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THE EFFECTIVENESS OF SIDE MARKER LAMPS: AN EXPERIMENTAL STUDY

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Abstract—The present experiment investigated the effect of small amber lamps mounted near the front and rear on each side of a passenger car—so called side marker lamps—on visual detection and recognition of passenger cars in complex nighttime environments. It was determined whether cars equipped with side marker lamps are detected and recognized earlier and more accurately than cars without side marker lamps. Subjects were presented with slides of natural nighttime scenes in which a car, either with or without side marker lamps, viewed from its side, approaching from a side street, was either present or not. Subjects determined as fast as possible whether a car was present or not. Reaction time measures (speed and accuracy) indicated that both under clear and fog visibility conditions, a car equipped with side marker lamps was detected and recognized earlier and more accurately than a car without side marker lamps. The results indicate that side marker lamps increase both lateral conspicuity and recognizability suggesting that side marker lamps may be effective in reducing the number of nighttime angle collisions. © 1997 Elsevier Science Ltd. All rights reserved

Keywords—Side marker lamps, Car driving, Reaction time, Fog

INTRODUCTION

Several years ago the Volvo Car Corporation considered whether to install side marker lamps on its future passenger cars. Side marker lamps are small lamps mounted at the front end and rear on each side of the vehicle, usually in or on the fenders or bumpers. Since 1969 side marker lamps have been mandatory in the United States. In the U.S., the front lamp must be amber and the rear lamp must be red. At this moment, the Groupe de Rapporteurs sur l'Eclairage (GRE, Meeting of the Experts on Lighting and Light Signaling) has not yet formulated the exact requirements for side marker lamps in Europe. The Volvo Car Corporation was considering whether to install amber side marker lamps on both the front and rear end of its passenger cars.

Although side markers lamps have been mandatory in the U.S. since 1969, the effect of side marker lamps has never been demonstrated experimentally. Flannagan and Sivak (1989) performed some computer modeling of the effects of side marker lamps in simple, dark environments. In addition, by means of accident statistics, Kahane (1983) failed to find an effect of side marker lamps on fatal angle collisions, while there was significant reduction in personal injuries.

The present study is the first study investigating experimentally the effect of side marker lamps in complex natural night environments. The study quantifies the effect of side maker lamps in relation to complexity of the environment, the atmospheric visibility, viewing angle and viewing distance. More specifically, it was investigated whether cars equipped with side marker lamps are detected and recognized earlier and more accurately than cars without side marker lamps.

As recognized by the NHTSA (Kahane, 1983),

> "the objective of side marker lamps is to make a vehicle visible from the side to the drivers of other vehicles, at night or other times when there is reduced visibility including dawn and dusk" (p.6).

It is assumed that due to the advance warning provided by the lamps drivers may be able to avoid a collision when approaching another vehicle at an angle at night.

The general notion of "visibility" can be broken down into two processes that play a crucial role in visual perception in driving (e.g. Theeuwes, 1991, 1993). In any situation, the driver first has to select where in the visual field the crucial information is present. This stage is followed by a recognition process: what is it that has just been selected. The

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"where" process depends on the conspicuity of the object which refers to the extent that an object stands out from the environment. The conspicuity of an object depends on the object–background relationship: an object may be conspicuous in one environment while inconspicuous in another. The "what" process depends on the extent to which an object has properties that are prototypical for such an object. Thus, it may take longer to recognize a tractor as a potential hazardous vehicle because the physical appearance of a tractor (the contours) and its speed do not resemble those of prototypical passenger cars.

The increased lateral visibility due to the side marker lamps may affect both perceptual processes (see also Sivak and Flannagan, 1993). Side marker lamps may increase the lateral conspicuity of a vehicle. Conspicuity is directly related to the probability of detecting a vehicle. A conspicuous vehicle will be detected earlier in time than an inconspicuous vehicle, especially in conditions of reduced visibility (fog and rain) and/or conditions in which there is a lot of visual noise (e.g. busy streets with billboards, street light, etc.). An improved detection of a potential hazardous vehicle is directly related to traffic safety. Side marker lamps may also speed up the recognition process. Especially from a side view, the front and rear lights give a poor representation of the body of a vehicle, making it harder to recognize it as a vehicle. A fast recognition is especially important in situations of visual overload (e.g. when approaching an intersection) in which many potentially dangerous objects demand attention. In addition, side marker lamps provide an additional coding that the vehicle is in fact a passenger car and not a bus, tractor, bike, or motor bike. Knowing that the vehicle is a passenger car of a particular length is important from a traffic safety point of view because this will activate expectations regarding the speed of travelling, priority regulations, etc. (see Theeuwes, 1996).

It is to be expected that side marker lamps will have benefits when the vehicle is viewed on a line perpendicular to the longitudinal axis of the vehicle. For certain types of vehicles (vehicles with headlights emitting light only to the front of the vehicle) there is hardly any lateral signal light except for reflection from chrome work and a dim diffuse reflection from the ground. In many cases however the illuminated path is lost in the general pattern of lighting (e.g. due to street light) or is lost due to an impoverished reflection from the ground (e.g. due to rain).

It is expected that side marker lamps can only prevent nighttime angle collisions (Kahane, 1983). During daytime the side marker lamps are too dim to increase the vehicle's conspicuity or its recognizability. The side marker lamps cannot prevent head-on, rear-end or sideswipe collisions because they are considerably dimmer than the head- or taillights of the other vehicle (NHTSA, Kahane, 1983). According the NHTSA (Kahane, 1983) the

> "purpose of side marker lamps is to enable a driver to see another vehicle that is approaching at an angle at night (or is standing still with its side facing the driver) and to see it early enough that the driver can stop in time to prevent a nighttime angle collision, at least, slow down or take evasive action to reduce the severity of the collision".

