COURSE HOLDING BY CYCLISTS AND MOPED RIDERS

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SUMMARY

About one third of all traffic fatalities in The Netherlands concerns cyclists or moped riders. Half of these fatalities is related to collisions with cars. 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 existing facilities it is necessary to gather more knowledge about the performance of cyclists and moped riders and about the factors influencing this performance.
The inability of cyclists and moped riders to handle their vehicle may result in conflicts. More uniformity in riders' performance gives better predictability for other road users. Handling qualities in specific riding tasks will depend on several factors: the geometry of the course to be followed, vehicle and rider characteristics, and disturbances. The Institute for Road Safety Research SWOV commissioned the Institute for Perception TNO to carry out a study concerning stability and manoeuvrability characteristics of single-track vehicles. Recordings were made during riding tests carried out by 16 year old subjects following different courses. The tests were done with different speeds, one or two hands on the handlebars, with and without side-wind and road-surface disturbances and with various models of bicycles and mopeds.
The results of the study, together with those from the literature, are relevant with regard to the design of traffic facilities, for the design of bicycles and mopeds, and for formulating traffic rules and codes.

Cyclists and moped riders need a certain lateral space in order to ride. This space consists of the width of their fysical contour and the width necessary for following a course. It appears that both cyclists and moped riders use a width of at least 1 metre on straight roads and cycle tracks, whereas near intersections this width should be at least 1.25 metre.
Road-surface and side-wind disturbances decrease riding performance,

especially at low speeds. This makes demands on the construction and maintenance of road surfaces and the design of the traffic environment. Overtaking two-wheelers by heavy lorries at close distances should be avoided.

Furthermore results point to differences between vehicle models with regard to performance in tasks involving stability and/or manoeuvrability. Manoeuvrability is very important especially in heavy traffic. Two-wheeler models with an extreme design, concerning for example the handlebars, can have worse handling qualities. This leads to the question whether there should be a formal distinction between bicycles for children used as a toy or as a means of transportation. The so called motorcycle model is less manoeuvrable than the traditional moped. New and existing two-wheeler models can be evaluated by means of riding tests related to realistic traffic situations. Research is necessary on the effect of rearview-mirrors because moped riders may have problems in hearing and seeing traffic behind them.

Riding single-handed interferes with performance. The advantages and disadvantages of direction indicators should be considered. It may be necessary to permit riding single-handed only in specific situations. Considering the unfavourable effect on carrying passengers an age limit of e.g. 16 years may be introduced, whereby young cyclists are not permitted to carry passengers.

1. INTRODUCTION

About one third of all traffic fatalities in The Netherlands concerns cyclists or moped riders. In 1976, for instance, 500 cyclists and 285 moped riders were killed, out of a total of 2432 traffic fatalities (CBS, 1978). Half of these fatalities is related to collisions with cars (Blokpoel, 1978). This type of traffic hazard can be prevented either by:

a. segregating the categories of road users (for instance separate cycle tracks) or by

b. integrating these categories by means of right-of-way and speed regulations (for instance in a "woonerf": residential yard).

Much of The Netherlands has an infrastructure in which such measures have not (yet) been applied.

In order to design safe bicycle and moped facilities and to be able to consider the safety of existing facilities, it is necessary to gather more knowledge about the "performance" - for example in terms of the required lane width - one may expect of two-wheeler riders. The question also arises whether this performance is materially influenced by characteristics of the single-track vehicle (e.g. design) and the rider (e.g. age) and by disturbing factors (e.g. putting one's hand out).

The riding task of cyclists and moped riders includes steering, i.e. controlling the course, and stabilising the vehicle. These activities together are called "course holding". Inability to course holding may lead to conflicts with other road users. Indirectly, course holding is also important for road safety, because as cyclists and moped riders can act more uniformly in course holding, their behaviour becomes more predictable. Other road users can then anticipate better and also respond better.

At the request of the Institute for Road Safety Research SWOV, the Institute for Perception TNO (IZF-TNO) carried out research into handling qualities and mopeds (Godthelp et al., 1975). It included riding tests in which, among other things, the subjects were given courses to follow. The research data were analysed further with respect to course holding. The results of the experiments, taken together with data from literature are discussed.

2. ASPECTS OF COURSE HOLDING

The following aspects are of importance with regard to course holding: the geometry of the course to be followed, riders' and vehicles' characteristics, and disturbing factors.

2.1. Course

The course to be followed is determined by the route 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, a.o., in manoeuvring in urban traffic and in bends aiming at riders to slow down and those in d. when turning off at intersections and in obstacle avoidance and overtaking.

2.2. Vehicle

On the whole the vehicle motion of bicycles and moped as such is unstable. Vehicle dynamics (for example Sharp, 1971; Weir, 1972; Roland, 1974) usually show three specific modes of motion for single-track vehicles. These are the non-oscillatory "capsize" mode and the oscillatory "weave" mode, both of which relate to the entire vehicle. The oscillatory "wobble" mode relates only to the front wheel section. The stability of these modes of motion depends firstly on the vehicle's speed and secondly on vehicle characteristics such as mechanical trail, moments of inertia around front wheel and steering head axis, centre of gravity of frame/rear wheel section, steering head angle, wheel base, stiffness of frame, fork and wheels, tyre properties and spring stiffness.
Stabilisation forms an essential part of the rider's task: moments have to be applied to the handlebars and saddle, and this is accom-

panied by course deviations. A consequence is the typical balancing motion of cycles and mopeds: swinging around an average course.

Changes in course may be gradual or abrupt. Straight and slightly curved courses require stable vehicle behaviour. More abrupt changes, however, make also demands on the vehicle's manoeuvrability. Stability cannot therefore simply be increased, as this might detract from manoeuvrability, which in the case of bicycles and mopeds is governed partly by the same vehicle characteristics as stability.

