

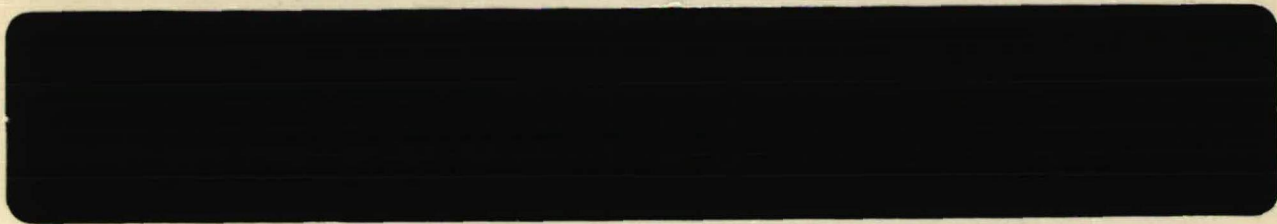
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**THE EFFECT OF LEAD VEHICLES ON
SPEED CHOICE UNDER RESTRICTED
SIGHT DISTANCES**

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Errata to the report IZF C-25 "The effect of lead vehicles on speed choice under restricted sight distances" by E. Tenkink.

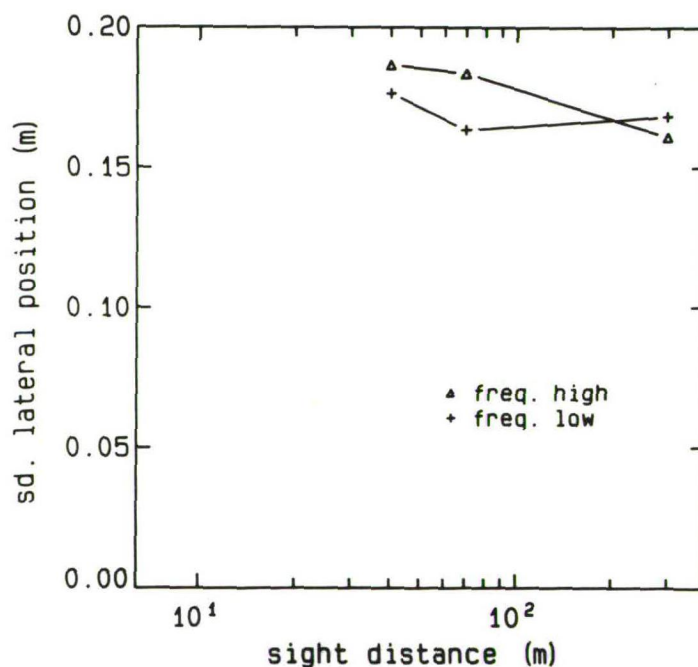
- p.13. The first two sentences of Par. 3.3.: "Analysis of variance... significance (Fig. 5)." should be replaced by the following text:

Analysis of variance of the speed showed no main effect of either sight distance or visibility distance (Fig. 4). Also, no main effect of the independent variables on the SDLP reached statistical significance (Fig. 5).

- p.14. 4th line from bottom line, after "...expl. var.)" should be added

", apparently allowing a corresponding reduction in SDLP ($F(2,22) = 4.7$; $p < 0.05$; 1.9 % expl. var.) (Fig. 5).".

- p.14. Fig. 5 should be replaced by the following figure:



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The effect of lead vehicles on speed choice under restricted sight distances

E. Tenkink

SUMMARY

This study deals with the effect of restricted sight distance on drivers speed choice. It is hypothesized that speed choice is dependent on uncertainties with respect to road way preview. In two experiments the importance of uncertainty about the ability to respond adequately to a slow moving lead vehicle on speed choice is explored. In experiment 1 the effects of lead vehicle's speed and sight distance were investigated because both factors might affect the ability to respond adequately. Subjects drove on a winding road in a driving simulator and were asked to choose the highest possible safe speed. The results show that speed is reduced with a reduction of the (known) lead vehicle speed.

In experiment 2 both the preview distance towards lead vehicles and the sight distance with respect to the road geometry were varied independently. Thus, the information relevant for the uncertainty about lead vehicles but also for the uncertainty about lane keeping was varied and the relative contribution was established.

No speed effect of sight distance with respect to road geometry could be established if subjects were provided with sufficient preview distance with respect to lead vehicles. It is concluded that speed choice at sight distances between 40 and 70 m is dominated by uncertainty about the ability to respond adequately to lead vehicles, rather than uncertainty about adequate lane keeping.