In order to estimate the safety benefits of side marker lamps, we investigated whether cars equipped with side marker lamps are detected and recognized sooner than cars without side marker lamps. In the present study, subjects were presented with slides of natural nighttime scenes in which a car approaching from one of the side streets might be present. Subjects had to determine as fast as possible whether or not a car was present in one of the side streets. The time it took to make this decision and its accuracy was recorded. In half of the trials no car was present and subjects were required to press the "no" button. In the other half of the trials a car was present and subjects had to press the "yes" button. In half of these trials the approaching car had its side markers on; in the other half it had its side markers off. The time it takes to detect this car and the number of errors ("misses": responding there is no car while in fact there is one) is an adequate measure for its conspicuity/recognizability. When side markers have a positive effect, it is expected that the search time to find the car is lower and the number of errors is smaller for a car equipped with side marker lamps than for a car not equipped with side marker lamps. A faster search time and smaller number of errors suggest that the car is more easily detected and recognized.

By means of computer modeling, the detection distances of the side marker lamps for different viewing angles were calculated (see Appendix A). When a vehicle at the far end of a side street starts to approach an observer, the headlamps of the approaching vehicle will be considerably brighter than the side marker lamps. At some viewing angle however, the lateral light output from the headlights will be equal to the lateral output of the side marker lamps. At this angle, the side marker lamp "takes over" from the headlights. For the side marker lamps used in the experiment, a viewing angle of 9° gave the same detection distance as the headlamp. Based on these calculations, it was decided to use visual angles of 0°, 10° and 20° in the search experiment (see Fig. 1). At 0° the side marker lamps are slightly more conspicuous than the headlamps, at 10° the lamps have a more or less equal conspicuity, and at 20° the headlamps are slightly more conspicuous than the side marker lamps.

METHODS

Construction of the stimulus material

Various different intersections within the Utrecht neighborhood were examined to see whether they would be suitable for use in the experiment. The intersections had to meet several requirements. First, since it was hypothesized that side marker lamps would be particularly beneficial in environments in which there was some visual noise, only sites with visual noise (street lights, lights from building, billboards) were selected. Second, pictures were taken from both 40 and 60 m from the crossing. These distances were chosen because they represent the more or less comfortable (60 m, braking with 2 m/s^2) and emergency stopping (40 m, braking with 3.5 m/s^2) distances required to come to a complete stop when driving 50 km/h (speed limit in a built-up area).

To obtain the three different visual angles mentioned above (0°, 10°, 20°) the intersections had to be unobstructed on both the right and left side (no buildings, houses, etc.). For example, to obtain an angle of 20° when viewing from a 60 m distance, the side street have to be unobstructed for a distance of 21.8 m into the side street (see next section). Third, it was hypothesized that vehicles' light signals would be particularly effective in those circumstances in which the ambient environment does not reveal the body of the vehicle. Thus, only sites were selected which did not have a lot of street lights in the side streets, and which did not have lights directly behind the vehicle. This latter condition could give away the body of the car by negative contrast (dark contour against a bright background).

Given these considerations, three different types of intersections were used. Slides of intersection 1 (a 4-way intersection) were taken at a two lane road with a separate bike path, intersecting with a similar two lane road without a separate bike path. This intersection was visually "quiet". There was no priority regulation at this intersection. Slides of intersection 2 (a 3-way intersection) were taken at a two-lane road intersecting with a large 4-lane priority road with a separating middle barrier and separate bike paths. This was a busy street with a lot of visual noise and distraction coming from the hospital located adjacent to the intersection. Slides of intersection 3 (a 3-way intersection) were taken at a two-lane road intersecting with a two lane road. This road was located in a business district. There were many street lights both along the street and in the far distance. There was no priority regulation.

The stimulus material used in the actual experiment consisted of colored 35 mm slides taken from a 40 and 60 m distance from the center of the selected crossings. The procedure for taking these pictures was as follows. The location at the center of the intersection on a line perpendicular to the longitudinal axis of the vehicle was marked representing the 0° angle condition. From this center point which coincided with the front side marker lamp, along the longitudinal axis, at 7 and 14.5 m to both the right and left side, two locations on the right and two locations on the left were marked representing the 10° and 20° angle for the 40 m distance condition. For the 60 m distance condition, these longitudinal distances were 10.5 and 21.8 m for the 10 and 20° conditions, respectively. Figure 1 gives an overview of the viewing angles used in the experiment.

The camera was positioned on a tripod at eye level (approximately 1.40 m), either 40 or 60 m away from the center point of the intersection. The experimental car (Volvo 460, see Fig. 2) was positioned with its longitudinal axis perpendicular to the camera with its front side marker lamps on the marked locations. At each location, two pictures were taken, one picture with the side marker lamps on and one picture with the side marker lamps off (side marker lamps could be switched off manually from inside the car while the headlamps were still lit). In order to make sure that the circumstances in which the pictures were taken were exactly identical, it was ensured that

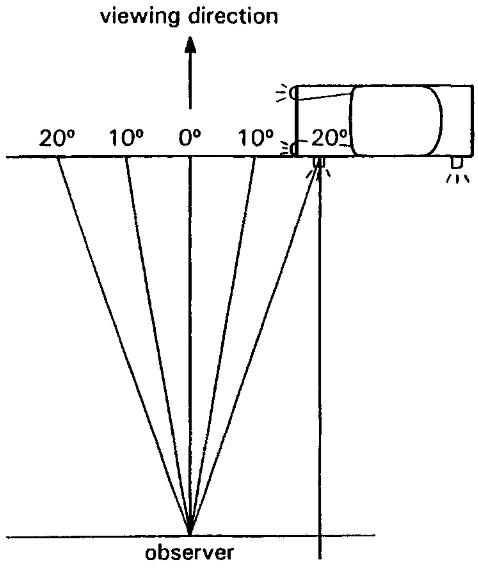

Fig. 1. The viewing angles in relation to the position of the car. In the experiment the car could either be located at the left or at the right side.

