries reflected significant variations in cycling habits and use of helmets. Both the similarities and the differences are important for general and country-specific implications.

Preliminary results from the survey offer important insights. The median distance cycled per week ranged from 30 km in Israel to 150 km in Greece. The overall median distance among all participating countries was around 50 km per week. More than 40% of all cyclists commonly rode city/hybrid bikes, 20% rode mountain bikes, and 15% rode road bikes. More than 60% of respondents reported wearing a helmet 'always' or 'almost always', and nearly 30% report wearing them 'never' or 'almost never'. Thus, both use and non-use of helmets seem to be strong habits that transcend times, situations, and locations. Approximately 25% of all respondents reported having been involved in at least one crash in the past year, with the lowest frequency in the Netherlands (15%) and the highest in Australia (46%) and Spain (45%). Among the most severe crashes, 53% were single-person accidents involving a fall. Less than 10% of crashes were reported to police, and only 32% of cyclists involved in a crash with a motor vehicle reported their accident to authorities. Further analysis of the complete survey results will be conducted to determine the influence of demographics, bicycle types, and attitudes about bicycling and helmet usage. Correlations between these factors and crash data will then be drawn.



Distribution of bicycle crashes by type.

Scientific Research Meetings

In addition to the survey and literature investigation, three Scientific Research Meetings took place, to stimulate discussion and investigation into three core aspects of the issue of cycling and helmet safety. The first focused on critical literature review, especially of the limited-circulation grey literature, and aimed to identify methodological and statistical problems related to scientific literature on bicycle helmets.

The second Scientific Research Meeting explored helmet use and habit strength, and posed the question: 'A safe choice or a good habit?'. The meeting aimed to increase the understanding of the relationship between helmet usage and theoretical construct of habits. A scientific publication of the results of this meeting is expected.

The third Scientific Research Meeting examined the effects of a helmet on cognitive performance. It aimed to gather and analyse the results of a laboratory study that evaluated the effects of helmets on cognitive function. This investigation concluded that it is unlikely that wearing a helmet would have a measurable effect on cognitive performance. This meeting resulted in a publication in Applied Ergonomics.

Published and Presented Research Studies by Working Group 2 Members

As a primary objective of the Working Group was to collect and distribute information to those involved in the examination of the topic of cycling and helmet usage, it is noteworthy that Working Group 2 members have collaborated with other Action members, other colleagues and graduate students to produce and disseminate their own research. Working Group members and their colleagues have, in the course of the Action, published 12 refereed journal articles, given 26 presentations at conferences, and published 5 technical reports on the topic.

Further Research

The multi-national survey that collected exposure, bicycle use, crash involvement and attitude data is a fertile resource of identifying further research. These analyses, which will continue past the life of the COST project, are expected to be carried out by the principal investigators from each of the participating countries.

The data and information collected by Working Group 2 was merely the first step towards more in-depth and extensive research in the following key areas:

- The patterns of helmet usage among different users (children, adults and sports enthusiasts);
- The use of helmets in different environments, such as rural roads, urban streets and bike trails;
- Bicyclists' concerns regarding safety and convenience, and the perceived impact of helmets on comfort and convenience;
- The benefit of helmets for enhancing visibility, and how variations in design and colour affect visibility in the daytime, at night and at dusk;
- The role of helmets in the acceptance of city-wide, pick-up-and-drop-off bicycles;
- The impact of helmets on the visual search behaviour of cyclists.

Working Group 3: **Impact Engineering**

Members Working Group 3

Working Group leaders: Dr. Peter Halldin and Prof. Dr. Remy Willinger

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Additional details on the work carried out by Working Group 3 in their final report: Willinger R, Halldin P, Bogerd CP, Deck C, Fahlstedt M (2015). Final report of Working Group 3: Impact engineering. COST Action TU1101 / HOPE, Brussels, Belgium.

Introduction

One of the primary ways to improve bicycle helmet technology is through the review and revision of the standards under which those helmets are tested. Current helmet testing for impact properties is not based on real accident conditions. Testing methods include a linear shock absorption test, during which a helmet is dropped vertically onto a horizontal flat surface, as well as a kerbstone-shaped surface. However, actual accident reports indicate that angled impact is far more common, and results in more serious brain injury. Compared to linear shock absorption, the rotational movement of the neck and head that results in the angled impact can cause both concussion and more severe brain injury, such as subdural hematoma and diffuse axonal injury.