Finally, possible practical implications of the results are discussed and a direction for further research is recommended.

Het effect van voorliggers op snelheidskeus bij beperkte zichtafstanden

E. Tenkink

SAMENVATTING

In deze studie worden effecten van het rijden met een beperkte zichtafstand op de rijsnelheid nader onderzocht. Verondersteld wordt dat de rijsnelheid zal afnemen als er onzekerheden zijn als gevolg van onvoldoende zicht op de weg. In twee experimenten wordt het belang voor rijsnelheid van de onzekerheid over de mogelijkheid om goed op voorliggers te kunnen reageren nagegaan.

In experiment 1 wordt het effect van de snelheid van voorliggers en van de zichtafstand onderzocht, omdat beide factoren direct de mogelijkheid zullen beïnvloeden om nog goed op voorliggers te kunnen reageren. Proefpersonen reden in een rijsimulator op een bochtige weg. Hun taak was om zo snel mogelijk en toch veilig te rijden. Een afnemende zichtafstand en een lagere verwachte snelheid van voorliggers leidde tot een afname van de snelheid.

In experiment 2 werd de afstand, waarop een voorligger zichtbaar werd (zichtbaarheidsafstand), en de zichtafstand, waarover de weg kan worden overzien, onafhankelijk van elkaar gevarieerd. Op deze wijze wordt de onzekerheid over voorliggers en over wegverloop onafhankelijk gevarieerd en wordt het onderlinge belang bepaald. Het resultaat laat zien dat er geen effect is van een beperking van de zichtafstand op de weg als de zichtbaarheidsafstand voor voorliggers maar voldoende is. De conclusie is dat voor snelheidskeuze bij beperkte zichtafstanden vanaf 40 m de onzekerheid over de mogelijkheid om op voorliggers te kunnen reageren van groter belang is dan de onzekerheid over de mogelijkheid om op de eigen weghelft te blijven.

Tot slot worden mogelijke praktische consequenties van de resultaten besproken en wordt een aanbeveling gedaan voor nader onderzoek.

1 INTRODUCTION

The relationship between restricted sight distance and speed choice is of prominent importance in 1) the geometrical design of roads and 2) in taking measures in situations with restricted sight distances. However, the mechanisms underlying speed reduction under condition of restricted sight distance are not fully understood. Therefore, the Transportation and Traffic Engineering Division of the Dutch Ministry of Transport commissioned a series of investigations into this relationship.

In many field studies it is found that sight distance is an important factor determining speed choice of car drivers. Typically, a reduction of sight distance below about 200 m leads to a reduction of the driving speed (a.o. Watts and Quimby, 1980; Michels and Van der Heijden, 1978; Hawkins, 1987; White and Jeffery, 1980).

The speed reduction is likely to result from the increased uncertainty about potential hazards as a consequence of the reduced sight distance. One potential hazard is that drivers with insufficient visual guidance would be unable to keep their lane. Thus, a gradual reduction of the sight distance would increase uncertainty about lane keeping performance on the road.

The importance of lane keeping performance for speed choice is suggested by various experimental findings.

Rockwell, Ernst, Rulon (1970) performed extensive field studies, where subjects drove at night on a nearly straight road in the absence of other traffic. The sight distance was controlled either by using special lamps illuminating various road sections or by using a special mask in front of the driver's face. The results converged nicely and show that lateral position control becomes less accurate at sight-distances below about 30 m, whereas speed reduction also becomes apparent below about 30 m, suggesting that speed choice and lane keeping performance are related.

Allen, McRuer, O'Hanlon et al. (1977) and Tenkink (1988) used driving simulators to test the effect of restricted sight distance on speed and lane keeping performance in the absence of other traffic. Subjects drove with an unpredictable steering task (curved roads, gusts of wind). The results show that at fixed speeds, restriction of sight distance to less than 70 m (Tenkink, 1988) and certainly to less than 40 m (Allen et al., 1977) led to diminished lateral position control and that freely chosen speeds are reduced such that the variation in lateral position was kept nearly constant.

However, the aforementioned studies were done in the absence of other traffic. It is likely that the potential presence of other traffic also affects drivers speed choice when sight distance is restricted. In particular, when the sight distance is reduced drivers should slow down in order to be able to respond adequately to obstacles or to slow moving vehicles.

The present study deals with the effect of the occurrence of lead vehicles (L.V.'s) on drivers speed choice under restricted sight distances. In experiment 1 the effect of factors affecting the ability to respond adequately are investigated, namely the lead vehicle's speed and the sight distance. This experiment further provides an estimation of the sight distance range over which a lead vehicle affects speed choice.

