COURSE HOLDING BY CYCLISTS AND MOPED RIDERS

(Revised version)

Article Applied Ergonomics 11 (1980) 4 (December): 227-235

R-80-46

J. Godthelp,
Institute for Perception TNO, Soesterberg
P.I.J. Wouters,
Institute for Road Safety Research SWOV, Voorburg

Voorburg, 1980
Institute for Road Safety Research SWOV, The Netherlands

CONTENTS

SUMMARY

Course holding by cyclists and moped riders includes both steering alongside a course and stabilising the vehicle. Inability to hold course may lead to conflicts with other road users. To design safe bicycle and moped facilities and to consider the safety of those existing, knowledge about performance during course holding is necessary.

Based on a literature survey the article discusses how course holding will be influenced by characteristics of the course, the vehicle and the rider. Effects of disturbing factors such as side-wind and road-surface unevenness are also described.

In a field study subjects carried out riding tests with various models of bicycles and mopeds on three courses. Speed, riding with one hand on the handlebars, side-wind and road-surface unevenness were included as independent variables.

Results indicate that cyclists and moped riders need a width of at least 1 metre on straight roads. At intersections this width should be at least 1.25 metre. Performance in the tests also showed differences between vehicle models and modes of riding.

1. INTRODUCTION

About one third of all traffic fatalities in The Netherlands concerns cyclists or moped riders (CBS, 1978). Half of these fatalities is related to collisions with cars (Blokpoel, 1978). This type of traffic hazard can be prevented either by segregating the categories of road users or by integrating these categories by means of right-of-way and speed regulations.
In order to design safe bicycle and moped facilities and to be able to consider the safety of conventional facilities, it is necessary to gather knowledge about the "performance" - for example in terms of the required lane width - one may expect of two-wheeler riders. The question arises whether this performance is influenced by characteristics of the course, the vehicle, the rider and by disturbing factors.

1.1. Course

The course to be followed is determined by the geometry of the road and the presence of other road users and/or obstacles. There are a number of basic forms:
a. straight course;
b. curve with a fixed radius and fixed orientation (direction);
c. curve with varying radii and/or changing orientation;
d. the transition from straight to curved and vice versa.
Courses as in a. and b. occur on straight and curved road sections. Courses as in c. occur when manoeuvring in urban traffic and in bends aimed at making riders slow down and those in d. when turning off at intersections and in obstacle avoidance and overtaking.

1.2. Vehicle

Straight and slightly curved courses do require stable vehicle behaviour. However, more abrupt changes also make demands on the manoeuvrability of the vehicle.
Stability of bicycles and mopeds as such depends on speed and on

vehicle characteristics such as mechanical trail, moments of inertia around front wheel and steering axis, centre of gravity of frame/ rear wheel section and others. Specific modes of motion of single-track vehicles are: the "capsize", the "weave" and the "wobble" mode (Sharp, 1971; Weir, 1972; Roland, 1974). The "capsize" and "weave" modes refer, respectively, to a non-oscillatory and an oscillatory motion of the entire vehicle. The "wobble" mode refers to the mode that is predominantly characterised by an oscillatory motion of the front frame assembly somewhat akin to wheel shimmy in automobiles and aircraft. Manoeuvrability is greatly governed by the same factors as stability. Therefore, stability cannot simply be increased, as this might detract from manoeuvrability. Stability and manoeuvrability of the two-wheeler/rider combination will also be influenced by the rider. On the one hand rider's position and posture will influence the mass distribution, of which the effect will depend on the ratio between the weights of the rider and of the vehicle. Ergonomic characteristics of bicycles and mopeds will also play a role. Rider's posture (bent forward or more upright), for instance, will influence his possibilities for steering and stabilising. Arnberg & Tydén (1974) and Mortimer et al. (1976) state that the height and configuration of the handlebars - and hence the rider's posture - can greatly effect manoeuvrability.

1.3. Rider

The rider's task involves both steering and stabilising. These activities together are called "course holding". The rider's actions comprise both moments applied to the handlebars and movements of the upper part of the body.

Steering concerns the course. Speed and course together determine the frequencies of the actions required for steering.

For stabilisation, the rider's actions are related to the two-wheeler's specific motions. Natural frequencies of these motions should be above the frequency range of the rider's response (i.e. > 1 Hz), for in this case fewer stabilising actions are needed. With low speed the natural frequency of the weave motion may come

within the rider's frequency range. Stabilisation may cost a great deal of effort in this situation. Design characteristics that "damp" this instability thus have a favourable effect on course holding.
A consequence of instability is the typical balancing motion of bicycles and mopeds: swinging around a specific trajectory (e.g.: Van Lunteren & Stassen (1970); Weir (1972); Eaton (1973) and Roland (1974)).
Little is known about the influence of age and riding experience on cyclists' and moped riders' riding behaviour. Arnberg et al. (1978) deal with these aspects for cyclists aged from 5 to 14 years. Riding tests, comparable in design with those discussed under "Experiment" below, did show strong age effects. In particular, young cyclists under 8 years appeared to have limited skills in realistic traffic situations.