Stability and manoeuvrability of the two-wheeler/rider combination depend on the vehicle dynamics and on steering and stabilisation by the rider (See 2.3.). Both aspects are moreover influenced by the rider's position and posture, because this influences the mass distribution (centre of gravity, moments of inertia), whose effect will be determined by the ratio between the weights of the rider and of the vehicle. This also determines the ergonomic characteristics of bicycles and mopeds. The rider's posture (bent forward or more upright), for instance, will affect his possibilities of steering and stabilising. Mortimer et al. (1976) and Arnberg et al. (1974) state by reference to experimental research that the configuration and height of the handlebars - and hence the rider's posture - can greatly affect manoeuvrability.

In choosing single-track vehicle characteristics, stability and manoeuvrability properties will have to be compared, taking the courses that occur in traffic into account.

2.3. Rider

In course holding the cyclist or moped rider steers and stabilises his vehicle. His actions comprise various forms of response. Both moments may be applied to the handlebars causing steer angles, and movements of the upper part of the body which leads to angles between the body of the vehicle and to moments on the saddle. The frequency range of these response forms is mostly limited to about

1 Hz. Research into this has been done, among others, by Van Lunteren et al. (1970), Weir (1972), Eaton (1973) and Roland (1974).
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 a two-wheeler's specific motions (See 2.2.). It is important for the natural frequencies of these motions to be as far as possible above the rider's frequency range, for in that case practically no stabilising actions are needed. The lower the speed, the lower the natural frequency of the weave motion and the more it comes within the rider's frequency range. A relatively large effort is needed to counteract the instability that then occurs. Design characteristics that "damp" this instability thus have a favourable effect on course holding.

Little is known about the influence of age, riding experience and such-like 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 in Section 3, did show strong age effects. In particular, young cyclists under 8 years appeared to have limited skills in realistic traffic situations.

2.4. Disturbing factors

When taking part in road traffic, course holding by cyclists and moped riders may be affected by disturbing factors.
For instance, 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. This deterioration in performance depends on the type of bicylce (Arnberg et al., 1974). Moreover, this rear orientation is often omitted (Dewar, 1978).
In The Netherlands cyclists are required by law to indicate their direction with hand signals when turning. The same applied to moped riders whose vehicles have no direction indicators etc. Riding with one hand, so as to carry hand-held load, for instance, is permitted.

Direction indication is frequently neglected, in up to about 65% of the cases (Herwig, 1969 I). One reason for this is the instability of two-wheelers (Herwig, 1969 II). Riding with one hand interferes with the application of moments to the handlebars. Moreover, if a moped rider lets go of the handlebars his speed may drop through the accelerator jumping back or he may be unable to operate the clutch. Besides, one means of braking may be forfeited.
The carriage of passengers and luggage is allowed by law subject to certain restrictions. This affects the position of the centre of gravity and the front/rear mass distribution important to the weave motion (e.g. Sharp, 1977). A greater weight will mostly reduce speeds, which also affects the stability of the weave motion. If the passenger's body movements are not attuned to the rider's, steering with the upper part of the body becomes more difficult. A retrospective study of traffic collisions involving child cyclists (Brezina et al., 1970) showed that in 20% of these collisions the cyclist was carrying a passenger or some hand-held load.
During course holding a rider responds to a combination of visual, vestibular, kinaesthetic and auditive stimuli. Visual information is of essential importance for steering and partly of importance for stabilisation. Poor visibility ahead, for example in case of precipitation, fog or darkness limits the preview distance and thus interferes with steering. Cutting off the peripheral visual field, an important factor in keeping balance, for instance while two-wheelers are overtaken by heavy lorries at close distances, while riding past walls, etc., influences stabilisation.
Cyclists and moped riders may be greatly inconvenienced by wind or by air displacement caused by lorries. When disturbances occur suddenly, there is no possibility of anticipation. Wind velocities can fluctuate at random around a mean value or come in gusts. In the latter case, periodicity - for instance due to buildings or groups of trees - can cause increasing course deviations. This can also happen when air is displaced by lorries.
Lastly, there is the effect of road-surface unevenness. Longitudinal grooves (for instance gutter edges, rails, joins in tiled paths and "rainurages") may influence the front-wheel movements essential for

stabilisation (Blaauw et al., 1978). Road-surface unevenness may cause undesired movements or thwart attempts to stabilise these.

3. EXPERIMENTS

The research covered a number of aspects relevant to course holding. It was focussed at analysing handling qualities of bicycles and mopeds. 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 these tests the subjects had to follow three specifically selected courses. The performances of combinations of rider/two-wheeler were determined. The most important parts of the research method are explained briefly below, after which the results are presented.

3.1. Method

3.1.1. Riding tests

The tests were arranged so that the influence of stability and manoeuvrability characteristics of bicycles and mopeds on course holding can be examined. In addition to "normal" practical situations, "critical" ones were also simulated.

Test 1: Course holding on a straight path
This test related primarily to the influence of vehicle stability on course holding.
The track (See Figure 1a for layout) consisted of a straight road with a path 0.15 metre wide marked by two 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 Illustration 1) and/or road-surface unevennesses. The side-wind disturbances had characteristics 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 by 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 and was marked with two lines 0.15 metre apart. The subjects had to cover the track as fast as possible and also 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, which occurs in practice on inclines from bridges for instance, forces the subjects, whatever the vehicle, to choose the highest speed almost uniformly. This has advantages in comparing the combination's performance. The criteria of performance were time ridden outside the markings and the maximum course deviation.

Test 3: Manoeuvring

In this test, the two-wheeler's manoeuvrability 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 (very) 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.

3.1.2. Vehicles

Three experiments were made, distinguishing between the single-track vehicles used for this research.

Experiment I: The instrumented bicycle

For the first experiment, a standard men's bicycle was converted into an instrumented bicycle, with which four relevant vehicle characteristics could be varied. Each of the four characteristics had two possible variations (See Table 1), so that a total of sixteen configurations of the bicycle could be tested, differing only in the respective characteristics. They related both to design characteristics (mechanical trail, moment of inertia of front wheel around its wheel-axis) as to the presence, for instance, of a carrier over the front wheel (moment of inertia of front wheel around steering head axis) and the rider's position and posture (distance between saddle and handlebars). A wide range of existing single-track vehicles was thus covered.