In order to create truly effective bicycle helmets that protect against the most common and severe types of head injury, new testing conditions and pass/fail criteria are essential. The resulting design improvements can, in turn, protect cyclists in both accidents due to falls, and collisions with other vehicles.

Working Group Focus

In relation to COST Action TU1101, the primary focus of Working Group 3 was to:

- Analyse the motion of the head (kinematics) at the moment of impact in real-world accident conditions;
- Explore helmet impact conditions in order to improve helmet testing;
- Review existing head injury criteria based on global kinetic parameters;
- Achieve progress in the field of Finite Element Model-based head injury criteria;
- Propose new pass/fail criteria for helmet testing;
- Present a new helmet test method and suggest areas for further research;

Overall Result

After thorough review of existing data, accident reports and testing data, Working Group 3 conducted real-world accident simulations, in which accident data was used to accurately reproduce actual reported accidents. In this way, the shortcomings of the current testing methods were exposed, thereby leading to the Working Group's recommendations for testing improvement. The recommended improvements have been realised within this COST Action, and the test apparatus exists. Initial tests clearly show that testing could be vastly improved by the inclusion of angled impact analysis and measurement of the rotational kinematics transferred through the helmet to the head. There is also a need to improve brain injury criteria in order to assess the head injury risk in a more realistic way.

The Working Group's own testing and biomechanics research also led to recommendations for a new bicycle helmet test method, including improved pass/fail testing criteria. These improvements could contribute to more advanced helmet design.

Implications for Industry

Working Group 3's primary output is the proposal of a new bicycle helmet test method, which considers tangential helmet impact and advanced head injury criteria. This progress will allow enhanced protection of bicyclist's heads.

The novel test method can be, and already is, considered to be current by the industry. New helmet design can now be evaluated under tangential head impact conditions. In this domain, no less than three helmet evaluation programmes have already be launched in Germany, France and Sweden.

With both improved testing and refined pass/fail criteria, helmets can be designed in a more effective way. This, in turn, can have a positive impact on the general perception of helmet efficacy, and thereby help improve helmet usage amongst cyclists. Most importantly, the improved helmet design can significantly reduce serious head injury in accidents.

Implications for Legislators

Working Group 3's output can aid in the improvement of both testing standards and helmet certification. In the near future, the proposal of new testing standards and pass/fail criteria should be discussed with the relevant standard bodies. In order to protect cyclists from serious head injury even better, the current industry standard is simply not enough. Helmet design, testing and certification must first be improved in order to protect against the most common – and often most devastating – types of injury. Standards like EN 1078 and EN 1080 are not enough to ensure that helmets are truly effective in preventing serious head injury in traffic accidents. Modifications to these standards can have a tremendous impact on cyclist safety and on injury prevention.

Bicycle Accident Reconstruction

Working Group 3's investigations began with a review of the typical impact situations for a bicyclist. This proved to be a complicated endeavour, as accidents can happen in a nearly infinite number of ways, under a multitude of different conditions, including – but not limited to – rate of travel, weather conditions, angle of impact, the involvement (or not) of other parties, and more. There is a limited amount of valid data available, but enough exists to make preliminary evaluations of accident conditions, based on the results of six recognised studies.

Reference	Study	Number of cases/simulations	Accident type	Speed (m/s)	Angle α (Degrees)	Surface
Verschueren 2009	Accident reconstruction	11	Single	7.7	40	Road
Verschueren 2009	Accident reconstruction	11	Car	6.0	50	Car
Bourdet et al. 2013	Accident reconstruction	24	Car	6,8	60	Car
Bourdet et al. 2012	MADYMO Paramtric study (5.5m/s)	612	Single	6.7	55	Road
Bourdet et al. 2012	MADYMO Paramtric study (11.0m/s)	612	Single	10.2	33	Road
Ricter et al. 2007	Real accident data (GIDAS)	4264	Car/Single	6.4	NA	Car or road

Impact speed and angle from detailed accident reconstruction studies.

The six studies evaluate accident reconstructions based on the GIDAS database, the French Accident Database, and the simulation programme MADYMO. Parameters such as accident type (single fall or collision with car), rate of speed, angle of impact and road surface type were included in the studies. In total, data from 5,534 accident reports were evaluated, and 46 accidents were reconstructed.