In experiment 2 the relative importance of both identified sources of uncertainty was established. Also, the frequency of occurrence of L.V.'s is manipulated in experiment 2 to verify if uncertainty about L.V.'s is affected by the amount of feedback or whether a decrease in the number of critical events induces a utility strategy or probability underestimation.

2 EXPERIMENT 1: EFFECT OF SIGHT DISTANCE AND LEAD VEHICLE SPEED

2.1 Introduction

If the presence of slow L.V.'s is an important factor in speed choice it should be expected that factors affecting the ability to respond adequately to these obstacles affect speed choice. The effect of two such factors, L.V. speed and the distance at which L.V. becomes visible, were investigated in experiment 1.

2.2 Method

Both experiments were run in a fixed base driving simulator. The perspective view of the outline of the road and of the L.V.'s was electronically generated (Evans and Sutherland PS 300) and projected in front of a mock-up of a car. The field of view was about 50°.

The road resembled a two-lane winding road with four curves to the left and four curves to the right (radii 200, 250, 330, and 500 m; deflection angle < 20°). Lane width was 3.6 m and the length was 1.8

km. A trial consisted of six contingent repetitions of this road section.

The L.V. was an outline drawing of a truck moving at a fixed lateral position and speed along the road. In each trial a total of five L.V.'s appeared. The time and position of occurrence was unpredictable to the subjects. The L.V.'s disappeared as soon as the subject decelerated to the speed of the L.V.

The sight distance was restricted by cutting off all contours beyond this distance.

The L.V. speed was either 30 or 40 km/h. Higher speeds were not considered because at the shorter sight distances a number of subjects would then drive at speeds equal to or less than 40 km/h. The L.V. speed was varied in blocks of four trials; half the subjects started with the lower, the other half with the faster of the two speeds.

The sight distances were 30, 40, 70 and 300 m. These values were chosen on the basis of an earlier experiment such that the expected differences in speed might be about equal. The latter distance allowed early L.V. detection and comfortable anticipation. This variable was fixed per trial and was presented in a digram balanced square, within a L.V. speed block.

Thus, each subject took part in eight conditions, namely two (L.V. speed) x four (sight distance).

The main dependent variable was the uninterrupted driving speed averaged over a length of 1 km. Two non-contiguous speed measurements were made on each trial. These measurements were made in the absence of a L.V.

Furthermore, we are also interested in possible effects on lane keeping performance. On a straight road lane keeping performance is usually expressed as the standard deviation of the lateral position. However, on a winding road, when the situation favours perfect lane keeping and the standard deviation should decrease, drivers tend to cut across curves and the standard deviation increases. To avoid this problem we measured the consistency in lateral position with which a location along the road is repeatedly passed. At each passage the lateral position was determined at various locations along the road. Six locations were selected at 300 m intervals. This distance allows for uncorrelated measurement. At each location a standard deviation was calculated based on the six values from each passage. The average of these standard deviations across locations was taken as a dependent variable (SDLP). SDLP is inversely related to the consistency in the

lateral position. Consistency will decrease (and SDLP will increase) if the visual information is insufficient to maintain lateral position.

Eight male subjects, aged between 25 and 45 (avg. 33.1) and with a driving experience between 10,000 and 30,000 km/year, took part in the experiment.

They were paid for their participation.

Subjects were given about one hour training to get acquainted with the driving situation. During this period they were presented with the various sight distance conditions and the proper L.V. speed. Drivers received another training before driving with the other L.V. speed.

The subjects task was to a) always avoid collision with a L.V., b) stay within lane (e.g. do not overtake L.V.) and c) drive as fast as possible.

Instructions b and c were made more explicit by reward for time gain and penalty points for lane edge crossings with which a small monetary reward could be earned.

Thus, when a L.V. appeared the proper action was to break until the speed was reduced to that of the L.V.. Then, the L.V. would disappear from view and the subject accelerated to the desired speed.

Subjects received no feed-back as to the absolute value of their speed.

2.3 Results and discussion

From Fig. 1 it may be seen that the average speed is reduced with restricted sight distances ($F(3,21)=27.6$; $p < 0.001$; 33% explained variance). The speed of about 80 km/h at 300 m is likely to be limited by the drivers' ability to stay within lane given the curvature of the road.

Furthermore, average speed also reduces significantly with a reduction of the L.V. speed from 40 to 30 km/h ($F(1,7)=5.7$; $p < 0.05$ 2.5% expl. var.). A post-hoc (Newman-Keuls; $p < 0.05$) test revealed that this reduction reached statistical significance at a sight distance of 40 m. Therefore, it may be concluded that the L.V. speed can be taken into account in speed choice. Thus, the ability to react adequately to a L.V. is of importance in speed choice.