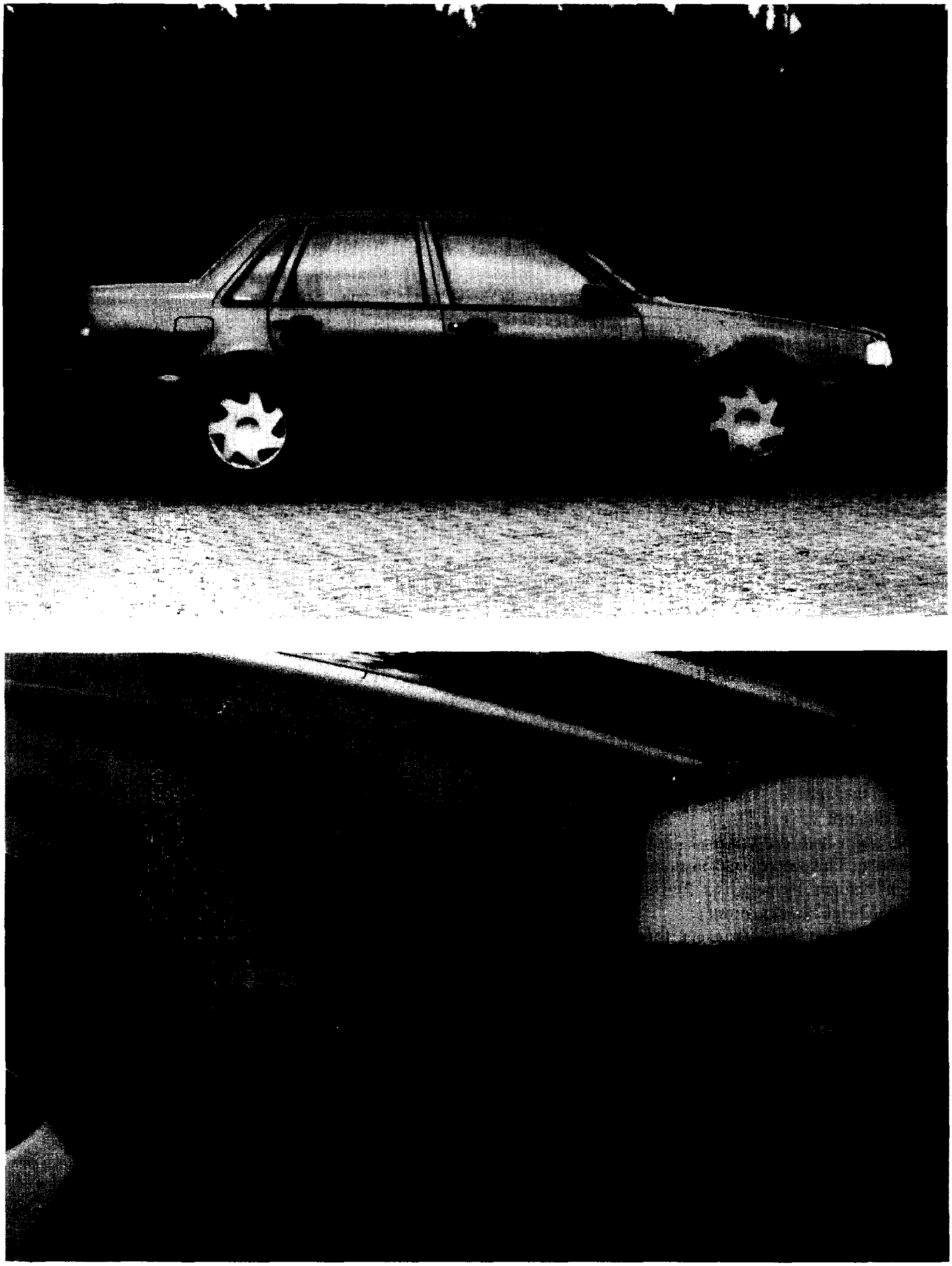

Fig. 2. Side view of the Volvo 460 with side marker lamps (top) and a close-up of a side marker lamp (bottom).

during picture taking no other traffic (cars, bikes, pedestrians) was present at the intersection.

For each intersection, 28 pictures were taken: 14 for the 40 m distance condition and 14 for the 60 m distance conditions. Of those 14 pictures, 7 were taken when the car was located on the right side, and 7 were taken when the car was located on the left side. Of these 7 pictures, one picture was taken from the intersection in which no car was present, and 6 were taken at each of the different angle locations (3 angle 0°, 10°, and 20° × 2 side marker lamp on/off). To allow for variation in ambient light from intersection to intersection, two different fixed exposure durations (4 and 8 s, aperture 5.6) were used. The ranges of luminances on the slides were as similar as possible to those in the real world. The pictures were taken at clear visibility conditions, at night between 8 p.m. and 2 a.m.

The experimental car

For the slide recordings, a Volvo 460 provided by the Volvo Car Corporation was used. Figure 2 gives a side view of the experimental car and a close-up of a side marker lamp. The side markers were prototypes (first shots from production tooling) with a reflector and lens.

The exact measured luminous intensities of the headlights and the side marker lamps are provided in Fig. 3.

Experiment

Subjects. Sixteen subjects ranging in age from 20 to 45 years participated as paid volunteers. Half of the subjects were male. All had normal or corrected-to-normal vision and had had their driving-license for at least 1 year.