1.4. Disturbing factors

Course holding by cyclists and moped riders may be affected by disturbing factors.
In right hand traffic a rider turning left at an intersection has to look backward to see the traffic situation. This may cause course deviations or poorer assessment of the situation behind him. Arnberg & Tydén (1974) indicated that performance in this task depends on bicycle model. Furthermore, Dewar (1978) showed that glancing behind is often omitted.
Riding with one hand on the handlebars will occur when indicating direction with hand signals and when carrying hand-held luggage. Direction indication is frequently neglected, in up to about 65% of the cases (Herwig, 1969a) and the instability of the two-wheeler appeared to be one of the reasons (Herwig, 1969b).
The carriage of luggage and/or passengers affects vehicle mass distribution and thus the characteristics of the weave motion (Sharp, 1971). A retrospective study of traffic collisions involving child cyclists (Brezina & Kramer, 1970) showed that in 20% of these collisions the cyclist was carrying a passenger or some hand-held load.

Poor visibility ahead, for example in case of fog or darkness, limits the preview distance and thus may interfere with steering. Cutting off the peripheral visual field, for instance while two-wheelers are overtaken by heavy lorries at close distance or while riding past walls, will affect stabilisation.
Air displacements caused by lorries and wind disturbances may strongly influence course holding. Location of buildings and trees will be important with respect to this point.
Lastly, the effect of road-surface unevenness should be mentioned. Longitudinal grooves will influence front-wheel motions (Blaauw & Godthelp, 1978). Different types of unevenness such as rails, joins in tiled paths, bumps etc. will be detrimental with regard to course holding.

2. EXPERIMENT

The purpose of the experiment was to evaluate a number of aspects which are relevant to course holding. To this end, subjects did riding tests with single-track vehicles of different designs at a number of speeds and with or without disturbing factors.
In the tests subjects had to follow three courses. Performance on the courses was evaluated.

2.1. Method

2.1.1. Riding tests

The tests were arranged so that the influence of stability and manoeuvrability characteristics of bicycles and mopeds on course holding could be examined. Both "normal" and "extreme" conditions were considered.

Test 1: Course holding on a straight path
The purpose of this test was primarily to analyse the influence of vehicle stability on course holding.
The track (See Figure 1a for layout) consisted of a straight road with a pathwidth of 0.15 metre, marked by lines.
Subjects were asked to ride the track as fast as possible (from A to B), leisurely (also from A to B), and as slowly as possible (from C to D), with either one or two hands on the handlebars, and with or without side-wind disturbances (See Figure 2) and/or road-surface unevennesses. The side-wind disturbances had characteristics whose nature was comparable with the air displacements caused by lorries.
In all cases the maximum course deviation was determined. At the two highest speeds, performance was also measured as the percentage of time ridden outside the prescribed 0.15 metre path. In riding slowly, the total track time and the consequent speed are also to be considered as criteria.

Test 2: Course holding in a curve

Here, both vehicle stability and manoeuvrability are important for course holding.

The track (See Figure 1b for layout) consisted of a sloping road section immediately followed by a sharp left turn which was marked with two lines 0.15 metre apart. The subjects had to cover the track as fast as possible or leisurely, with one or both hands on the handlebars. Riding down the slope increases the speed, which makes the bend more difficult to take. This "critical" situation may occur in practice on inclines from bridges etc. The criteria of performance in this test were time ridden outside the markings and the maximum course deviation.

Test 3: Manoeuvring

In this test, the manoeuvrability of the bicycle mainly governs the ability to carry out the manoeuvres.

The track (See Figure 1c for layout) was indicated by pylons to be passed on the right and left alternately. They were located so that the course consisted of sharp curves with a variety of radii and varying bend orientation.

The subjects were asked to cover the circuit as quickly as possible, with either one or both hands on the handlebars.

The criterion was the time needed to cover the distance between pylons 2 to 4.

2.1.2. Vehicles

Three experiments were carried out, each considering performance with a particular type of two-wheeler.

Experiment I: The instrumented bicycle

For the first experiment, a standard men's bicycle was converted into an instrumented bicycle. Four relevant vehicle characteristics could be varied on this bicycle. They are related both to design characteristics (mechanical trail, moment of inertia of front wheel around its wheel-axis and its steering head axis) and the rider's position and posture (distance between saddle and handlebars). Mechanical trail could be adjusted by way of a special construction on the front-wheel fork. Moments of inertia were varied with additional weights on the front-wheel and steering axis respectively. Saddle position could be adjusted alongside a slide mounted on the original saddle pin. Two values of each characteristic were considered (see Table 1), so that a total of 16 configurations of the bicycle could be tested, differing only in the respective characteristics. A wide range of existing single-track vehicles was thus covered.

Experiment II: Popular bicycles

In the second experiment a comparison was made between performance with the instrumented bicycle and four popular bicycles.
Based on the results of the first experiment, the following four models were selected (See Figure 3A):

a. folding small wheeler; sitting position normal;
b. standard men's bicycle with high handlebars; position upright;
c. racing bicycle; bent over position;
d. standard ladies' bicycle; position normal.

In design, model a. differs substantially from model d.; the sitting position is about the same. Models b. and c. are characterised by extreme positions.

Experiment III: Popular mopeds

In the third experiment, the tests were made with mopeds, in order to make a comparison between bicycles and mopeds. Moreover this experiment should give insight in the differences between mopeds.
Four popular mopeds were selected (See Figure 3B):

a. light moped; engine on front wheel; position normal;
b. heavier moped with high handlebars; position upright;
c. light moped; engine between wheels; position normal;
d. heavy moped; motorcycle model; position more bent over.

The distance between the pylons proved too short for mopeds in test 3. The track was therefore lengthened from 11.1 to 13.5 metres.

2.1.3. Subjects

The tests in each experiment were carried out by four subjects. The composition of the group differed per experiment. All subjects were aged 16. The choice of this age was based on accident and user statistics. Around this age most fatal accidents occur in absolute terms among cyclists and moped riders. Moreover, bicycle and moped usage is very high at this age.