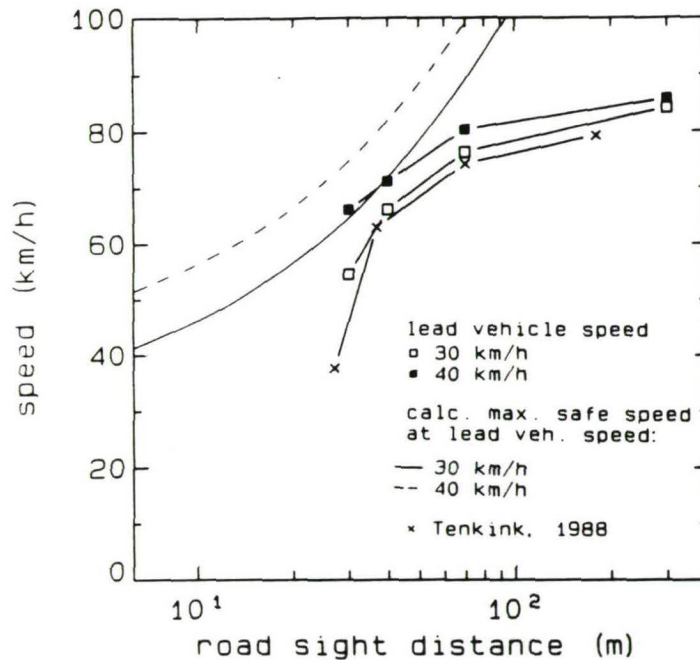


Fig. 1 Average speed choice and the calculated maximum safe speed as a function of lead vehicle speed and sight distance.

Furthermore, the average speed difference of 11.5 km/h at 30 m sight distance resulting from the differences in L.V. speed is about equal to the speed difference of the L.V. of 10 km/h. A speed reduction of 10 km/h following the reduction in L.V. speed would enable subjects to decelerate to the L.V. speed with the same average deceleration and within the same time interval. Thus, average speed choice appears to be quite accurately adjusted to the change in expected speed of the L.V. at the shortest sight distance.

Average speed choice at the shortest sight distance appears to be even objectively adequate. Figure 1 also gives the calculated maximum safe speed, assuming that subjects should be able to break for the L.V. with a deceleration of 3 m/s^2 and a reaction time of 1.5 s. It may be seen that the average speeds are well below these normative speed values. However, it should be noted that on the average about one out of eight subjects exceeds the normative speed. This occurred in all conditions, except at 300 m sight distance. At a sight distance of 30 m only one subject actually "collided" with a L.V., which drove at 30 km/h.

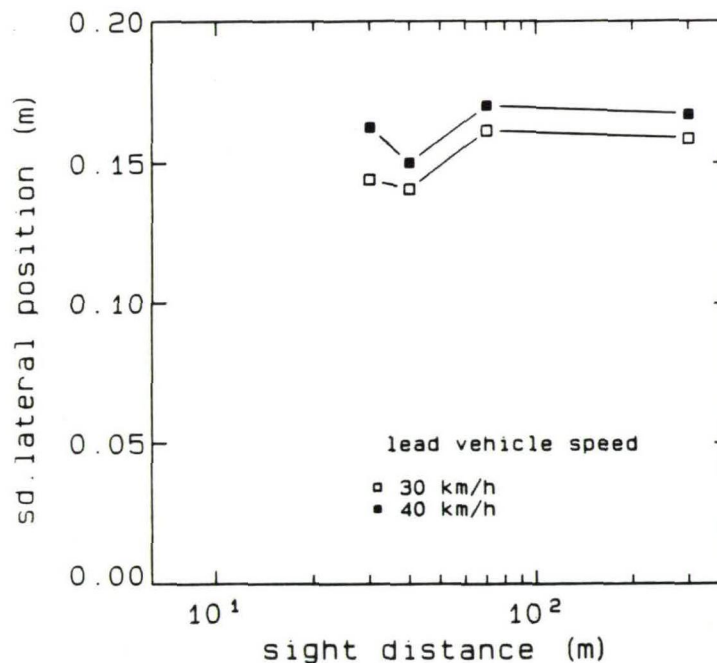


Fig. 2 Average standard deviation of the lateral position (SDLP) as a function of lead vehicle speed and sight distance.