Although the 'most common' impact angle is still difficult to evaluate exactly, it is clear from the reconstructions that impact angles are usually far removed from the direct, 90-degree impact conditions under which helmets are currently tested. There remains a lack of additional, detailed accident reconstructions, which would provide a statistically based decision on the most common types of bicycle accidents. Based on existing data and literature review, Working Group 3 proposes to keep the shock absorption tests defined in EN 1078 and EN 1080, but to complement these with three angled (oblique) tests, using an impact angle of 45 degrees at a speed of 6.5 m/s.

New Helmet Impact Conditions

Current testing is shown to be deficient in three key areas. First, it does not include testing for impacts at an angle, although the majority of accident data indicates that angled impacts are common and cause significant injury. Second, testing does not currently account for realistic brain injury criteria, despite the fact that this is shown to have an effect on impact conditions. Third, data is available to analyse the impact location on the helmet after an actual accident. This data indicates that the testing line defined in EN 1078 is too high. Working Group 3, in conjunction with Working Group 1, therefore proposes to lower the test line, so that the helmet covers more of the head, whilst still creating a design that is attractive and accepted by the end consumer.

Working Group 3 proposes new test methods for improving testing in bicycle helmets from these three critical points of view. First, impact testing to accommodate the 45-degree-angle impact condition. Second, testing to account for the effect of a more realistic pass/fail criteria. The third testing improvement would be to lower the testing line for the impact location on the helmet.

Pass/Fail Criteria

Next, Working Group 3 has evaluated and analysed current pass/fail criteria for helmet testing, and discovered a number of antiquated or inadequate parameters for these tests. In an extensive evaluation, the Working Group has examined head injury criteria at a number of different levels. These include an evaluation of existing head injury criteria, as well as a review of specific head injury criteria based on:

- Translational acceleration;
- Rotational acceleration and velocity;
- Combined rotational and translational acceleration;
- Finite Element (FE) Head Model-based head injury criteria;

The group also introduced advanced head models, which enable the computation of axon strain at the time of impact. The simulation of 115 real-world head trauma incidents were used to define initial limits for model-specific based brain injury criteria, as well as post-processing tools for end-users. Finally, a coupled experimental versus numerical test method was defined.

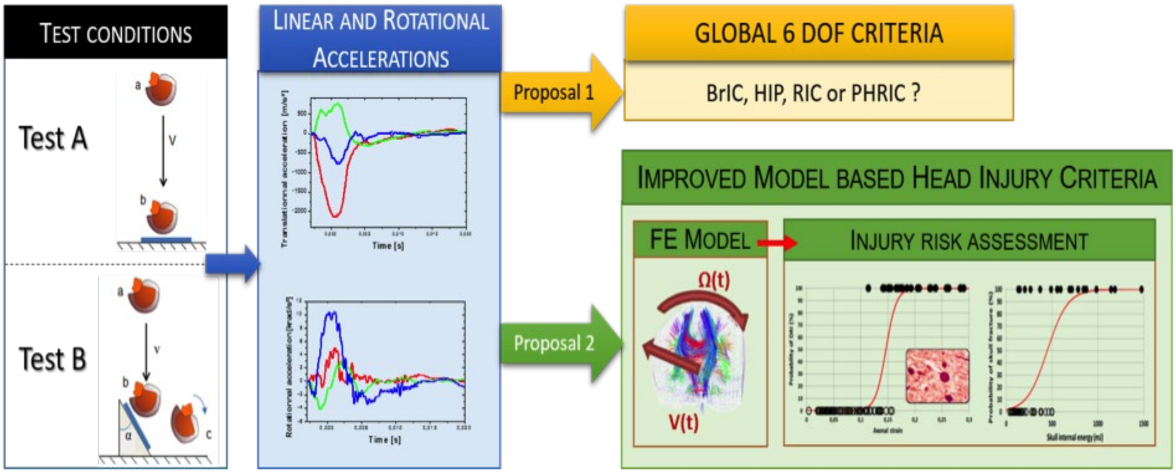

Illustration of the coupled experimental versus numerical head impact test method based on head FE modelling

After the evaluations were complete, the Working Group reached the conclusion that it is possible to use both global pass/fail criteria, such as BRIC, RIC, HIP or PrHIC, or to use the more advanced, model-based pass/fail criteria that were developed within the group. Both methods, however, do need further work in order to be tuned to a final pass/fail criteria used in a helmet test standard.