2.1.4. Procedure

The subjects were instructed beforehand about the test conditions: speed, course, disturbance, one or both hands on the handlebars. Moreover, every subject did three training runs to become familiar with the test conditions.

In Experiment I the 16 configurations of the instrumented bicycle were ridden in each test as described under "Riding tests" above. Each subject rode once on each configuration for every condition. The order in which configurations were ridden varied with the test conditions.
In Experiments II and III only a part of the test conditions was carried out. Test conditions were selected on the basis of the experience gained in Experiment I; see Table 2.
In Experiments II and III each condition was ridden three times per subject on a given bicycle/moped. In Experiment II all tests were done with one and with both hands on the handlebars. In Experiment III it proved necessary to omit runs with one hand in "course holding on a straight path" and "manoeuvring" because of the specific conditions and/or the required speed control.

All runs were recorded on video tapes which were afterwards analysed. The camera positions in the tests are shown in the appropriate figures. As fas as the nature of the results permitted, the significance of the differences between conditions was tested with analysis of variance and supplementary Newman-Keuls' tests. The differences in composition of the groups of subjects permitted only a limited assessment of differences in performance as between experiments.

2.2. Results

The results of the individual tests are given below. For the various two-wheeler types an overall picture is given regarding the performance in a given test, especially in terms of course deviations and - where relevant - the results are focused on differences between two-wheeler types and models of two-wheelers respectively. No detailed description is given of the effects of the vehicle characteristics as varied in Experiment I (for which see Godthelp & Buist, 1975).

2.2.1. Course holding on a straight path

Figure 4 gives frequency distributions of the maximum course deviations at low speed with the instrumented bicycle. From these distributions 85% and 95% values are derived with respect to the path width used. Figure 5 (for the instrumented bicycle) and Figure 6 (for the popular bicycles and mopeds) give the values ascertained in this way for the path width (85% and 95% values of course deviations left + right) for all the separate conditions for straight course holding together with the speeds.

Speed

Big course deviations occur especially at very low speeds. The required path width may be as much as 0.6 to 0.8 metre. At "leisurely" and "high" speeds the path width is often much less: about 0.2 metre. A greater deviation, up to about 0.3 metre, is found at these speeds with a combination of side-wind and road-surface disturbances.

Vehicles

The differences between vehicles are very slight as regards deviations. Speeds in "slow as possible" course holding differ between bicycles and mopeds. With the popular bicycles and mopeds average speeds were 0.36 m/s (= 1.3 km/h) and 0.97 m/s (= 3.5 km/h), respectively.

One hand on handlebars

In this test, riding with one or both hands was compared for bicycles only. Particularly at low speeds there is a significant decline in performance through using only one hand. The effect of disturbances also proves to be stronger when one hand is used.

Disturbances

The effect of disturbances at a particular speed can only be assessed for the instrumented bicycle (Figure 5). In riding "as slowly as possible" side-wind disturbances result in greater course deviation and higher speed. At "leisurely" and "high" speeds the effect of just side-wind or road-surface disturbance is small. However, for riding with one hand the tendency exists for the 95 percentile deviations to be larger under conditions with disturbances. This effect is most pronounced for conditions with both side-wind and road-surface disturbance.

2.2.2. Course holding in a curve

The 85 and 95 percentile values of the maximum course deviations were also derived from the frequency distributions about course holding in a curve. The results are given in Figure 7.

Speed

The runs with the instrumented bicycle clearly indicate a speed effect. At "high" speed there are greater course deviations than at a "leisurely" speed. Combined with the results for the popular vehicles, the rough values for the necessary path width for 95 percentile deviations at speeds of 5 m/s (= 18 km/h) and 3.33 m/s (= 12 km/h) are 0.6 m and 0.4 m, respectively.

Vehicles

Figure 8 shows the average percentage of the time that was ridden outside the prescribed course. A distinction is made between bicycles and mopeds. Differences between the two are fairly slight. There are effects, however, within the types. Performance with the racing bicycle and the standard model with high handlebars differs significantly from that with the other two bicycles. With these other models path deviations (averaged over conditions with one and both hands) occur for about 25% of the time. For the racing bicycle this goes up to nearly 50%, while it is a little less than 40% for the bicycle with the two high handlebars. Within mopeds, the heavy "motorcycle" model was significantly better than the other three models.

One hand on handlebars

In course holding on a curve, using only one hand appears to affect performance particularly when riding a bicycle. This effect did not exist in the case of mopeds.

2.2.3. Manoeuvring

Figures 9 and 10 show the mean track times in this test for the distance between pylons 2 to 4 for the various vehicles.

Vehicles

Bicycles and mopeds cannot be compared in this test because the track was adapted for the moped runs (See 2.1.2.). However, comparisons can be made within the types of vehicles. The racing bicycle differs in track time (4.4 s) significantly from the other three (mean 3.6 s). As to the mopeds, the heavier model with high handlebars (4.5 s) differs significantly from the other three mopeds. The "motorcycle" model (4.0 s) also differs significantly from the light moped with the engine on the front wheel (3.4 s).

One hand on handlebars

Performance declined when the bicycles were ridden with one hand. The track times with one hand and both hands for the popular bicycles averaged 4.5 s and 3.4 s respectively. This comparison cannot be made for mopeds in the present experiment because it proved hardly possible to ride a moped with only one hand in such manoeuvres.