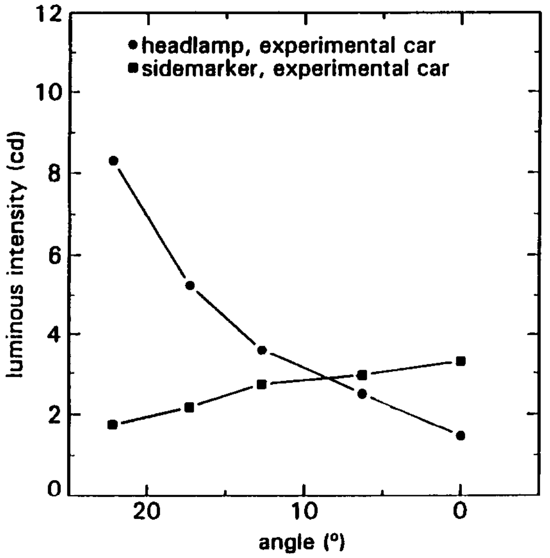

Fig. 3. Luminous intensities of (nearest) headlamp and side marker lamp of the experimental car used for the slide recording and the laboratory data at different angles.

Apparatus . A stimulus–response interface with external clocks (accuracy of 1 ms) connected to an IBM AT-3 with video-digitizer (Matrox Inc.) controlled the timing of the events, controlled slide projectors and recorded reaction times (RTs) and errors. The response panels consisted of left and right response keys (1 × 1 cm), which were mounted 0.5 cm apart.

The stimuli were projected by means of a random access Kodak carousel slide projector (Kodak Carousel S-AV 2000) on a white screen (170 × 215 cm). Stimuli subtended 178 × 100 cm constituting a visual angle of about 45° in the horizontal and about 30° in the vertical direction. Meteorological visibility of fog (100 m) was simulated by projecting stray light with an additional slide projector on the projected slide, and reducing the light output of the slide projector that projected the slides. The reduction of the light output of the slide projector was 22% corresponding to the transmission of the atmosphere at 50 m distance and a visibility of 100 m (see eqn (2)). The straylight luminance was set to 0.36 cd/m^2. This corresponded to 43% of the measured average road luminance on the slides. The 43% factor was calculated by means of eqns (5) and (6).

Two subjects separated by wooden partitions were tested in a dimly-lit room. Subjects were positioned centrally in front of the screen, 60 cm apart implying that they saw slides under a lateral angle of about 9°. Subjects were seated approximately 175 cm from the screen, comprising those visual angles that occur when viewing the scene in reality. The center of the screen was located 160 cm above the floor of the room. An intercom was used for communication with the subject.

Experimental design and procedure. The experiment involved a within-subject design with 5 factors, all varied within blocks: car (present/absent), side marker lamp (on/off), distance (40 and 60 m), angle (0°, 10° and 20°), type of intersection (visually quiet, visually busy, visually bright intersections). Visibility (fog of 100 m and clear) was varied within subjects between blocks of trials. All slides were presented 8 times. In half of the trials the car was located at the left side, in the other half it was located on the right side. In total there were 1152 trials.

Within each block of trials, slides were presented in a random order. Half of the subjects started with the clear visibility condition, the other half within the 100 m fog condition. Each block consisted of 288 trials and lasted approximately 40 minutes with a short break after 20 minutes. After a block of trials, subjects rested for 15 minutes.

Prior to the start of the experiment subjects received written instructions. It was explained that subjects had to search for a car coming from one of the side streets as fast as possible while minimizing errors. Half of the subjects were told that they had to press the right button as fast as possible when a car was present, and press the left button as soon as possible when no car was present. This assignment was reversed for the other half. Subjects pressed the buttons with their thumbs. Subjects were told that in only half of the cases a car was actually present. In addition, they were told that the car was either equipped or not equipped with side marker lamps. In order to minimize guessing, it was stressed that subjects had to visually search for the car and respond when they were sure about their decision. There was no feedback regarding the response. Before each visibility condition, subjects received approximately 15 random practice trials. Subjects who first started with the fog condition received a few slides in the clear visibility condition to get them acquainted to the type of slides they would receive.

The sequence of events during a trial was as follows: subjects were instructed to fixate the middle of the screen where the slide would be presented. As soon as the slide was presented subjects were allowed to start searching. The display remained on until both subjects emitted a response.

Results and discussion

Car present/absent responses. Mean reaction times (RT) and error rates were computed for each subject in each condition. Individual mean correct RTs were submitted to an analysis of variance (ANOVA) with car present/absent and visibility (fog/clear) as main factors. There was a main effect in RT of car present/absent [$F(1,15)=44.6$; $p<0.01$] and for visibility [$F(1,15)=14.6$; $p<0.01$]. The interaction between these variables failed to reach significance. Figure 4 gives the effect of car present/absent for clear and fog conditions. As expected, the fog condition gave much longer search times (about 241 ms longer) than the clear visibility condition. In addition, deciding that a car is absent takes about 300 ms longer than deciding that it is present, suggesting that subjects search serially through the scene and respond "car present" as soon as they found the car (e.g. serial self-terminating search). If they do not find the car, they keep on searching until they have scanned the whole scene and respond "car not present". Similar to visual search occurring during driving, subjects made eye movements while searching the scene because the slides were presented at large visual angles corresponding to the real situation. The absence of an interaction between visibility and target present/absent indicates that in the case of fog, each eye fixation takes somewhat longer than in the clear visibility condition; yet, fog does not increase the number of fixations necessary to decide that no car is present.

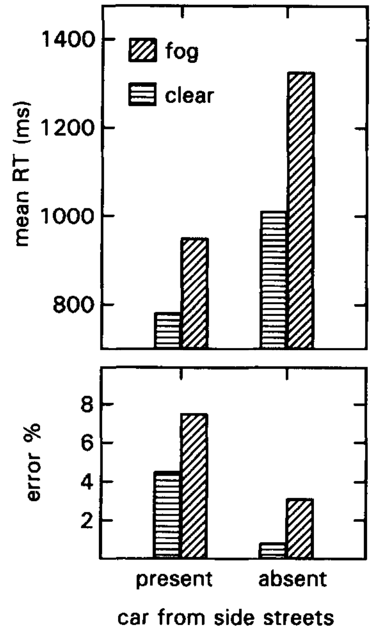

Fig. 4. Mean reaction time and error percentage for car present and absent responses in clear and fog visibility conditions.