Fig. 2 shows that the SDLP is reduced as sight distance becomes 40 m or less ($F(3,21)=3.4$; $p < 0.05$; 4.9% expl.var.). A subsequent analysis of variance of the SDLP data at 30 and 40 m showed that the increase at 30 m sight distance, suggested in Fig. 2, is not significant. A reduction of the SDLP with sight distance should be expected if the uncertainty about the ability to respond to L.V.'s is dominating speed choice. Then, the speed reduction, which is not caused by a lack of information about lane keeping, should enable drivers to improve lane keeping performance and decrease SDLP (Tenkink, 1988). The difference between the L.V.'s speed conditions was not statistically significant.

Thus, we conclude that L.V. speed affects speed choice at sight distances of 70 m and less and that the average speed is quite adequately adjusted to accommodate the restricted sight distance at which L.V.'s can appear. Yet, this does not mean that uncertainty about lane keeping is not important at these sight distances. Fig. 1 also shows that the speed reduction with restricted sight distances is similar to the reduction in an earlier experiment on a winding road (Tenkink, 1988). Because other traffic was absent in that experiment Tenkink

concluded that the uncertainty about lane keeping determines speed choice at these sight distances. This result strongly suggests that, in addition to the apparent effects of L.V.'s presence, the uncertainty about lane keeping performance also governs speed choice. The relative importance of both uncertainty factors is investigated in experiment 2.

3 EXPERIMENT 2: EFFECT OF SIGHT DISTANCE AND VISIBILITY DISTANCE

3.1 Introduction

The principal aim of experiment 2 was to establish the relative contribution of the two identified sources of uncertainty to speed choice. It is conceivable that the two sources contribute simultaneously in their effect on speed choice. Alternatively, it may also be that one source prevails completely over the other.

To investigate this, we distinguished between the sight distance (the distance over which the road outline could be seen) and the visibility distance (the distance at which a L.V. would become visible). It was assumed that a reduction of the sight distance contributes exclusively to the uncertainty about lane keeping. On the other hand, a reduction of the visibility distance is assumed to selectively increase the uncertainty about the ability to adapt speed adequately with respect to the L.V.. Thus, to establish the effects of each source of uncertainty separately and in combination visibility distance and sight distance were varied independently. This artificial dissociation was realized in the driving simulator. Fig. 3 schematically presents the four extreme conditions.

A secondary question of experiment 2 was about the effect of L.V. frequency on speed choice. Two interesting hypotheses may be opposed. Firstly, a decrease in the L.V. frequency would reduce the frequency with which the adequacy of a response can be verified. Since this increases the uncertainty about the adequacy of such a response this should lead to *speed reduction*. Alternatively, the reduction in the frequency of critical events reduces the overall likelihood of an "accident". Thus, either due to utility-evaluations or due to probability underestimation of small frequencies, (cf. Fuller, 1989; Svenson, 1977) one might expect an *increase in speed*.

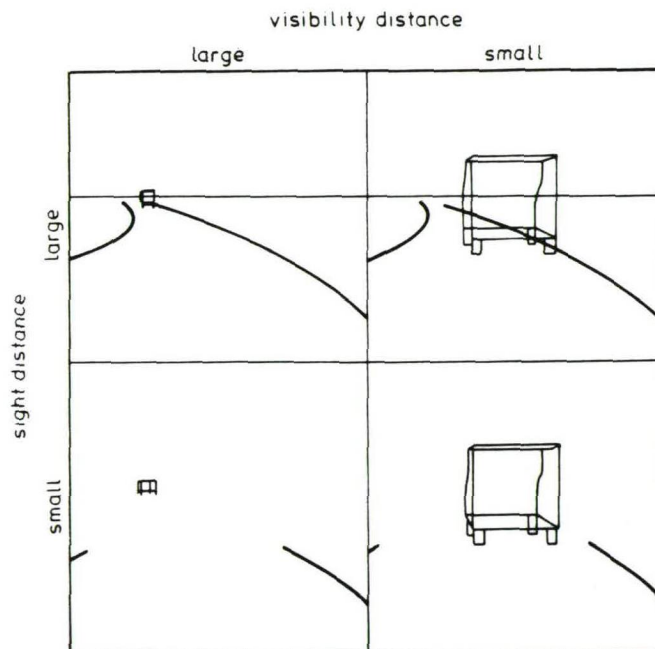


Fig. 3 Examples of the stimuli when sight distance and visibility distance are varied independently.

3.2 Method

In experiment 2 the same methods and procedures were used as in the previous experiment. A different group of twelve male subjects took part in the experiments. Their age was between 25 and 51 (avg.: 32.6) and the driving experience as in experiment 1.