3. DISCUSSION

The practical consequences of both the literature survey and the experimental investigation will be discussed in the following paragraphs.

3.1. Traffic facilities

Including any luggage, etc., cyclists and moped riders are not allowed to exceed a width of 0.75 metre in The Netherlands. The customary handlebar widths of bicycles and mopeds are 0.55 metre and 0.7 metre respectively. Present-day cycles for young people, however, often have handlebars with the dimensions of moped handlebars. In view of these figures and the possibility of carrying luggage, etc. a width of their physical contour of 0.75 metre seems to be a practical, relevant size. The lateral space provided for a cyclist or moped rider on the road (of which the necessary lane width is a derivative) should therefore have this contour width of 0.75 metre, plus the path width needed for course holding.

The results in Figures 5, 6 and 7 give an indication of the path widths needed under given circumstances for different courses. By reference to these, the following can be said about the lateral space needed by single-track vehicles:

1. On straight roads and cycle tracks or those with gentle curves where a reasonably high speed can be maintained, a cyclist or moped rider needs a lateral space of at least 1 metre wide. At lower speeds and/or with interfering factors, more space may be required.
2. At intersections the approaching speed may be limited, while turning off, direction indication and rear orientation may be needed. Drury et al. (1975) stated that for backward glancing during course holding (leisurely speed, both hands holding handlebars) a space of about 1.05 m to 1.20 metre wide is needed. This figure can be combined with the results of the present experiments, in which the effects of low speed, direction indication and riding a curve are examined. The available data together indicate that for manoeuvres at and on intersections, a lateral space of at least

1.25 metre wide must be available for both cyclists and moped riders. Although the present research results still have to be tested under practical conditions, the stated lateral space widths are likely to be lower limits, for the following reasons:

A. The experiments were made with subjects all aged 16. Especially in the case of cyclists, the performance of younger as well as older road users will probably be no better in the situations concerned (see Arnberg et al., 1978).

B. Effects of disturbances in visual field, carriage of luggage and passengers, were not covered.

C. When riding near pavement edges, past parked cars, walls, etc., cyclists and moped riders often take a larger distance from the obstacle than necessary ("obstacle fright").

The effects of road-surface and side-wind disturbances on cyclists' performance were apparent especially at low speeds and in riding with one hand. Road-surface unevenness is of frequent occurrence on roads used by cyclists and moped riders. Such unevenness can interfere with steering and stabilising as found in this and other research (Blaauw & Godthelp, 1978). An analysis of factors leading to accidents of child cyclists (Wright, 1974) shows that road-surface unevenness constitutes a real danger. Wind effects are often intensified in places between buildings, discontinuities in groups of trees and so on. In the present research, the subjects were quite able to anticipate wind effects, and at reasonably high speeds the effect of the disturbance appears to be limited. In practical situations, it seems important to avoid sudden gusts of wind by proper design of the environment. Air displacements caused by passing lorries are great, especially at high driving speeds and with sidewind. In the case of two-wheelers overtaken by heavy lorries at close distances, a part of the field of vision is shut off as well. Together with a reduced lane width these aspects may lead to a sudden fright. Disturbances like these should be obviated wherever possible.

3.2. Vehicle design

It is often assumed that further improvement of single-track vehicles is hardly possible because they have evolved to their present form as the result of very lengthy practical experience. Research suggests that this assumption is not entirely correct. Pronounced differences between two-wheeled vehicles appeared during tests that make demands on stability and/or manoeuvrability.
Arnberg & Tydén (1974) studied cyclists looking behind during straight course holding (path width 0.5 metre, track length 15 metres). Such a situation arises in preparing to turn left at an intersection. With the three types of bicycle investigated: small-wheeled, standard and rodeo, the probability of making mistakes in following the course and assessing the situation behind was 10%, 20% and 50% respectively. One typical feature of the rodeo type is a long saddle set far back, the so called banana seat.
The effect of handlebar configuration on manoeuvrability, as found by Arnberg & Tydén (1974) and Mortimer et al. (1976), is substantiated by the present research. This configuration partly determines how the rider sits. Extreme designs of handlebars lead to limited manoeuvrability, which is reduced particularly by racing handlebars. Manoeuvrability is very important especially in heavy traffic, in evading other traffic and avoiding obstacles and so on. Of course it may be so that after prolonged experience performance improves, even in case of extreme configurations. In fact, ordinary ways of bicycle use do not lead to this kind of experience. Especially for younger cyclists these problems lead to the question whether there should be a formal distinction between bicycles used as a toy and those used as a means of transportation.

Overall, the available information suggests that unlimited acceptance of new (especially extreme) models of single-track vehicles may be detrimental to road safety. Riding tests based on actual traffic situations do allow the assessment of both existing vehicles and any to be newly introduced.

The study had only an exploratory nature as far as mopeds were concerned. High speeds were not considered. There proved to be differences in manoeuvrability between the various moped models. The poorer performance of the "motorcycle" type in course holding in a curve was striking. Its performance in manoeuvring was poorer too. This may be due to differences in design and mass. Further research into the riding characteristics of mopeds at high speed is necessary; this is because of the comparatively large number of single-vehicle accidents with them.

The course deviations found by Arnberg & Tydén (1974) and Drury et al. (1975) due to rear orientation also suggest that further research is required into the effect of rearview mirrors for single-track vehicles. Especially moped riders repeatedly have to overtake slower cyclists and ride in other vehicles' lanes.