A New Helmet Test Method

As a result of this extensive investigation, Working Group 3 concludes by proposing an advanced, scientific helmet test method, based on real-world data and new biomechanical research results. The primary aspects of this new bicycle helmet test method are the introduction of tangential helmet impact and improved pass/fail criteria that can predict brain injuries, in addition to predicting skull fractures as it does today. It can easily lead to changes to the way helmets are certified and improve helmet efficacy in accidents. By adding real accident data and new biomechanical knowledge to the current regulation tests EN 1078 and EN 1080, the protective aspects of bicycle helmets can be vastly improved. Specific new testing parameters and methods, based on actual accident data and new biomechanical criteria, would bring the certification standards to a much higher, more effective level.

Further Research

Working Group 3 has been closely interacting with Working Group 11 of the CEN TC158, which is investigating the specifications for a new testing method. Certain details of that study provide ample opportunity for further study, such as the definition of calibration tests for HIII head forms and the spread and variation between helmets and different test labs. Research in the domain of brain injury criteria also need further efforts: first, to continue efforts to define injury criteria based on six-dimensional global head kinematic parameters. Second, for benchmark studies between different FE head models in order to achieve harmonisation of model-based injury criteria.

Further research in the field will also be organised within a variety of EU projects, including HEADS, MOTORIST, SmartHelmets, Safe2Wheelers, as well as national projects in Sweden, Germany and France.

Working Group 4: **Ergonomics of Thermal Aspects of Helmet Usage**

Members Working Group 4

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Additional details on the work carried out by Working Group 4 in their final report: Annaheim S, Aerts J-M, Bröde P, De Bruyne G, Flouris AD, Hursa Sajatovic A, Kuklane K, Martinez N, Sotto Mayor T, Bogerd CP (2015). Final report of Working Group 4: Ergonomics of thermal effects. COST Action TU1101 / HOPE, Brussels, Belgium.

Introduction

When it comes to thermal comfort, the head is one of the most sensitive body parts. According to studies, the head is responsible for up to 1/4 to 1/3 of total body heat loss in warm climates, although it makes up only 7-10% of the body's surface area. The head contributes most strongly to the perception of overall body comfort, especially in warm conditions.

One of the most common reasons bicyclists give for not wearing helmets is the discomfort and excessive heat that helmets create. A recent study among German helmet users indicated that 57% of them complained about excessive sweating – far more than impaired visual field (9%) or perceived head pressure (10%). Other factors certainly play an important role, such as design, convenience, vanity, social perception, cultural norms and fashion. Similar results were found in the survey conducted by Working Group 2.

The bottom line is, cyclists are not likely to wear a helmet that is uncomfortably warm. Dramatic improvements can be made in helmet design, based on scientific, state-of-the-art developments in thermal comfort. More comfortable helmets can potentially increase helmet use among bicyclists.

Working Group Focus

In relation to COST Action TU1101, the primary focus of Working Group 4 was to:

- Produce an overview of the scientific state of the art, including suggestions for future directions for thermal aspects of helmets;
- Create models and experimental simulations to help in Research and Development of more thermally comfortable bike helmet designs;
- Contribute to guidelines, directives and norms for both testing helmets and regulating their production;
- Investigate new materials and helmet forms to determine optimal design and minimal thermal discomfort;
- Test new helmet designs and their thermal properties;
- Establish project initiatives to improve thermal aspects of helmet design. Information & Communication Technology (ICT) also plays a role in this;
- Improve thermal comfort for cyclists who will eventually wear the helmets.

Overall Result

Through literature review, scientific modelling, experimental simulation and real-world testing, Working Group 4 has not only been able to establish a core set of guidelines and testing protocols, but has made the first steps towards viable solutions. In fact, two additional research projects have already engaged with researchers from this Working Group. The results have clear implications for both the design and creation of better, more comfortable headgear.

Implications for Industry

The results of Working Group 4's investigation have direct implications for the bicycle helmet manufacturing industry. The output offers ways to accurately and effectively monitor and model thermo-physiological responses. This, together with psychological considerations, can result in headgear that is better accepted by prospective users.

The two factors that have a strong impact on the thermal properties of helmets, and consequently on overall thermal comfort, are wind speed and body posture. Helmets must therefore be adjusted for the type of cycling activity. In addition, improved radiant shielding properties contribute to overall comfort, and several design improvements are offered to optimise this effect. These improvements also include the adjustment of inlet and outlet air vents, and the air channels that connect them, to further improve air convection capabilities.