In order to achieve homogeneity of the error variance, the mean error rates per cell were transformed by means of an arcsine transformation. This measure was subjected to the same ANOVA as the response data. There was a main effect on the arcsine transformed error rate of present/absent [$F(1,15)=27.4$; $p<0.01$] and of visibility [$F(1,15)=7.5$; $p<0.05$]. This analysis indicates, as evident in Fig. 4, that there were more errors in the fog condition (average of 5.3%) than in the clear condition (average of 2.6%). Subjects tend to make more errors when a car is present, than when it is absent, indicating a tendency to miss the car (i.e. respond "car not present") while in fact it is present.

Type of intersection. In order to determine the effect of the side marker at each of the three intersections, mean RTs were submitted to an ANOVA with type of intersection and side marker on/off as main factors. There was a main effect on RT of type of intersection [$F(2,30)=85.5$; $p<0.01$] and of side marker on/off [$F(1,15)=53.6$; $p<0.01$]. The interaction between these variables was also significant [$F(2,30)=14.1$; $p<0.01$]. As clear from Fig. 5, the effect of side markers at the "bright" intersection

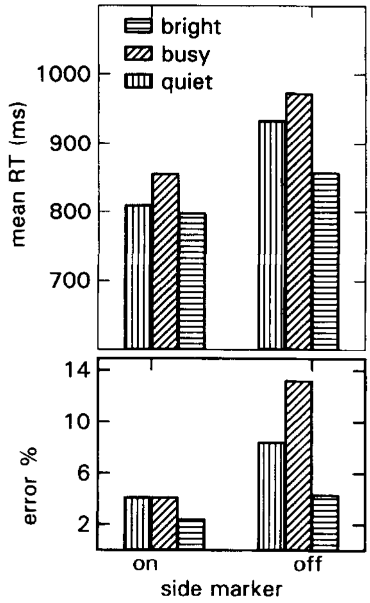

Fig. 5. Mean reaction time and error percentage for the different intersections.

near the business district is somewhat reduced relative to the effects of side markers at the other intersections. At the intersection near the business district there is relatively more light on the road surface which might have resulted in a reduced effect of side markers. In addition, it is possible that false reflections of the orange street lights on the car coating might have diminished the effect of the side marker somewhat. It is important that the effect of the side marker at the visually quiet intersection is similar to the effect at the busy street where there is a lot of visual noise and distraction. Note however that, overall, relative to the "quiet" intersection, visual noise and distraction present at the "busy" intersection does give longer search times ($p<0.01$).

Although the effect of side markers seems somewhat reduced at the "bright" intersection, planned comparisons revealed that the effect was reliable at all intersections (all comparisons $p<0.01$). An ANOVA performed on the arcsine transformed error scores showed the same effects as found on the response data (all ps<0.01). As clear from Fig. 5, errors tend to mimic the response times.

Effects of side markers. Since all intersections showed a reliable effect of side markers, the response data and error data were collapsed over intersections. The mean RTs and arcsine transformed error data of each subject of target present trials were submitted to an ANOVA with visibility (clear/fog), distance (40, 60 m), angle (0°, 10°, 20°) and side marker (on/off) as main factors. Table 1 gives an overview of all effects on mean RT and mean transformed error rates.

In the following section, only the interactions with side marker on/off will be addressed, because these are the only ones relevant for the discussion on the effectiveness of side markers. Since the effects found on the error scores mimic the effects as found on the RT data, there is no separate discussion of the errors. Conclusions based on the RT data also apply to the error data. The ANOVA indicates the error differences mimic the RT difference (except for the angle × side marker interaction), indicating that differences in response latencies cannot be attributed to trading speed for accuracy. Generally, there are significantly fewer errors in conditions side marker on (on the average 3.5%) than in condition side marker off (on the average 8.6%) suggesting that subjects are less likely to miss a car (e.g., "respond car not present") when in fact it is present. These findings are important because failing to detect a car while in fact it is present is immediately related to traffic safety.

Figure 6 gives the interaction between side markers and visibility. As clear from this figure, the effect of side marker is greater during fog (about 147 ms) than during clear weather (about 54 ms). Note however that planned comparisons also showed that in the clear visibility condition, the effect of the side marker lamps is reliable ($p<0.01$).

Figure 7 presents the interaction between distance and side marker. As clear, response times are significantly slower when the viewing distance is 60 m than when it is 40 m. The effect of the side marker is slightly larger at 60 m (about 120 ms) than at 40 m (80 ms).

Figure 8 shows the interaction between side marker and angle. As clear, when the car is located at a viewing angle of 20°, the effect of the side marker is relatively small, exactly as was predicted by the calculation of detection distances, and by the actual measurements of the luminous outputs of the side marker lamps and headlamps of the car (see "Methods"). At a viewing angle of 20°, it was calculated and measured that the headlamps had a higher luminous intensity than the side marker lamps, implying that the detection of the car at these angles will primarily be based on the headlamps' output rather than on the side marker lamps output. The small yet reliable advantage ($p<0.01$) of side marker lamp at the 20° angle (41 ms) suggests that side marker lamps still have some benefits even when the luminous intensity of the side marker lamp is less than the luminous intensity of the headlamp. According to the calculations, the side marker lamps were presumed to be more conspicuous than the headlamps only for

Table 1. The significant main effects and interactions on RT and arcsine transformed error rates