The frequency of L.V.'s was either five (high) or one (low) per trial. This variable was presented in blocks of trials; half the subjects started with the high, the other half with the low frequency.

The L.V.'s speed was always 30 km/h.

The visibility distance used were 70 and 300 m. The 70 m condition was chosen because at that distance a speed change was not yet physically necessary (cf. Fig. 1). Visibility distance was presented in blocks of trials, the order alternating between L.V. frequency blocks.

Sight distances were 40, 70 and 300 m, presented in a latin-square order within the visibility block.

Thus, each subject took part in twelve trials, namely two (L.V. frequency) x two (visibility distance) x three (sight distance).

The dependent variables speed and the SDLP were measured as in experiment 1.

3.3 Results

Analysis of variance of the speed showed no main effect of either sight distance or visibility distance, but did reveal an interaction effect of sight distance with frequency ($F(2,22)=4.8$; $p < 0.05$; 1.3% expl. var.) (Fig. 4). No effect of the independent variables on the SDLP reached statistical significance (Fig. 5).

The lack of an effect of sight distance means that, in this experiment, the increasing uncertainty about ability to keep within a lane is relatively unimportant at these sight distances. The visual information at 40 m is still adequate to maintain both speed and SDLP.

In particular in the condition with visibility distance of 300 m this suggests that presenting subjects with a certainty of being able to respond adequately dominates speed choice, even at a road way sight distance of only 40 m (Fig. 4).

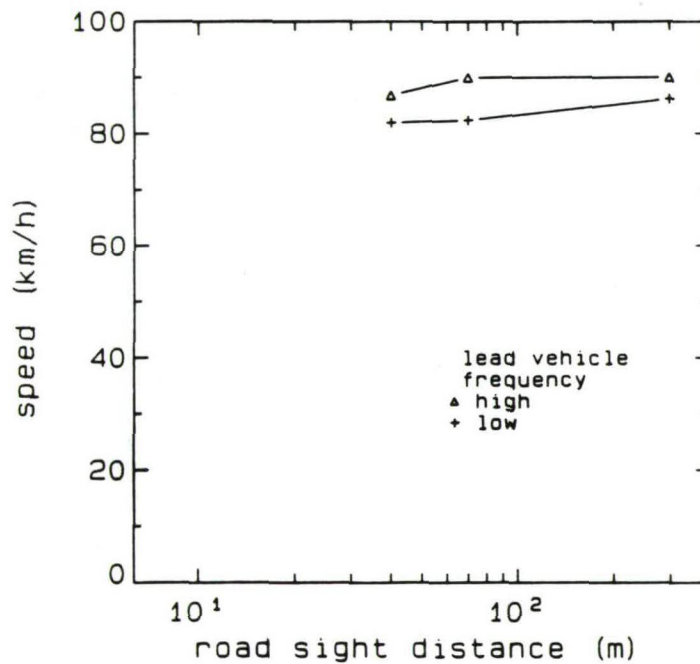


Fig. 4 Average speed as a function of sight distance and L.V. frequency.

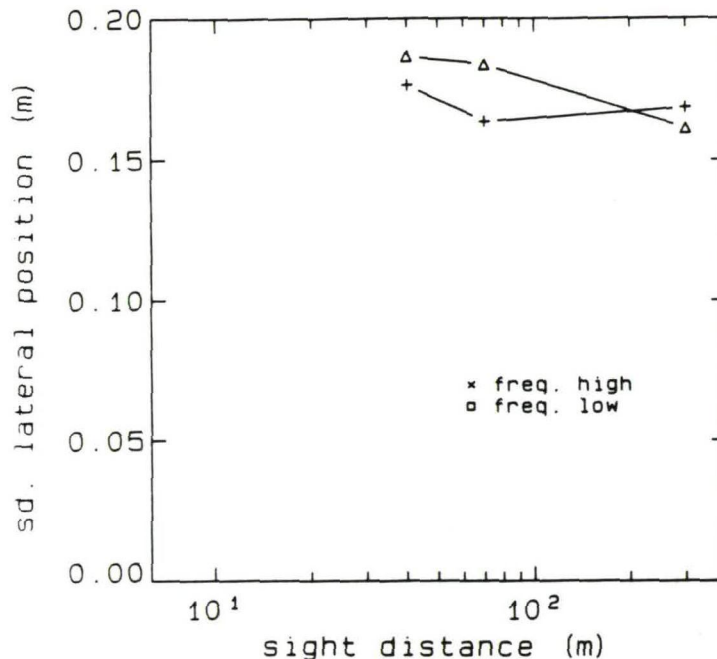


Fig. 5 Standard deviation of the lateral position as a function of sight distance.