3.3. Traffic rules and codes

Bicycles and mopeds are ridden with one hand on the handlebars when the rider is carrying some hand-held load. Besides, single-handed riding is unavoidably when indicating direction. Results of the present experiments show that riding with one hand interferes with stabilisation, steering and speed regulation and in counteracting disturbances, this effect being most pronounced at low speeds. Some riding tests could not be done with one hand by moped riders. It should be considered whether to avoid single-handed riding. Means of securing and transporting luggage are needed. The advantages and disadvantages of direction indicators should be examined.

As regards carrying pillion passengers, it is stated above that two-wheeler's motions can be affected adversely by a change in the centre of gravity, lower speed, insufficient co-ordination between the movements of passenger and rider, and so on. In The Netherlands, cyclists under 18 years are allowed to carry not more than one person, who must not be older than the cyclist himself. Cyclists over 18 may carry not more than one person over 10 years or two children under 10. Moped riders are allowed to carry not more than one person. Considering the adverse effects of carrying passengers, an age limit of, for instance, 16 years may be introduced under which cyclists are not permitted to carry passengers. In the case of cyclists, fixing an upper age limit for passengers might also be considered. No definite conclusions can be drawn about this yet from the present research. Further experimental research and analysis of accident statistics could provide the necessary additional information on this.

REFERENCES

Arnberg, P.W. & Tydén, T. (1974). "Stability and manoeuvrability performance of different types of bicycles". Report No. 45A. National Swedish Road and Traffic Research Institute, Stockholm.

Arnberg, P.W.; Ohlsson, E.; Westerberg, A. & Öström, C.A. (1978). "The ability of preschool- and schoolchildren to manoeuvre their bicycles". Report No. 149A. National Swedish Road and Traffic Institute, Stockholm.

Blaauw, G.J. & Godthelp, J. (1978). "Riding behaviour of motorcyclists as influenced by pavement characteristics". SAE paper 780314.

Blokpoel, A. (1978). "De verkeersonveiligheid van voetgangers, fietsers en bromfietsers binnen de bebouwde kom in cijfers". Een statistische beschrijving van de landelijke gegevens betreffende verkeersongevallen en verkeersslachtoffers. Bijdrage Congresboek Nationaal Verkeersveiligheidscongres 1978, Amsterdam, 19-20 april 1978. R-78-9. SWOV, Voorburg.*

Brezina, E. & Kramer, M. (1970). "An investigation of rider, bicycle and environmental variables in urban bicycle collisions". Ontario Department of Transport, Ontario.

Centraal Bureau voor de Statistiek CBS (1978). "Statistiek van de verkeersongevallen op de openbare weg 1976". Staatsuitgeverij, 's-Gravenhage.*

Dewar, R.E. (1978). "Bicycle riding practices: implications for safety campaigns". Journal of Safety Research 10 (1978) 1: 35-42.

Drury, C.G.; Zajkowski, M.M.; Daniels, E.B. & Kobas, G.V. (1975). "Bicycle safety-effective intervention strategies". Report 75/HF/01. Department of Industrial Engineering. State University New York, Buffalow, New York.

Eaton, D.J. (1973). "Man-machine dynamics in the stabilization of single-track vehicles". Dissertation. Highway Safety Research Institute, University of Michigan, Ann Arbor.

Godthelp, J. & Buist, M. (1975). "Stability and manoeuvrability characteristics of single-track vehicles", Report IZF 1975-C2. Instituut voor Zintuigfysiologie TNO, Soesterberg.

Herwig, B. (1969a). "Fehlverhaltensweisen im öffentlichen Strassenverkehr". Zeitschrift für Verkehrssicherheit 15 (1969) 1: 48-54.

Herwig, B. (1969b). "Faktor "Fahrzeug" und Häufigkeit des Unterlassens der Richtungsanzeige". Zeitschrift für Verkehrssicherheit 15 (1969) 4: 270-285.

Van Lunteren, A. & Stassen, H.G. (1970). "Investigations on the bicycle simulator". Annual report 1969 of the Man-machine systems group, WTHD 21. Technische Hogeschool Delft.

Mortimer, R.G.; Domas, P.A. & Dewar, R.E. (1976). "The relationship of bicycle manoeuvrability to handlebar configuration". Applied Ergonomics 7 (1976) 4 (December): 213-219.

Roland, R.D. (1974). "Computer simulation of bicycle dynamics". In: Mechanics and Sport, published by The American Society of Mechanical Engineers, New York.

Sharp, R.S. (1971). "The stability and control of motorcycles". J. Mech. Engng. Sci. 13 (1971) 5: 316-329.

Weir, D.H. (1972). "Motorcycle handling dynamics and rider control and the effect of design configuration on response and performance". Dissertation. University of California, Los Angeles.

Wright, P.H. (1974). "An overview of the bicycle accident problem". In: Proceedings of the Third Int. Congres on Automotive Safety, San Francisco, California, July 1974. U.S. Department of Transportation, Washington, D.C.

*Only in Dutch

TABLES

Table 1. The four adjustable vehicle characteristics of the instrumented bicycle.

Table 2. Conditions in Experiments II and III.