Effect	RT	Transformed error rate
Side marker on/off	$F(1,15)=53.6^{**}$	$F(1,15)=40.7^{**}$
Visibility (clear/fog)	$F(1,15)=19.3^{**}$	$F(1,15)=7.5^{*}$
Distance (40 m/60 m)	$F(1,15)=158.0^{**}$	$F(1,15)=43.5^{**}$
Angle	$F(2,30)=67.7^{**}$	$F(2,30)=19.8^{**}$
Distance × angle	$F(2,30)=47.2^{**}$	$F(2,30)=16.1^{**}$
Distance × side marker on/off	$F(1,15)=8.4^{*}$	$F(1,15)=29.5^{**}$
Angle × side marker on/off	$F(2,30)=18.1^{**}$	ns
Distance × visibility	$F(1,15)=23.9^{**}$	$F(1,15)=5.1^{*}$
Angle × visibility	$F(2,30)=13.5^{**}$	$F(2,30)=8.4^{**}$
Side marker on/off × visibility	$F(1,15)=15.6^{**}$	$F(1,15)=21.3^{**}$
Distance × angle × sidemarker	$F(2,30)=3.72^{**}$	$F(2,30)=5.7^{**}$
Angle × side marker × visibility	$F(2,30)=12.2^{**}$	$F(2,30)=6.4^{**}$

$^{**}p<0.01$; $^{*}p<0.05$.

viewing angles smaller than 9°, a result which is confirmed by the search data.

Figure 9 gives the second order interaction between angle, visibility and side marker on/off. This figure shows the same trend as the previous figure: the largest effects are found at the 0° viewing angle and the smallest effects at the 20° viewing angle. Note that the actual measurements of the luminous intensities (see "General Discussion") revealed that at 10° viewing angle, the luminous intensities of side marker lamps and headlamps are about equal. The search data show that at these equal intensities, there is still a substantial benefit of the side marker lamps both in fog (about 174 ms) and clear visibility conditions (60 ms). The maximum effect of side marker lamps at 0° is about 221 ms in fog and about 62 ms in clear visibility conditions.

GENERAL DISCUSSION

The results of the present study are clear: cars equipped with side marker lamps are detected earlier than cars that do not have side marker lamps both in clear and adverse (fog) visibility conditions. In addition, cars equipped with side marker lamps are

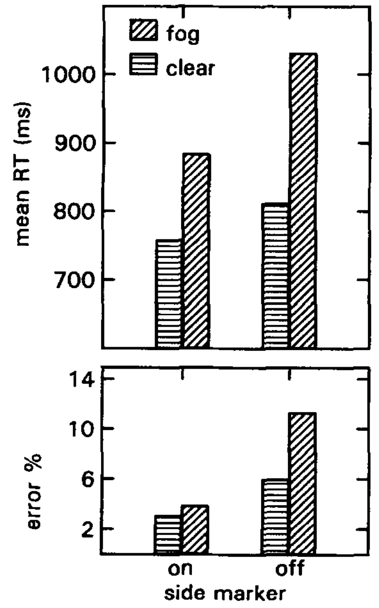

Fig. 6. Mean reaction time and error percentage for side marker on and off conditions in clear and fog visibility conditions.

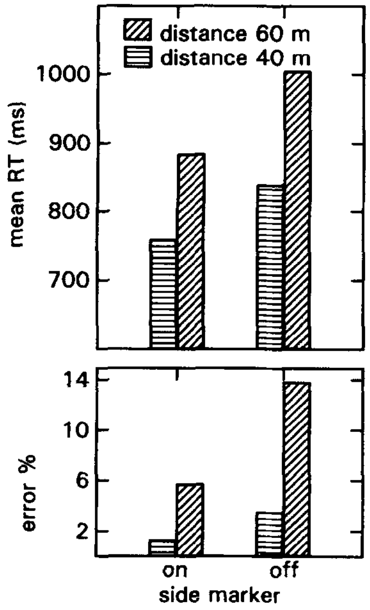

Fig. 7. Mean reaction time and error percentage for side marker on and off conditions for 40 and 60 m distance from the intersection.

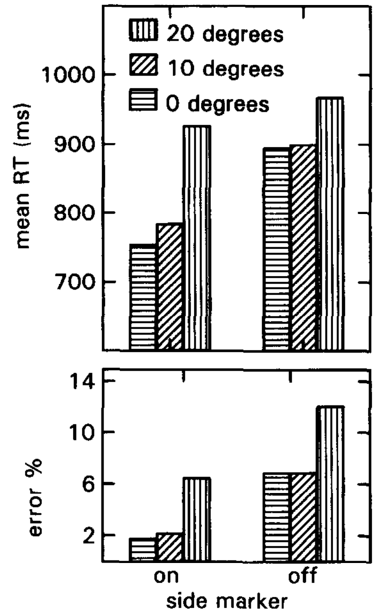

Fig. 8. Mean reaction time and error percentage for side marker on and off conditions for viewing angles of 0°, 10°, 20°.

less likely to be missed than cars that do not have side marker lamps both in clear and adverse visibility conditions. The beneficial effects of side marker lamps occurred both in relatively visually quiet streets as in busy streets in which there was a lot of visual noise.

In real driving the effects of the side markers may even be larger than those reported here because while approaching an intersection, drivers have to search for various potential targets at the same time, have to shift gears, reduce speed, and look for traffic signs (see also Theeuwes and Alferdinck, 1995). In the present experiment, drivers were solely focused on detecting a car in a side street. Even in these circumstances, the side marker lamps showed a robust and reliable effect indicating that side marker lamps should be considered as an effective property that allows a significant increase in the lateral conspicuity and recognizability.