The lack of a statistically significant difference in speed between a visibility distance of 300 and 70 m is not easily explained. It was expected that subjects at 70 m sight/visibility distance would become uncertain about an adequate response and, consequently, reduce their speed. Apparently, subjects behave as if they are as certain whether the visibility distance is 70 m or 300 m. Indeed, there is no objective need for a speed reduction as the average speed is still well below the maximum safe speed¹ (cf. Fig. 1).

From Fig. 4 it may also be seen that a reduction in L.V. frequency leads to a speed reduction at the shorter sight distances ($F(2,22)=4.8$; $p < 0.05$; 1.3% expl. var.). This finding contradicts the utility-interpretation in which a decrease in the overall probability of an "accident" would be traded against time-gain by increasing speed. Rather, it appears that a low frequency increases uncertainty

¹As in experiment 1 individual speeds did exceed this normative speed. In fact, in the 70 m visibility condition on average about 4 out of 12 subjects exceeded the maximum safe speed. Again only one subject "collided" with the lead vehicle. Two subjects had to swerve into the other lane to avoid "collision".

about the adequacy of a response by reducing the amount of feed-back per unit of time.

4 DISCUSSION, CONCLUSIONS AND RECOMMENDATION FOR RESEARCH

The results of both experiments support the importance of lead vehicles on speed choice under restricted sight distances. Firstly, average speeds are quite adequately adjusted to the differences in expected lead vehicle speed. In addition, the decrease of the standard deviation of the lateral position (SDLP) in these conditions further indicates that lane keeping does not constitute a problem. Thirdly, providing a fixed distance at which the lead vehicle becomes visible nullifies the effect of a reduction in sight distance on the road outline found in experiment 1 on average speed and SDLP. This means that the uncertainty about the ability to respond adequately to lead vehicles rather than uncertainty with respect to lane keeping dominates speed choice for the sight/visibility distances between 40 and 70 m.

The lack of any effect on speed and SDLP at these sight distances implies that uncertainty about the ability to stay within lane becomes important only at sight distances less than 40 m. This is consistent with the results of Rockwell et al. and Allen et al. who found speed reductions at sight distances less than 30 m in the absence of other traffic (Fig. 6). If the experimenters' guarantee is sufficient to convince drivers that there will be no obstacles or slow moving vehicles on the road these findings constitute a straightforward measure of the effective range of sight distances in which lane keeping uncertainty dominates speed choice. The drivers must have been very confident indeed, because at an the average speed of about 70 km/h at 20 m sight distance (Rockwell et al, 1970) they would need an extreme deceleration (over 9 m/s^2) to stop in front of an obstacle.

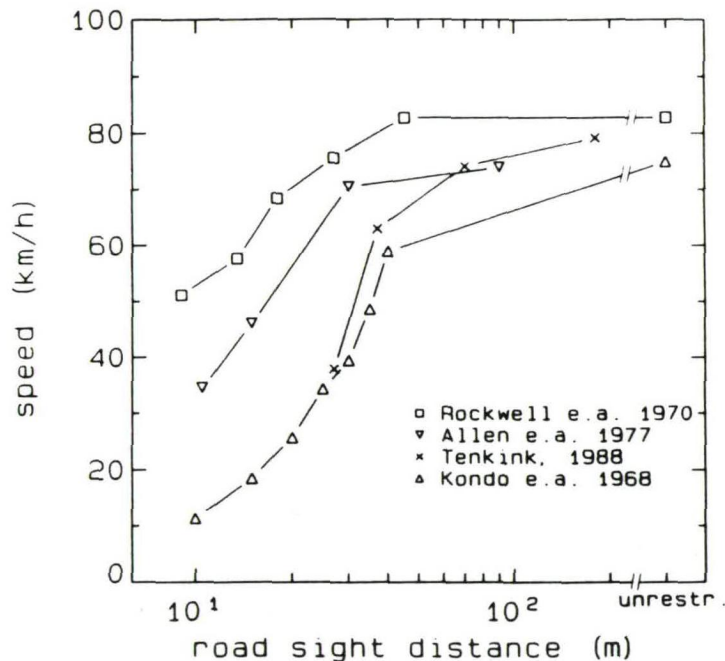


Fig. 6 Speed ~~reduction~~ as a function of sight distance in the absence of other traffic (data from: Kondo and Ajimine, 1968; Rockwell et al, 1970; Allen et al., 1977; Tenkink, 1988).