Experiment II: Popular bicycles

The second experiment was made in order to compare performance with the instrumented bicycle and with popular bicycles on the market. Based also on the results of the first experiment, the following four models were selected (See Figure 2A):

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 before mentioned tests were made with mopeds, to make a comparison possible between bicycles and mopeds in these situations. Moreover this experiment should give more insight in the differences between mopeds.

Four popular mopeds were selected for the experiment (See Figure 2B):

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.

3.1.3. Subjects

The tests in each experiment were each done 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, and bicycle and moped usage also being very high.

3.1.4. 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 trial runs to become familiar with the test conditions.

In experiment I the sixteen configurations of the instrumented bicycle were ridden in each test as described in 3.1.1. 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.

3.2. 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 as between two-wheelers 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 et al., 1975).

3.2.1. Course holding on a straight path

Figure 3 gives frequency distributions of 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. Figures 4 and 5 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 only with a combination side-wind and road-surface disturbances.

Vehicles

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

One hand on handlebars

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

Disturbances

The effect of disturbances at the separate speeds can be assessed only for the instrumented bicycle (Figure 4). 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 the side-wind or road-surface disturbance separately is noticeable especially in riding with one hand. With a combination of side-wind and road-surface disturbances there is also an effect on riding with both hands.

3.2.2. Course holding in a curve

From frequency distributions of course deviations the 85% and 95% values were also derived for the required path width in riding a curve. The results are given in Figure 6.

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 at speeds of 5 metre/s (= 18 km/hr) and 3.33 metre/s (= 12 km/hr) are 0.6 metre and 0.4 metre, respectively.

Vehicles

Figure 7 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. Performances with the racing bicycle and the standard model with high handlebars differ significantly from those with the other two bicycles. With these models there were path deviations 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 that with the high handlebars. Within mopeds, the heavy "motorcycle" model differs significantly from the other three.

One hand on handlebars

In course holding in 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.

3.2.3. Manoeuvring

Figures 8 and 9 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 3.1.2.). Comparisons can, however, 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

Here, too, 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. 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.

4. DISCUSSION

Section 2 discussed aspects of course holding by cyclists and moped riders. It firstly went into the characteristics of the course, then those of the vehicle, after that those of the rider and finally into the effect of disturbing factors. The influence of some aspects on course holding was known from literature. There are no quantitative data for assessing other aspects, and possible effects can only be presumed to exist on the grounds of theoretical considerations. For some of these latter aspects, the research described in Section 3 provides additional information.

This discussion goes into the possible practical consequences on traffic facilities for cyclists and moped riders, vehicle design and traffic rules and codes.

4.1. Traffic facilities

Including any carried luggage, etc., in The Netherlands cyclists and moped riders are not allowed to exceed a width of 0.75 metre. 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 fysical contour of 0.75 metre seems to be a practical, relevant size. The lateral space provided for one cyclist or moped riders 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 4, 5 and 6 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 where there are interfering factors, he will need more.
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 rear orientation during course holding (leisurely speed, both hands holding handlebars) a space 1.05 m to 1.20 metre wide is needed. This figure can be combined with the results of the present research, 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 hardly covered in the research, if at all.
C. When riding near pavement edges, past parked cars, walls, etc. cyclists and moped riders often allow a wider distance from the obstacle than they need ("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 an moped riders. For instance there are tram rails, gutter edges, joins between cycle track and main carriageway, patterns in roads paved with bricks or tiles, cracks in asphalt, etc. Such unevenness can interfere with steering and stability of single-track vehicles as found in this and other research (Blaauw et al., 1978). An analysis of factors leading to accidents to child cyclists (Wright, 1974) shows that road-surface unevenness constitutes a real danger. Wind effects are often intensified in places through 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 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. Disturbance and situations like these should be obviated wherever possible.

4.2. 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. In particular, it should be recognised that pronounced differences exist between two-wheeled vehicles when activities that make demands on stability and/ or manoeuvrability are involved.

Arnberg et al. (1974) studied rear orientation in straight course holding (path widt 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 et al. (1974) and Mortimer et al. (1976), is substantiated by the present research. This configuration partly determines how the rider sits. Extreme design 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.

These problems lead to the question whether there should be a formal distinction between bicycles for children used as a toy and those used as a means of transportation. The rider's age will, of course, also play a part in this.

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 offer scope for assessing both existing vehicles and any to be newly introduced.

The study had only a 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, a.o. because of the comparatively large number of single-vehicles accidents with them.

The course deviations found by Arnberg et al. (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. The use of rearview mirrors may cause problems, for instance for cyclists. Firstly, because it is more difficult to estimate the speed and direction of following traffic with a mirror than without it. Secondly, because a mirror fixed on a bicycle moves about a lot, especially at low speeds. Besides this, protruding parts such as mirrors might worsen the consequences of accidents.
With regard to this point mopeds differ from bicycles in a number of ways. Not only there is mostly a legal minimum riding age for them (in The Netherlands 16 years), but vehicle motions are more stable owing to the higher average speeds, and vibrations are absorbed to some extent by the suspension. In addition, moped riders repeatedly have to overtake slower cyclists and ride in other vehicles' lanes.

Rear orientation is required again and again for this, especially because the engine noise often obstructs moped riders being warned auditively. In addition, moped riders' helmets may cut off part of their peripheral vision. All this makes it important to have a fuller evaluation of rearview mirrors, especially for moped riders. In case of motorcycles, the results may also be of some use.

4.3. 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 in case of indicating the direction. Results of the present experiments show that riding with one hand interferes with stabilisation, steering and speed regulation and in counteracting disturbances. Some riding tests could not even be done with one hand by moped riders. It should be considered whether to restrict 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 in 2.4. 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, it might also be considered fixing an upper age limit for passengers. 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.