Figure 9 shows that side marker lamps are especially beneficial at viewing angles smaller than 20° at which the side marker lamps are equal or more conspicuous than the headlamps. The effect of side markers at 20° (about 40 ms both in fog and clear conditions), suggests that side markers not only help to find the car but also help to identify the detected light source as a car. This argument is based on the assumption that at 20° the more conspicuous headlamps are used to detect the car while the less conspicuous side marker lamps possibly speed up the process of recognizing the detected lights as being a car. Whether side marker lamps also help to recognize the car at greater viewing angles at which the headlamps become much more conspicuous is unclear.

The beneficial effects of side marker lamps occurred both in relatively dark, quiet streets as well as in busy, visually noisy streets. Note however that at all the intersections selected for this experiment, there was not a lot of (street) light which could have lit the body of the car nor were there bright lights

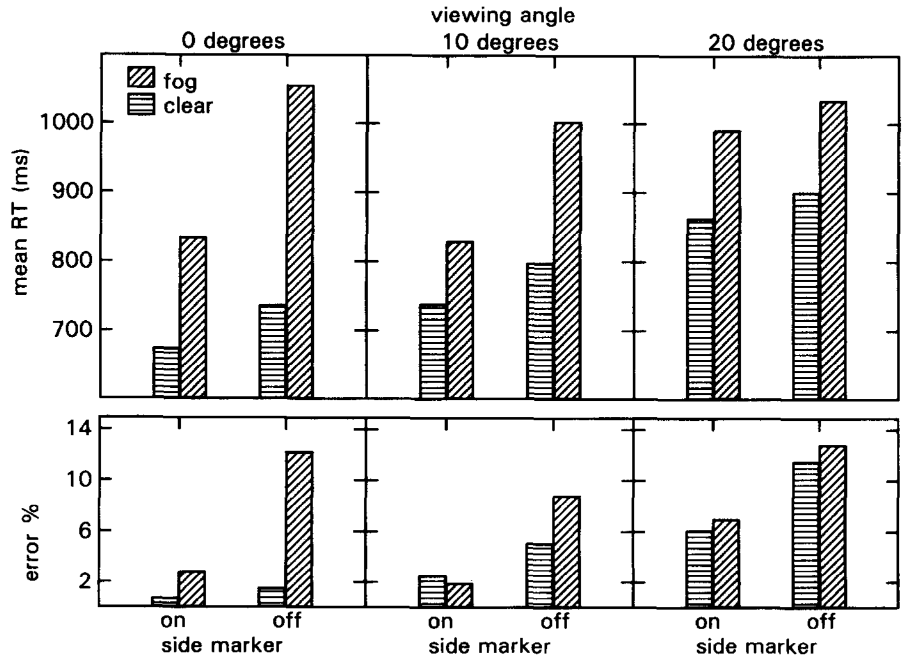

Fig. 9. Mean reaction time and error percentage for side marker on and off conditions for viewing angles of 0°, 10°, 20° in fog and clear visibility conditions.

behind the car which could have revealed the car by negative contrast. It is possible that at these intersections the effects of the side marker lamps are somewhat reduced. Yet, as argued earlier, because side marker lamps also help to recognize a car, it is also possible there are benefits of side marker lamps in these circumstances.

In actual traffic, the greatest benefits of side marker lamps are expected when the vehicle with side marker lamps is viewed on lines perpendicular to the longitudinal axis of the car not exceeding 10° of visual angle. There is still some benefit of side marker lamps at viewing angles between 10° and 20°. The present study did not include larger viewing angles, so it remains unclear whether benefits are to be expected at angles larger than 20°. Figure 10 gives the viewing angles for different collision scenarios in which the car on the main road has a relatively high speed (50–85 km/h) and the car in the side road a relatively low speed (5–30 km/h). Figure 10 represents a situation in which both cars have a constant speed and are on a collision course. As is clear from Fig. 10, when the car from the side street has a speed of 10 km/h or less, and the car on the main road a speed of 55 km/h or more the viewing angles are always below 10°, the range in which side marker lamps are most effective. When the speed of the car from the side street is between 10 and 20 km/h and the speed of the car in the main street is 55 km/h or more, the viewing angles are between 10 and 20°, the range in which there is still some benefit from the side marker lamps. Note that when the car from the side street has no speed, in order to be on a collision course the car from the side street is standing still in the middle of the intersection, giving a viewing angle of 0°. There are still other scenarios in which side marker lamps might be beneficial. For example, at an approach to an intersection when another car is waiting to cross the street and starts pulling out when the approaching car is close to the intersection. In addition, one can think of situations like a car pulling out of driveway or a car making a U-turn on the street. In all these situations, the viewing angles are quite small and the speed of car with which the approaching car is going to collide is also quite small.

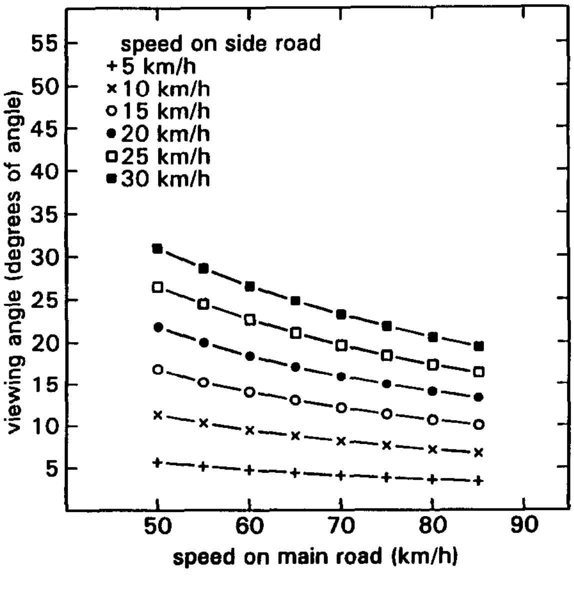

Fig. 10. Collision scenarios: viewing angles as a function of the speed of the car on the main road for different speeds of the car on the side road.