Characteristic	Unit	Variations	
Mechanical trail	m	0	0.05
Moment of inertia of front wheel around wheel axis	kgm^2	0.17	0.34
Moment of inertia of front wheel around steering head axis	kgm^2	0.15	0.30
Distance between saddle and handlebars	m	0.39	0.51

Table 1. The four adjustable vehicle characteristics of the instrumented bicycle

	Experiment II popular bicycles speed	hands	disturbance	Experiment III popular mopeds speed	hands	disturbance
Test 1	high	1 and 2	side wind + road surface	leisurely	2	side wind + road surface
	low	1 and 2	none	low	2	none
Test 2	high	1 and 2	none	leisurely	1 and 2	none
Test 3	-	1 and 2	none	-	2	none

Table 2. Conditions in experiments II and III

FIGURES

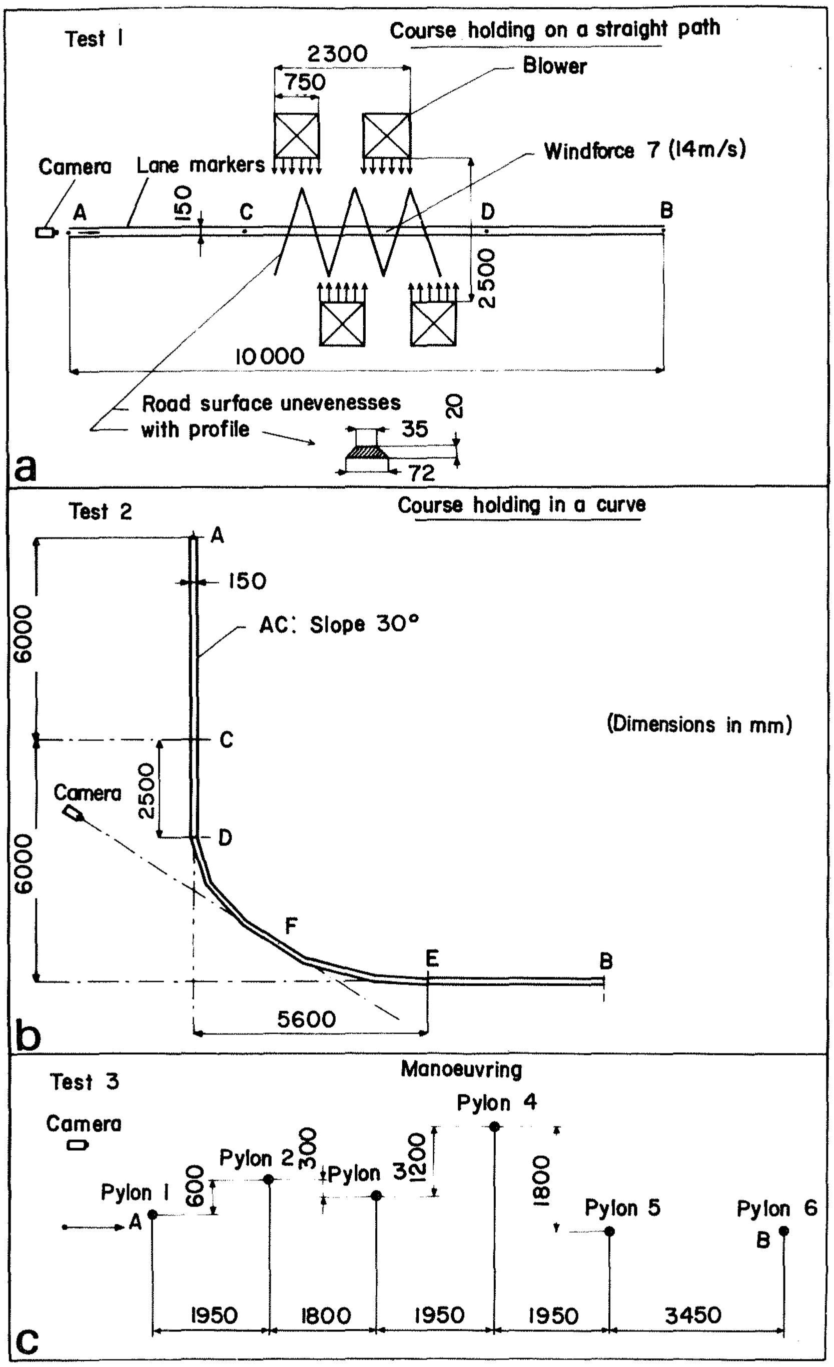

Figure 1. The three riding tests.

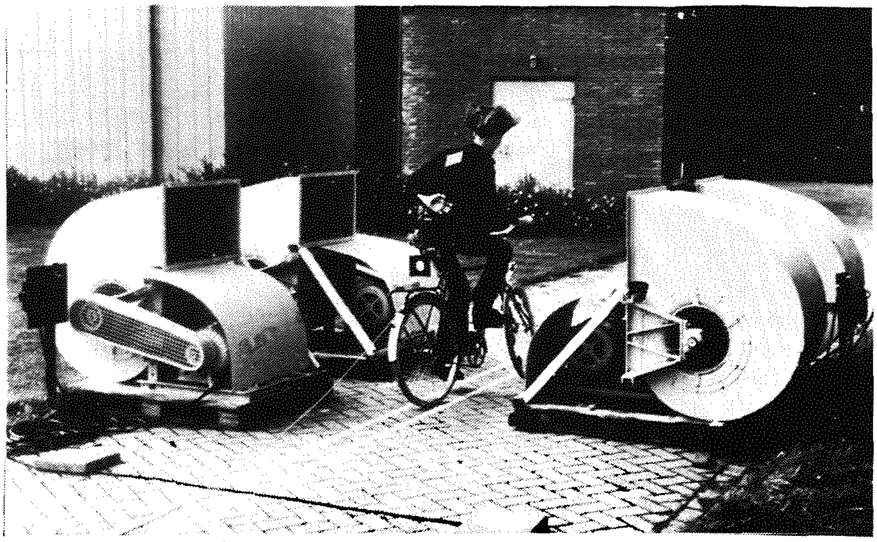

Figure 2. Course holding with side-wind disturbance.