However, two earlier findings suggest that the experimenters guarantee may not always be sufficient. Firstly, also in the absence of other traffic Tenkink (1988) and Kondo et al. (1968) found speed reductions at sight distances between 40 and 70 m, comparable with the results from experiment 1. Secondly, on a straight road Tenkink found substantial speed reductions already at 70 m sight distance, whereas the steering task was highly predictable and even at fixed speeds and a sight distance as low as 27 m no problems on lateral position control were noted. Thus, on a straight road no indication was found that the speed reduction was the result of an increase in lane keeping problems. A possible explanation is that uncertainty about the possibility of an adequate response may be important to the driver, even in the absence of lead vehicles.

The speed reduction with the lower lead vehicle frequency supports such possibility. A low frequency would lead to an increase in this uncertainty because of a lack of proper feed-back on successful responses. In the complete absence of obstacles or lead vehicles the uncertainty about the adequacy of a response may actually be very high, and, therefore, the effect of restricted sight distance on speed

choice may have been affected by this uncertainty factor. Thus, even in earlier experiments (Rockwell, Ernst, Rulon, 1970; Allen, McRuer, O'Hanlon et al., 1977; Tenkink, 1988) the speed reduction with restricted sight distances might, at least in part, have been caused by the (implied) presence of obstacles or lead vehicles, even though lead vehicles were actually absent.

The results relate to various accident causes and behavior in real driving under restricted sight distances. We will discuss these relations and suggest further research.

The results may be of relevance to the use of *fog lights*, and in the near future, to the use of advanced *anti-collision warning systems*. Both devices are intended to allow drivers to anticipate lead vehicles under bad visibility conditions. If drivers use the certainty about lead vehicles provided by such devices to maintain their driving speed, as in the experiments, then the reduction of visual information with restricted sight distances will adversely affect lateral position control, because SDLP at a sight distance of 40 m increased in experiment 2 relative to experiment 1.

However, care should be taken to generalize the results to real driving. In the experiments the relative importance of the two uncertainty factors is likely to be affected by the task instruction. Thus, although the importance of the uncertainty about lead vehicles is demonstrated, it will require further field testing to establish its relative importance to that of the uncertainty with respect to lane keeping in a real fog situations with oncoming vehicles, necessitating perfect lane keeping.

The results further show that speed is reduced at restricted sight distances if the frequency of occurrence of lead vehicles is low. This suggests that drivers in fog may maintain driving speed on *busy roads*, but may reduce speed on *quiet roads*, because of a lack of verification and a increasing uncertainty about the ability to respond adequately to lead vehicles.

However, at present this proposition cannot be verified because we lack the relevant speed and accident data.

The results demonstrate that, on average, drivers can use visual cues and experience to adapt their driving speed to the visibility distance and speed of lead vehicles quite adequately. However, this does not mean that any driver will respond adequately at all times. Firstly, even in our experiments incidents were observed, notably swerving into the other lane and even "colliding" with a lead vehicle. Such errors

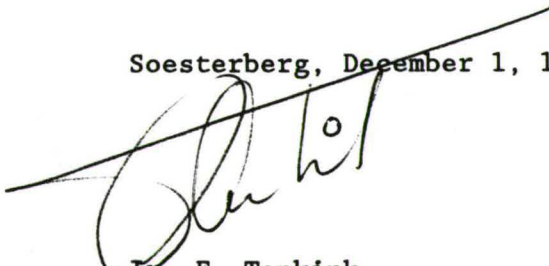
may reflect possible causes for accidents in real situations, where sight distance is restricted (e.g. fog). Furthermore, in reality the situation is still much more complex. In particular, the speed and frequency of occurrence of lead vehicles varies and cannot a priori be known. Then, drivers will probably choose a speed on the basis of their *expectancy about the lead vehicle speed and frequency*. As a result accidents may occur as a mismatch between speed choice based on expected lead vehicle speeds and an unexpected incident. An important example is the confrontation with an unexpected traffic jam in fog on a motorway. Knowledge of the factors affecting these expected speeds in restricted sight distances may provide alternative ways to affect driver's speed and detailed guidelines for selecting proper advisory speeds in such situations.

Therefore, it is recommended to study the factors affecting this speed expectancy in a subsequent experiment by comparing speed choice at various fixed lead vehicle speeds with speed choice when drivers are confronted with an unknown frequency and speed distribution of lead vehicles.

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Soesterberg, December 1, 1989



Dr. E. Tenkink