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*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			Experiment III popular mopeds		
	speed	hands	disturbance	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	-	leisurely	1 and 2	-
Test 3	-	1 and 2	-	-	2	-

Table 2. Conditions in experiments II and III

FIGURES

Figure 1. The three riding tests.

Figure 2. Popular single-track vehicles.

Figure 3. Frequency distribution of course deviations in test 1: "Course holding on a straight path" (instrumented bicycle, at low speed, 64 runs per diagram).

Figure 4. Required path width in test 1: "Course holding on a straight path" (instrumented bicycle, 1280 runs).

Figure 5. Required path width in test 1: "Course holding on a straight path" (popular single-track vehicles, 288 runs).

Figure 6. Required path width in test 2: "Course holding in a curve" (488 runs).

Figure 7. Time (%) outside prescribed path in test 2: "Course holding in a curve" (768 runs).

Figure 8. Track time in test 3: "Manoeuvring" (popular bicycles, 384 runs).

Figure 9. Track time in test 3: "Manoeuvring" (popular mopeds, 192 runs).

Illustration 1. Course holding with side-wind disturbance.

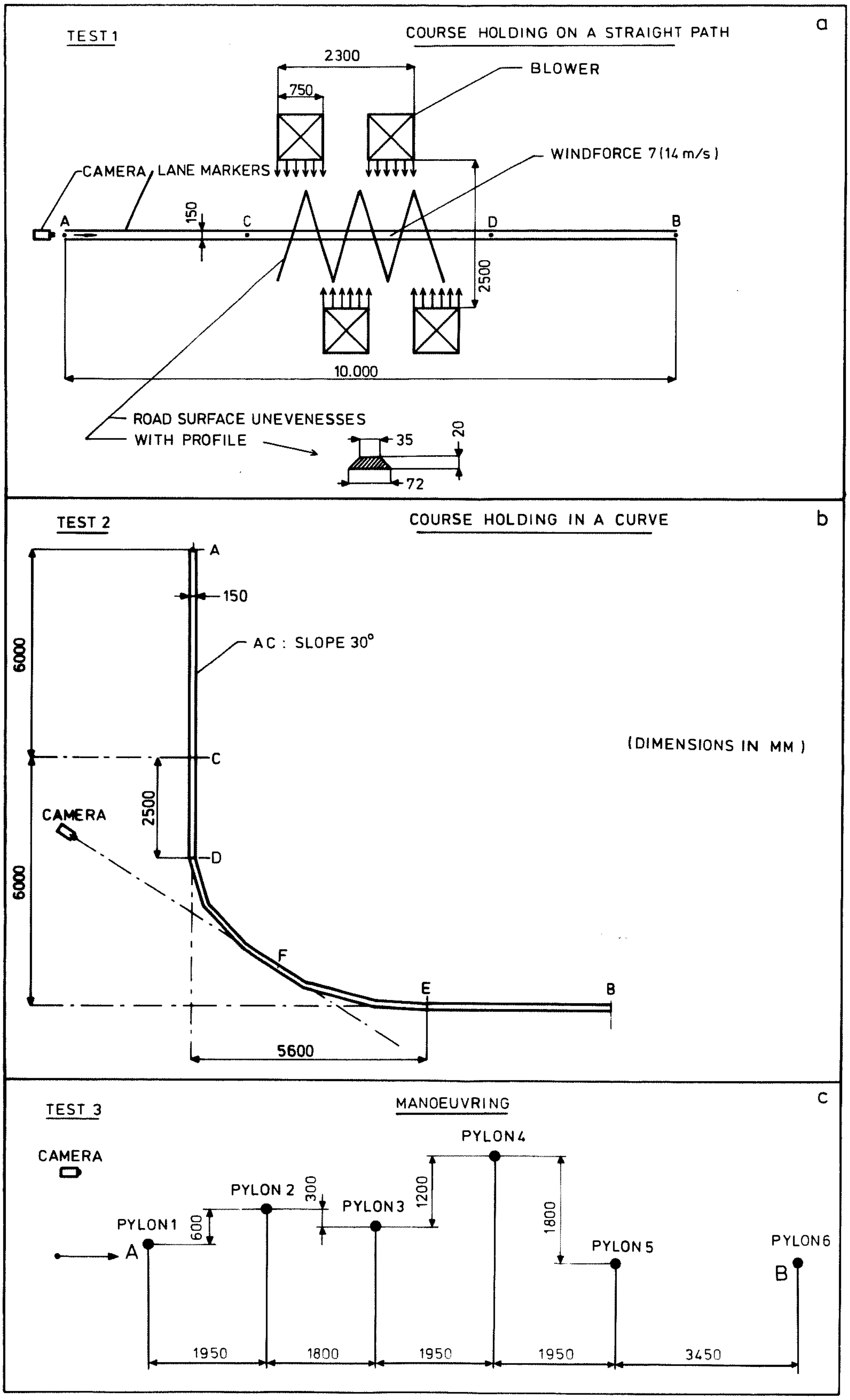


Figure 1. The three riding tests.