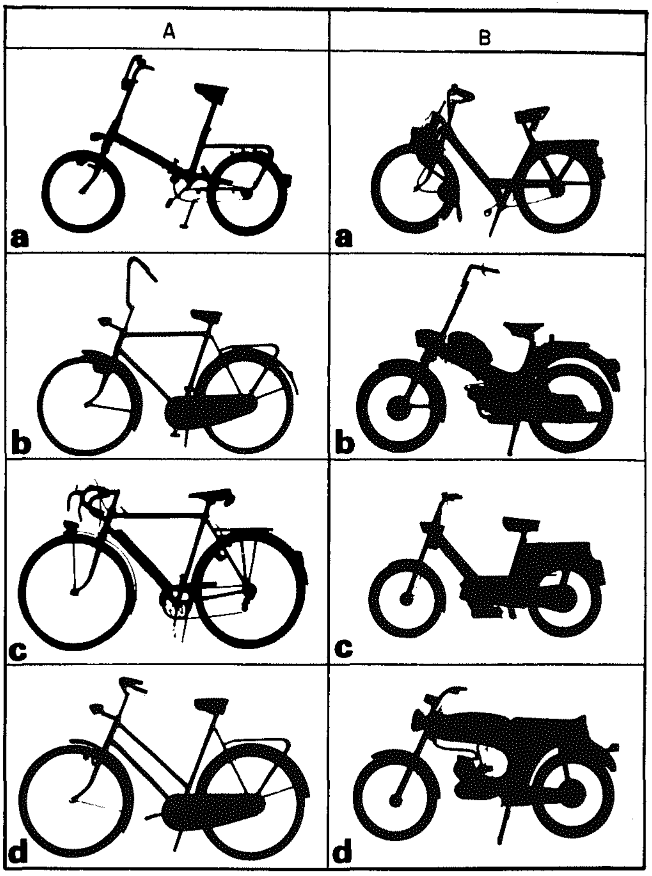

Figure 3. Popular single-track vehicles.

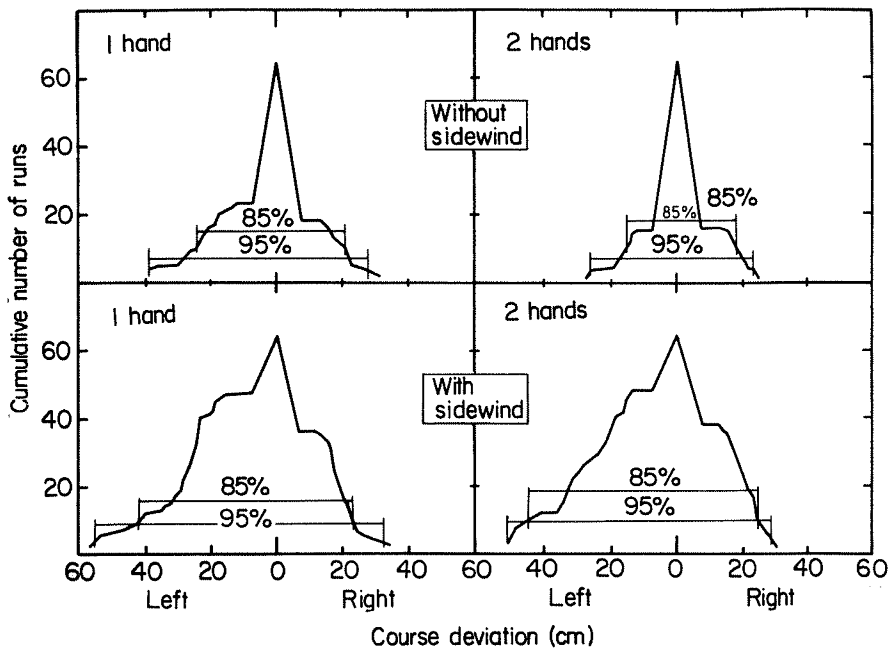

Figure 4. Frequency distribution of maximum course deviations in test 1: "Course holding on a straight path" (instrumented bicycle, at low speed, 64 runs per diagram).

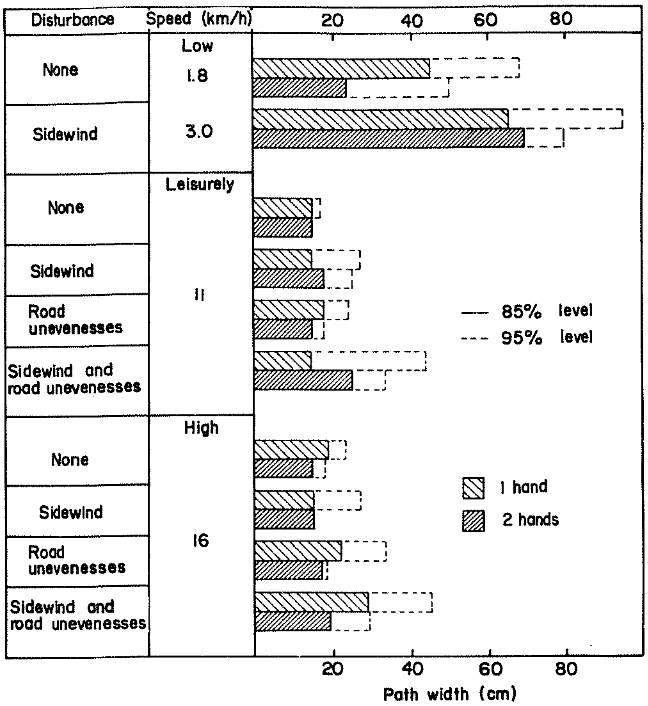

Figure 5. Required path width in test 1: "Course holding on a straight path" (instrumented bicycle, 1280 runs).