The finding that side marker lamps significantly reduced the number of errors (number of missed cars) is important because failing to detect a car and therefore failing to act upon that car is immediately related to traffic safety. At viewing angles of 0° and 10°, a car without side marker lamps is 3 times more likely to be missed than a car equipped with side marker lamps (see Fig. 8). At 20°, a car without side marker lamps is twice as likely to be missed than a car with side marker lamps.

Overall, the present study shows reliable beneficial effects of side marker lamps in both clear and foggy conditions, visually quiet and noisy intersections, at close (40 m) and farther (60 m) distances, and at various viewing angles (0°, 10°, 20°). Based on these findings, it is reasonable to conclude that side marker lamps are effective in increasing a vehicle's lateral conspicuity and recognizability, and therefore might be effective in reducing the number of nighttime angle collisions at intersections. Based on the present findings, in 1995, the Volvo Car Corporation introduced side marker lamps in Europe on its newest models, the Volvo S40 and V40.

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REFERENCES

Alferdinck, J. W. A. M. (1992) *Light Technical Requirements of Self-luminous Traffic Control Systems; A Literature Survey Applied to a Fog Warning Sign.* Report IZF 1992 C-6 (in Dutch). TNO Institute for Perception, Soesterberg, The Netherlands.

Alferdinck, J. W. A. M. and Nieuwhof, J. L. W. M. (1989) *Simulation of Long Range Atmosphere Effects in Short Range Thermal Infrared and CCD Images.* Report IZF 1992-27. TNO Institute for Perception, Soesterberg, The Netherlands.

Flannagan, M. and Sivak, M. (1989) *Nighttime Visibility of Side Marker Lamps.* Report No. UMTRI-89-21. The University of Michigan Transportation Research Institute, Ann Arbor, MI.

Kahane, C. J. (1983) *An Evaluation of Side Marker Lamps* *for Cars, Trucks and Buses*. NHSTA Technical Report DOT HS-806 430. Washington, DC.

Padmos, P. and Vos, J. J. (1974) *Intensity Control of Approach and Runway Lighting at Low Visibility at Night; A Theoretical Study*. Report IZF 1974-C2. TNO Institute for Perception, Soesterberg, The Netherlands.

Sivak, M. and Flannagan, M. (1993) Human factors considerations in the design of vehicle headlamps and signal lamps. In *Automotive Ergonomics*, eds B. Peacock and W. Karwowski. Taylor and Francis, London.

Theeuwes, J. (1991) Visual selection: exogenous and endogenous control. In *Vision in Vehicle III*, eds A. Gale et al., pp. 53–62. North Holland, Amsterdam.

Theeuwes, J. (1993) Visual attention and driving behavior. In *Human Factors in Road Traffic*, ed. J. A. Santos. Esher, Lisboa.

Theeuwes, J. (1996) Visual search at intersection: an eye movement analysis. In *Vision in Vehicles V*, ed. A. Gale et al., pp. 125–134. Elsevier Science BV, Amsterdam.

Theeuwes, J. and Alferdinck, J. W. A. M. (1995) Rear light arrangements for cars equipped with a center high-mounted stop lamp. *Human Factors* **37**, 371–380.

APPENDIX

Calculation of detection distances

When the illuminance on the eye of an observer caused by a point light source reaches a certain level (threshold level) the light is visible. For detection by night the threshold level ($E_{th,d}$) is 2×10^{-7} lx. The illuminance on the observer's eye depends on the luminous intensity of the light (I in cd), the viewing distance (R in m), and the transmission of the atmosphere (T) and can be calculated by

$$E=\frac{IT}{R^2} \tag{1}$$

The transmission of the atmosphere T can expressed as

$$T=\exp(-sR) \tag{2}$$

The parameter s is the extinction coefficient and depends on type and amount of rain, fog, etc. In case of fog the extinction coefficient becomes

$$s_{fog}=\frac{3}{V} \tag{3}$$

V is the meteorological visibility (in m) and is defined as the distance at which an object with an intrinsic contrast of 1 can just be perceived against the background of the sky, with the contrast threshold set at 0.05. For rain the extinction coefficient (s_{rain} in m^{-1}) depends on the rainrate r (in mm/h) and the type of rain (drizzle, widespread, or thunderstorm) (Alferdinck and Nieuwhof, 1989). For average rain the next equation can be used.

$$s_{rain}=0.000331\ r^{0.63} \tag{4}$$

A sharp shower has a rain rate of about 4 mm/h, resulting in a extinction coefficient of $7.93\times10^{-4}\,m^{-1}$. The corresponding meteorological visibility of 3784 m can be calculated using eqn (3).

The headlamps of the car of an observer and the public lighting can cause a veiling luminance (L_v) (Alferdinck, 1992), which increases the background luminance and thus threshold of the detection of light sources. For public lighting the veiling luminance is

$$L_{v,PL}=0.024\ E_{PL}(1-\exp(-3\frac{R}{V})) \tag{5}$$

E_{PL} is the illuminance on the road of the public lighting.

The veiling luminance due to the headlamps is

$$L_{v,headlamp}=\frac{15}{V} \tag{6}$$

The total veiling luminance is the sum of eqn (5) and (6). Taking 15 lx for E_{PL}, the veiling luminance varies between 0.66 and 0.0062 cd/m^2 for visibilities between 50 and 20 000 m. This results in an increase of the threshold illuminance at low visibilities of 50, 200, and 1000 with respectively a factor 3.72, 2.10, and 1.28 (Padmos and Vos, 1974).

To calculate the detection distance, R can be resolved iteratively from eqn (1) for a given I and V, with $E=E_{th,d}$ or $E=E_{th,c}$. $E_{th,d}$ and $E_{th,c}$ should be corrected for the veiling luminance.