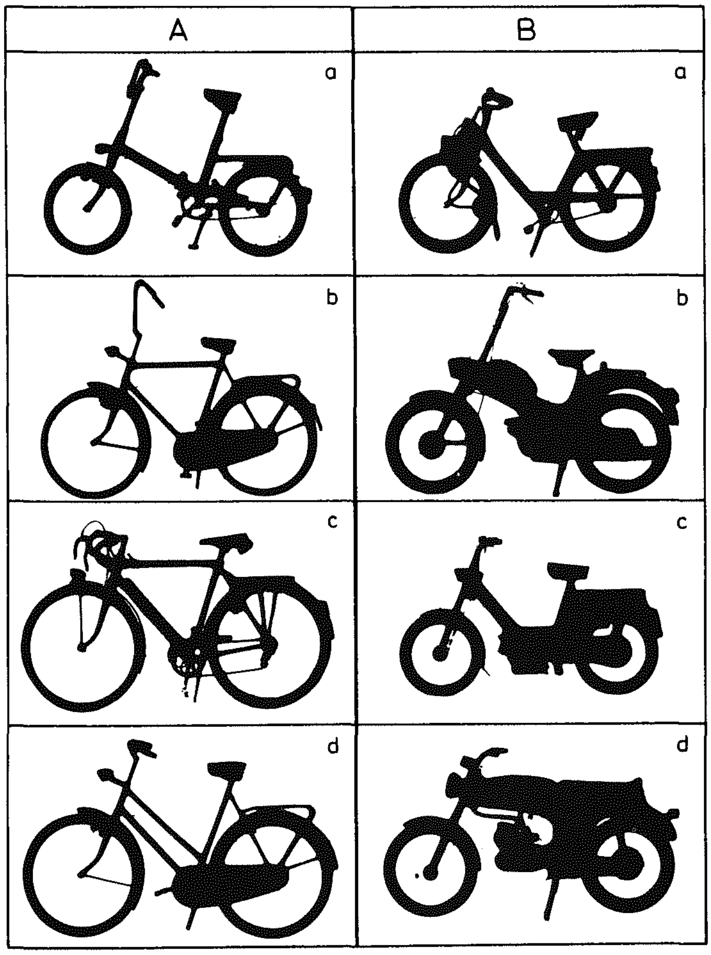
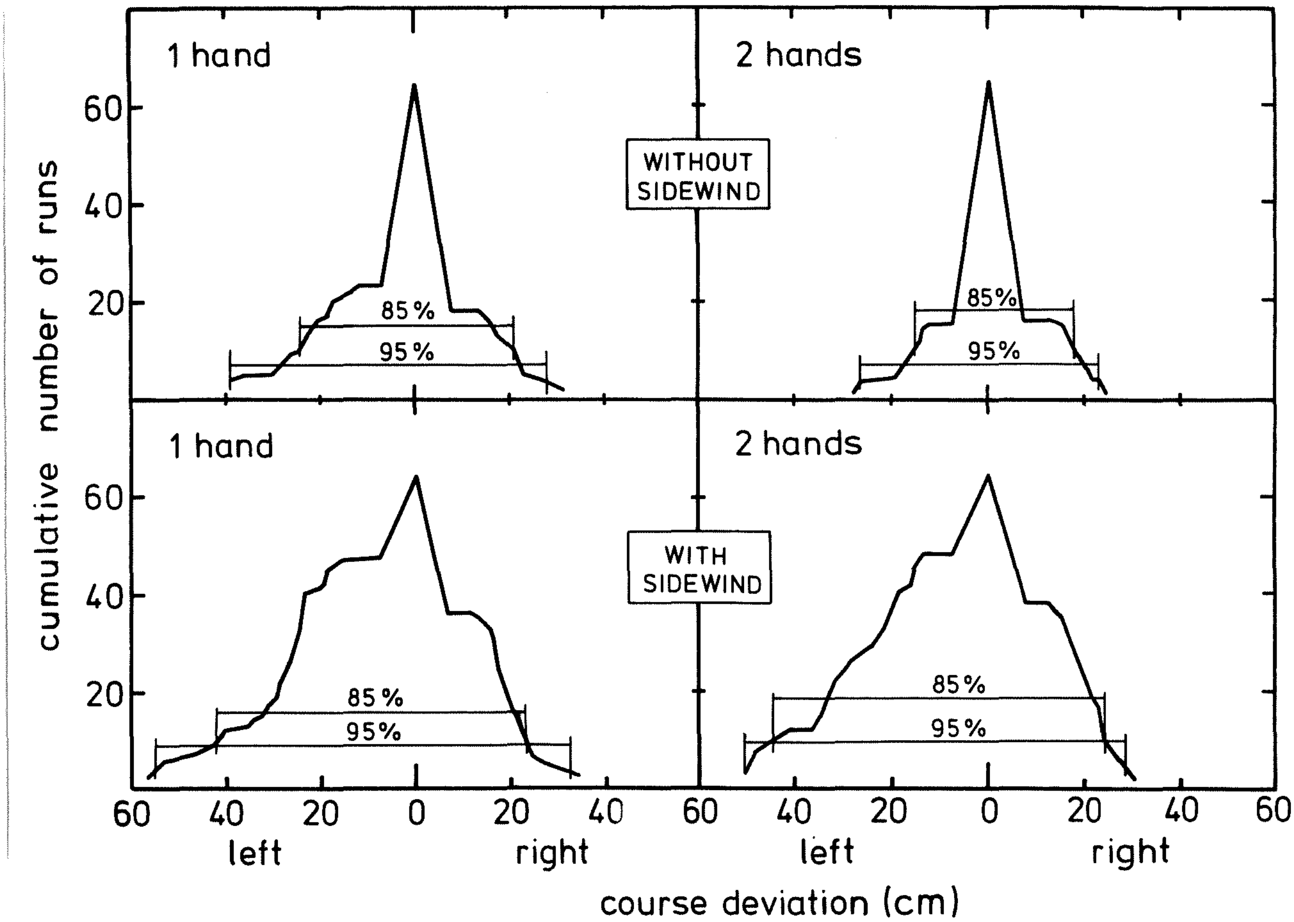


Figure 2. Popular single-track vehicles.