Working Group 4's output shows that different methodologies, including computational modelling, can help in the development of new and effective helmet design, while experimental simulation can provide proof of concept and optimisation capabilities. Furthermore, the possibility of adding active cooling systems to helmet design were explored. Dynamic vents or active cooling systems that regulate heat loss can be controlled by models that predict thermal comfort at the head, so as to optimise thermal comfort in the design stages.

Implications for Legislators

Legislators can play a key role in both the establishment of industry standards and the increase in helmet-wearing compliance. A multitude of studies indicate that thermal comfort is a primary factor in whether or not bicyclists wear helmets. Therefore, the conclusions drawn by Working Group 4 that indicate ways to increase thermal comfort are key to overall compliance.

Furthermore, legislation that provides minimal design requirements regarding heat transfer in helmets, in addition to protective properties, will improve manufacturing and encourage usage. However, care must be taken to avoid over-regulating the designs, as this inhibits innovation.

Working Group 4's output provides methods for the evaluation and assessment of thermal properties – both ventilation and radiant shielding. With these new parameters, thermal property information can be made available to customers. This can assist in customers' evaluation of wearer comfort, and influence their buying decisions. Thermal properties will therefore become a direct priority for manufacturers, and they will maximise thermal comfort in future helmet designs.

Standardisation of Test Methods

Studies show that the current methods used by manufacturers to assess cooling capacity and thermal comfort include some parameters that are not relevant, and subjective feedback from wearers, which is not enough to effectively assess the effectiveness of different cooling methods.

Working Group 4 has therefore provided the initial ideas to begin developing a standard for assessing cooling effectiveness. These standards will allow for accurate and consistent testing of products, and will help make thermal comfort a direct priority for manufacturers. It will also allow manufacturers to clearly, objectively and accurately inform customers about the cooling effectiveness of various helmet types. This will help influence buying decisions.

In turn, standardisation of testing and modelling methodologies would allow legislators to regulate the production of helmets within the comfort-level boundaries necessary to encourage helmet usage among citizens. And, it will allow for comfort levels to be incorporated into legislation, along with safety standards.

Creating the modelling framework

Of course, many factors contribute to the perceived comfort of helmets. Parameters like outdoor temperature, exposure duration, level of activity, clothing characteristics and the helmet materials and thermal properties all impact thermal comfort. Taking all of these factors into account, Working Group 4 was able to develop a method for simulating, predicting and assessing thermal comfort in bicycle helmets. Further recommendations have been made to improve local head sweating models, the biophysical testing of a helmet's thermal properties, and of course, human trials on head perspiration. The results of similar tests are already being used to evaluate thermal comfort in other body regions, as well, and can have implications for clothing and equipment development.

Using the methods set forth from Working Group 4's output, helmet manufacturers can create accurate models to simulate, test and assess the comfort levels of various helmet designs, and more quickly and accurately achieve better results in achieving more comfort for helmet wearers.

Managing thermoregulation

The next development involved modelling that could accurately assess core body temperature in relation to metabolic activity and skin temperature, with the goal of real-time, overall body temperature management (thermoregulation). The results indicated that core body temperature could be accurately modelled, based on actual data, using either metabolic activity alone, or the combination of metabolic activity and skin temperature. These models, based on empirical data, can also be interpreted in a mechanistic way, and compared to a more sophisticated model, such as the 'Fiala thermal Physiology and Comfort' (FPC) model. Of course, overall core body temperature control is a key factor in dynamically predicting perceived comfort when wearing protective headgear.

Combining mathematics and manikins

For the first time ever, mathematical models of human physiology have been combined with a single body part manikin to establish a more accurate and complete evaluation of thermal comfort. In this way, comfort can be assessed under dynamic conditions, such as varying outdoor temperature, clothing and activity levels, and provide a coherent physiological control. This model performed well when predicting the overall physiological response under changing conditions.

The advanced thermal manikin headform at Empa.

Industrial Application: Testing Helmets on the Market

In a broad and multi-faceted investigation, a number of factors were addressed related to the reasons why bicyclists in Europe do not wish to wear a helmet. Chief among them were design, the problem of mussed or matted hair, the social perception of helmeted bicyclists, the lack of convenience involved in carrying and storing a helmet, the lack of thermal comfort, and increased heat/sweating. Although studies show that helmets do help keep cyclists warm in cold weather, the fact that helmets are not compatible with other clothing was a deterrent.