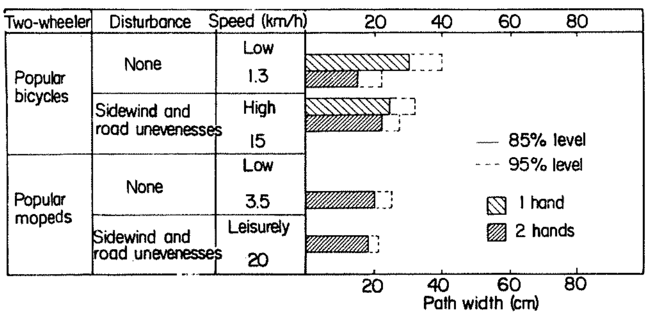

Figure 6. Required path width in test 1: "Course holding on a straight path" (popular single-track vehicles, 288 runs).

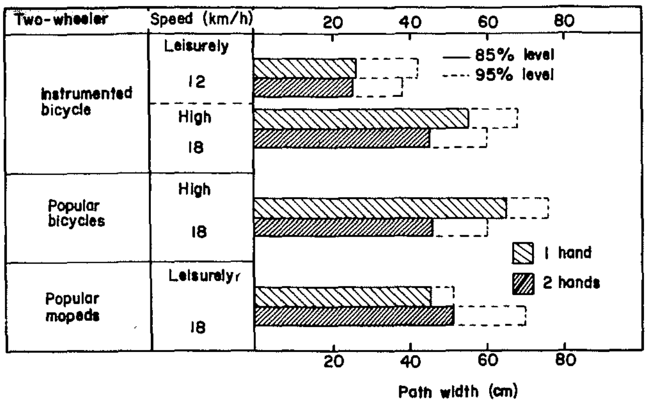

Figure 7. Required path width in test 2: "Course holding in a curve" (488 runs).

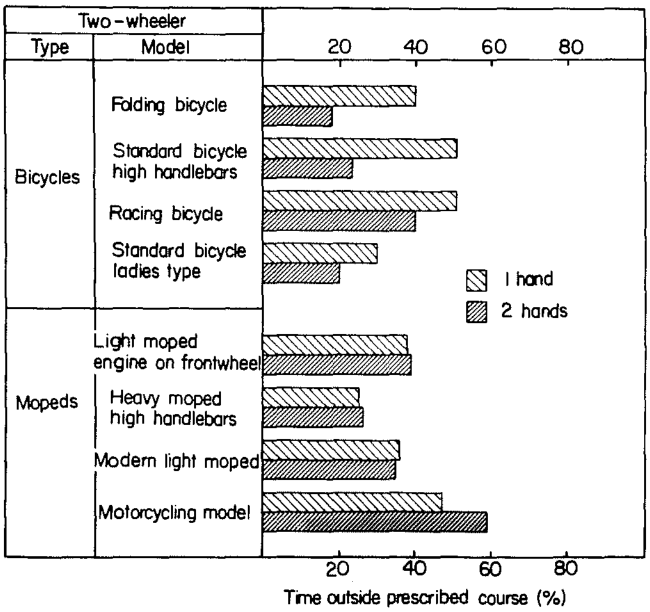

Figure 8. Time (%) outside prescribed path in test 2: "Course holding in a curve" (768 runs).

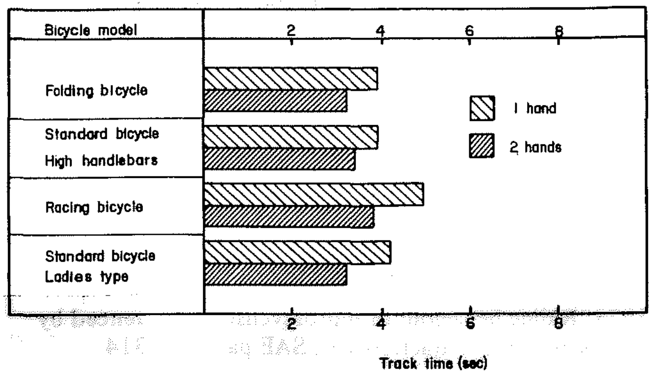

Figure 9. Track time in test 3: "Manoeuvring" (popular bicycles, 384 runs).

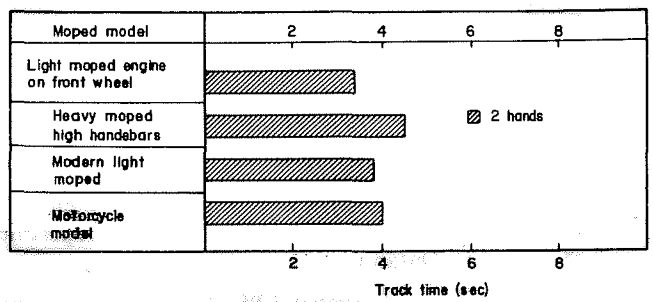

Figure 10. Track time in test 3: "Manoeuvring" (popular mopeds, 192 runs).