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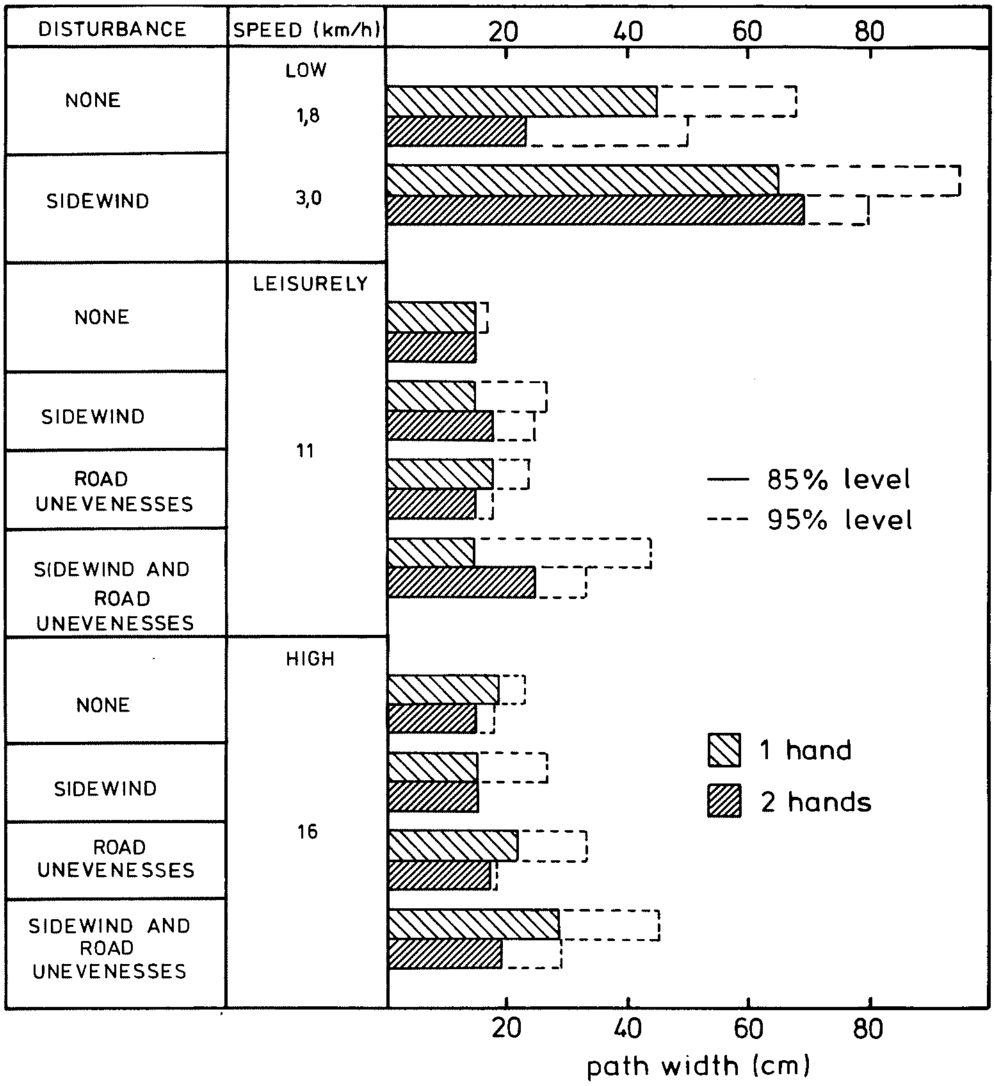


Figure 4. Required path width in test 1: "Course holding on a straight path" (instrumented bicycle, 1280 runs).

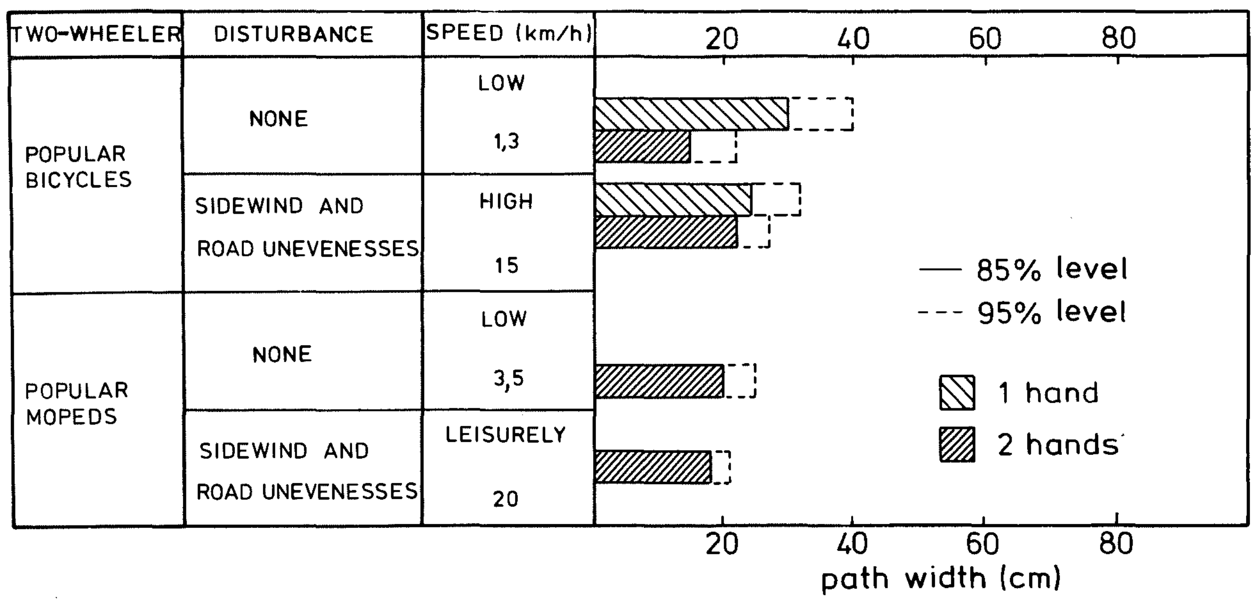


Figure 5. Required path width in test 1: "Course holding on a straight path" (popular single-track vehicles, 288 runs).