Working Group 4's investigation included an evaluation of bicycle helmets currently on the market. Several designs and helmet covers were tested for their ability to transfer and dissipate local heat accumulation. Using head manikins, a variety of testing scenarios resulted in data related to convective cooling (through proper air flow) and radiant shielding (protection from direct sunlight). The differences in convective heat loss were measured. The areas of the head most affected by radiant heat were determined, and the ways in which helmets can actually drastically increase heat loss were determined.

Innovative Design Solutions for Ventilation

To dig even more deeply into the possibilities, a group of design students developed various new and innovative helmet designs, attempting to surpass the thermal comfort capabilities of the helmets currently available. The designs were tested against factors like wind speed and the affect of hair on ventilation. In the end, the ability to customise helmets for specific user needs became the most effective solution.

The tested helmets with codes and authors' names.

Some of the helmets designed in this experiment performed better in practically any condition, as compared to helmets currently on the market. In more than half the cases, the new designs performed better than the best helmets currently on the market.

However, more research is necessary to put these results into full context. It proved difficult to find a single new design that performed well in multiple factors. The best helmet design for sweat evaporation was not the same as the best helmet design for insulation. This indicates that bicyclists' solutions must be defined by the user's bicycling activity, weather conditions, speed of travel, etc. In addition, at this point in the investigation, the protective factor of the various designs was not taken into consideration, and could affect final designs. However, there was a clear indication that the new designs developed during the investigation could significantly improve helmet ventilation, as compared to helmets currently on the market.

Further Research

Already, the research conducted by Working Group 4 has captured the attention of the industry. The results and findings were used as a catalyst for the involvement of members of the Working Group in two other key studies, namely:

- INTHEL.COM: A study aimed at improving the safety of electrical bicycles (e-bikes) through the development of an intelligent helmet system;
- SmartHELMET: A project that brings together academic partners and industry representatives to develop safer, smarter and more comfortable helmets, which will contribute to helmet acceptance and increased bicycle use.

Potential for further study

Based on available literature and Working Group 4's output, the areas with the greatest potential for further development in improving thermal properties of headgear include:

- Modelling of the head's sweat rates;
- The effect of hairstyle on forced convection;
- Development of active control systems for improved thermal comfort;
- A laminar system that creates an optically closed surface relative to the radiant source;
- More actively combining thermal knowledge to impact overall knowledge.

In addition, each individual facet of Working Group 4's investigation resulted in advice and proposals for further study and inquiry, including:

- Modelling framework: Improving and validating applied models;
- Managing thermoregulation: Managing thermoregulation in real time;
- Head simulators: Defining the physiological limitations and validating the coupled system in a wide range of exposures;
- Thermal properties of bicycle helmets: Improving global dry heat loss through better design;
- Design solutions for ventilation: Selecting the best of the innovative new solutions and continued impact testing, as well as model development.

Conclusion

The objectives of this COST Action were undoubtedly achieved. Nearly 60 researchers from 21 countries came together and shared knowledge, information and expertise in order to accelerate progress in effective helmet manufacturing and legislation. For perhaps the first time, the issue of bicycle helmets was addressed from an international perspective.

In addition to the tangible results that each Working Group was able to attain, HOPE researchers have also uncovered a variety of additional questions, conditions, theories and variables. These must all be explored further in order to obtain a clear, overall view of this topic from a European perspective.

In short, the topic of bicycle helmet manufacturing and usage is far from being exhausted. Only through further collaboration, investigation and discovery can true solutions be uncovered. And only through real cooperation amongst researchers can the various factors that influence helmet usage all be addressed simultaneously.

Safety is far from the only deciding factor as to whether or not a cyclist wears a helmet. Issues of comfort, culture, perception, convenience and quality must all be taken into account in order to find solutions that are acceptable to potential users. And it is only through further collaboration that those solutions can be found

Appendix 1: About HOPE

In order to continue to provide information and updates, and to ensure that the information gathered during this Action will remain accessible, HOPE will manage and maintain their website, bicycle-helmets.eu, for a period of ten years. This will ensure that access remains open and freely available to all interested parties.

More information about COST Action TU1101 is available on the COST website.

Appendix 2: All HOPE Members

Action Chair: Dr. CP (Niels) Bogerd

Title(s)	First	Last	Affiliation	Country
Prof. Dr.	Jean-Marie	Aerts	Katholieke Universiteit Leuven	BE
Ms.	Helena	Aljaste	Estonian Academy of Arts	EE
Dr.	Simon	Annaheim	Empa	CH
Ms.	Inger M	Bernhoft	Technical University of Denmark	DK
Dr.	Cornelis P.	Bogerd	TNO	NL
Mr.	Peter	Bröde	Leibniz Research Centre for Working Environment and Human Factors (IfADo)	DE
Dr.	Viola	Cavallo	Ifsttar-LPC	FR
Prof. Dr.	David	Crundall	Nottingham Trent University	UK
Dr.	Guido	De Bruyne	Lazer Sports	BE
Dr.	Maartje	de Goede	TNO	NL
Ms.	Stefanie	de Hair-Buijssen	TNO	NL
Dr.	Caroline	Deck	Université de Strasbourg	FR
Dr.	Metoda	Dodič Fikfak	University Medical Centre	SI
Dr.	Nenad	Drvar	Topomatika	HR
Prof. Dr.	Joannes	El. Chliaoutakis	Technological Educational Institute of Crete	GR
Prof. Dr.	Andreas	Flouris	Centre for Research and Technology Thessaly	GR
Dr.	Aslak	Fyhri	Institute for Transport Economics (TOI)	NO
Prof. Dr.	Michael	Gilchrist	University College Dublin	IE

Title(s)	First	Last	Affiliation	Country
Dr.	Thierry	Goger	COST Office	BE
Dr.	Charles	Goldenbeld	SWOV	NL
Dr.	Peter	Halldin	MIPS	SE
Prof. Dr.	Narelle	Haworth	Queensland University of Technology	AU
	Sixten	Heidmets	Estonian Academy of Arts	EE
Dr.	Nigel	Holt	Aberystwyth University	UK
Dr.	Maura	Houtenbos	SWOV	NL
Dr.	Anica	Hursa Sajatovic	University of Zagrab	HR
Prof. Dr.	Svein	Kleiven	KTH Royal Institute of Technology	SE
Dr.	Kalev	Kuklane	Lund Univeristy	SE
Dr.	Timo	Lajunen		NO
Ms.	Natividad	Martinez	Empa	CH
Dr.	Tiago Sotto	Mayor	Empa	PT
Prof. Dr.	Igor	Mekjavic	Institute Jozef Stefan	SI
Prof. Dr.	Nigel J	Mills	University of Birmingham	UK
Prof. Dr.	Gabriel	Molina	University of Valencia	ES
Dr.	Anna	Morandi	University of Pavia	IT
Prof. Dr.	Stephan	Odenwald	Chemnitz University of Technology	DE
Dr.	Tal	Oron-Gilad	Ben-Gurion University of the Negev	IL
Dr.	Chiara	Orsi	University of Pavia	IT
Prof.	Dietmar	Otte	Medical University Hannover	DE
Dr.	Maria	Papadakaki	Technological Educational Institute of Crete	GR
Mr.	Kalle	Parkkar	Finnish Motor Insurers' Centre	FI
Prof. Dr.	Joao M	Pereira Dias	Technical University of Lisbon	PT
Ms.	Sasa	Pisot	University of Primorska	SI
Ms.	Raquel	Puchades	Facthum.lab-INTRAS/ University of Valencia	ES
Dr.	René	Rossi	Empa	CH
Prof. Dr.	Torbjorn	Rundmo		NO

Title(s)	First	Last	Affiliation	Country
Ms.	Dianna	Rus	Cluj School of Public Health	RO
Prof. Dr.	Kai-Uwe	Schmitt	AGU Zürich	CH
Prof. Dr.	David	Shinar	Ben Gurion University of the Negev	IL
Ms.	Antonietta	Stendardo	University of Pavia	IT
Mr.	Than	Thinh	University College Dublin	IE
Ms.	Anita	Tontsch	INTRAS / University of Valencia	ES
Dr.	Georgia	Tzamalouka	Technological Educational Institute of Athens	GR
Prof. Dr.	Pedro	Valero Mora	University of Valencia	ES
Mr.	Lex	Van Rooij	TNO	NL
Dr.	Ian	Walker	University of Bath	UK
Mr.	Malcolm	Wardlaw	Transport and Health Study group	GB
Mr.	Toni	Weber	AGU Zürich	CH
Prof. Dr.	Remy	Willinger	Université de Strasbourg	FR
Mr.	Ceri	Woolsgrove	European Cyclist's Federation	BE
Dr.	Meltem	Saplioglu	Suleyman Demirel University	TR