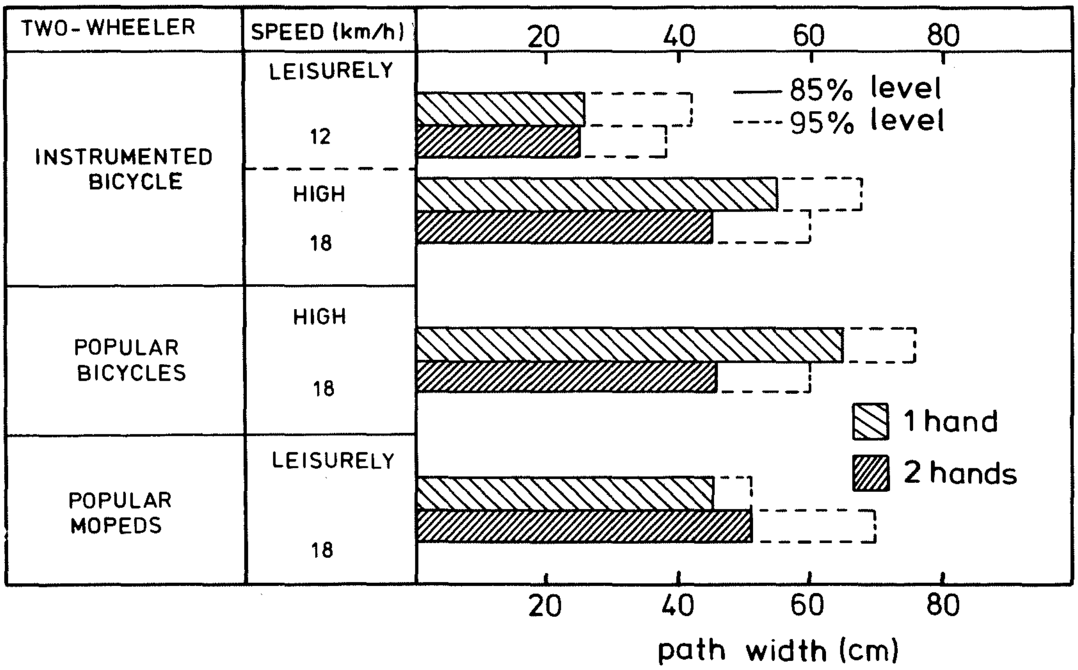


Figure 6. Required path width in test 2: "Course holding in a curve" (488 runs).

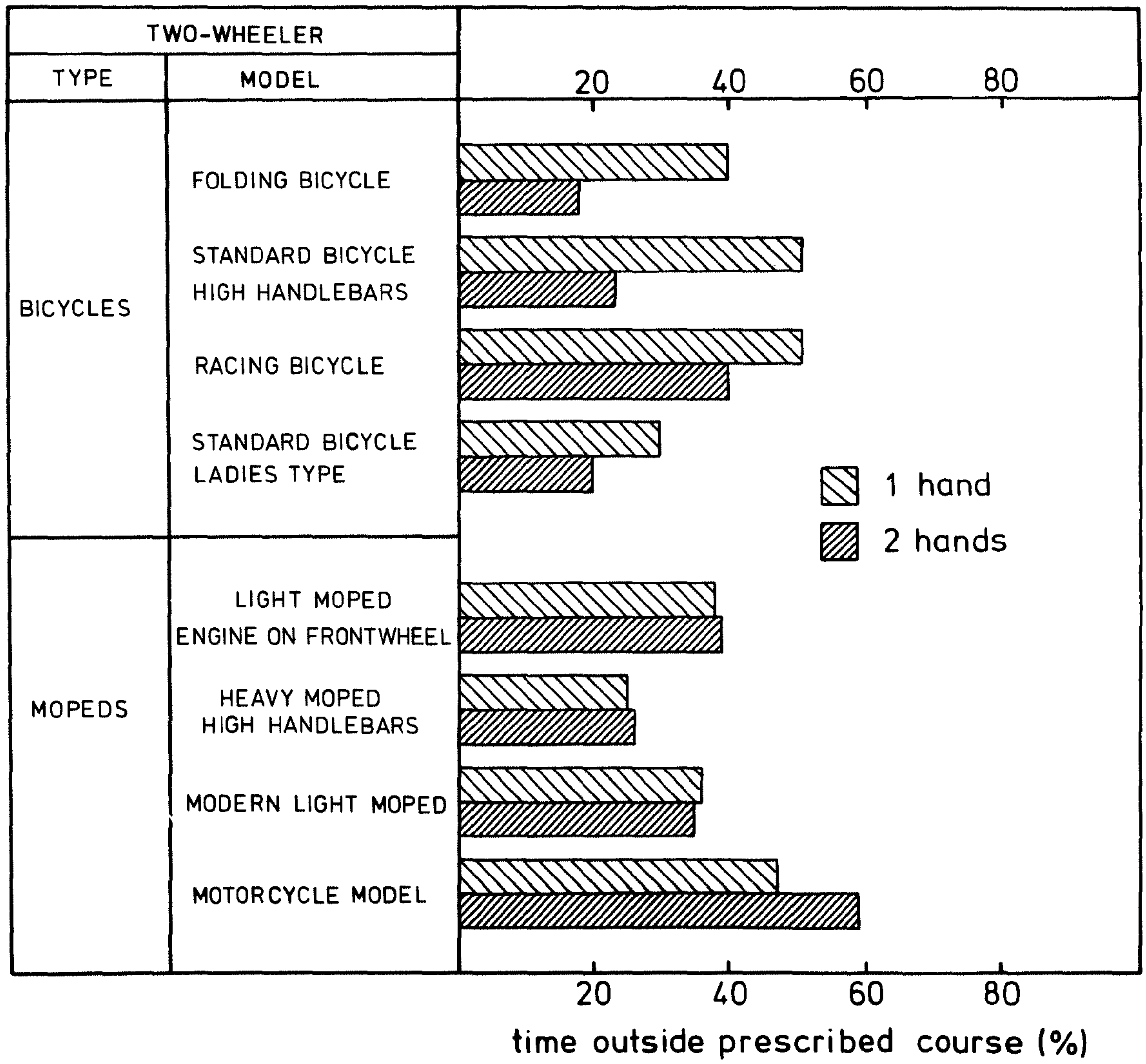


Figure 7. Time (%) outside prescribed path in test 2: "Course holding in a curve" (768 runs).

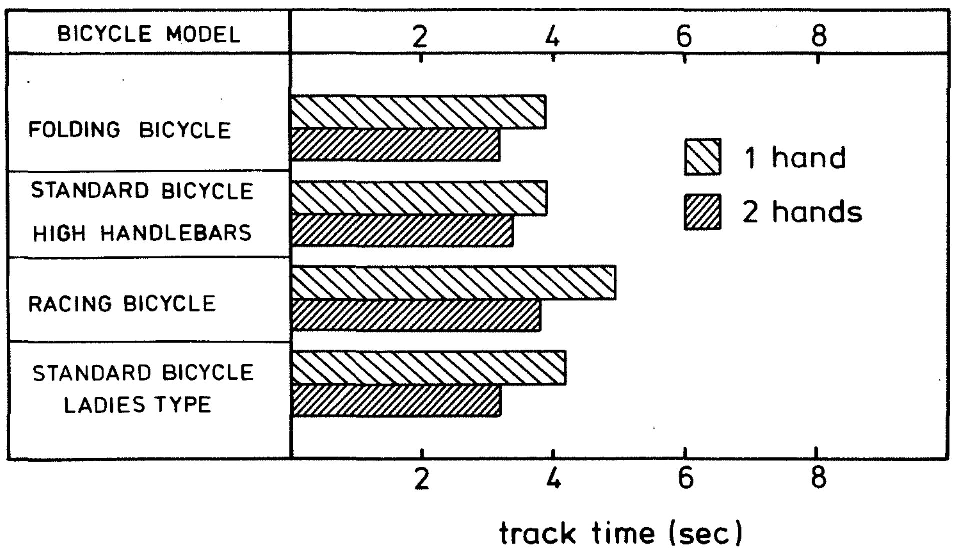
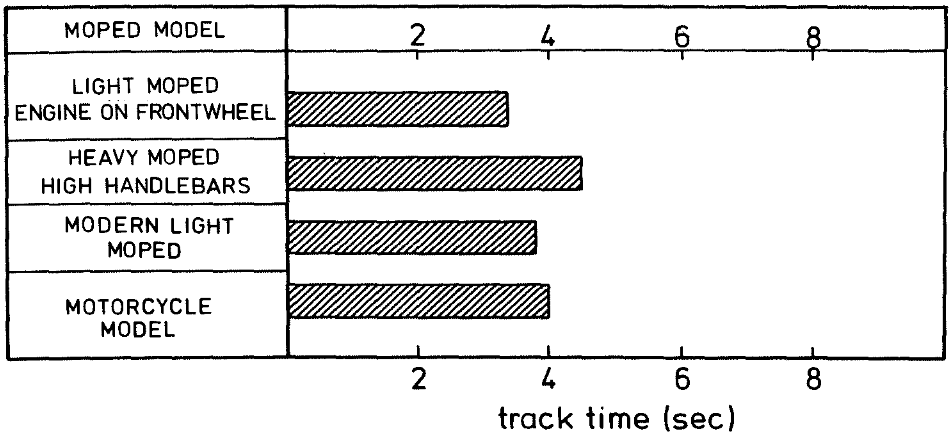


Figure 8. Track time in test 3: "Manoeuvring" (popular bicycles, 384 runs).



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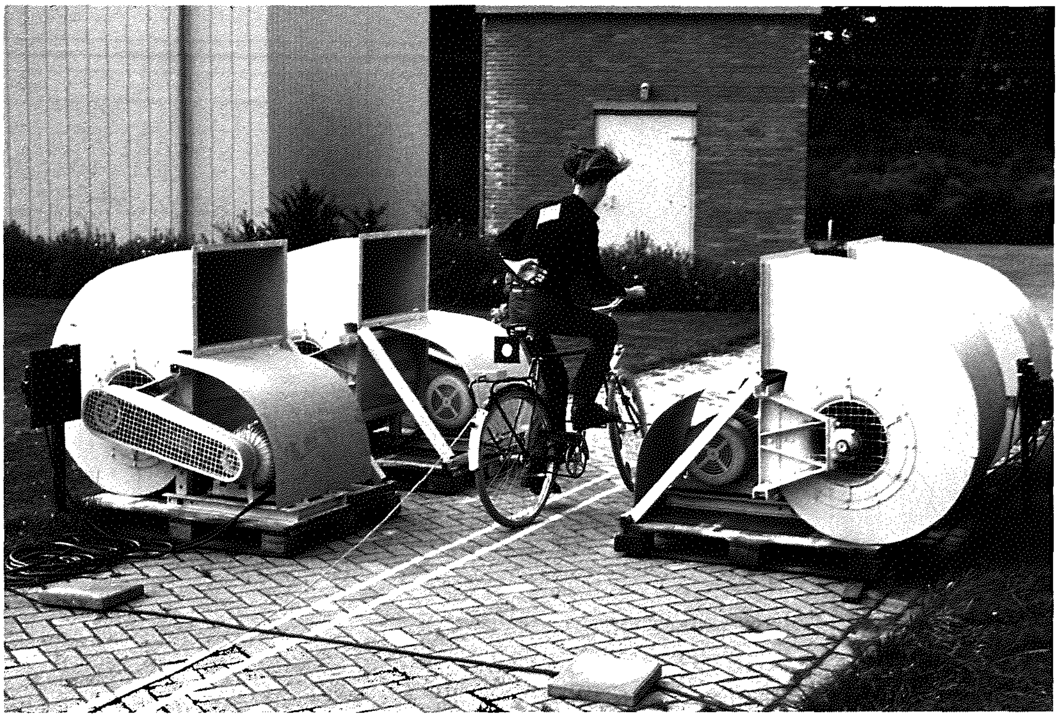

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