Simulating the Effect of Low Lying Sun and Worn Windscreens in a Driving Simulator

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Abstract *- In the VTI Simulator III a method to create dazzle was tested and driver behaviour during dazzling was observed. Three windscreens with different degree of wear were used. In order to simulate a low lying sun in the driving simulator a halogen lamp was mounted in front of the windscreen. There were 24 subjects that all drove with each of the three windscreens. The drivers passed two obstacles during each drive. Afterwards they were asked to express their opinion about the experiment. They assessed both the simulated environment, including the simulated sun, and the driving task as realistic. Speed, braking power, steering-wheel angle, lateral position, and sight length were measured. The results showed a reduction in sight length when driving with worn windscreens. When the drivers had to make way for an obstacle on the road they discovered the obstacles later, used a harder braking power and took a more powerful action to avoid the obstacle, despite the fact that the average speed decreased significantly. Only when driving with the new windscreen all drivers managed to avoid collisions when passing the obstacles. The results indicate that driver behaviour and safety margins are severely affected by worn windscreens. The halogen lamp used in this study proved to be sufficient enough to simulate a low lying sun, thereby creating a sense of dazzling.*

Résumé *- L'objectif de l'étude présente est de tester une nouvelle méthode pour créer un éblouissement dans un simulateur de conduite. Le comportement du conducteur au cours de l'éblouissement a été observé dans le simulateur de conduite III du VTI. Trois pare-brises avec différents degrés d'usure ont été utilisés. Afin de simuler un soleil de faible altitude dans le simulateur de conduite, une lampe halogène a été monté à l'avant du pare-brise. Au total, 24 sujets ont participé à cette expérience et ils ont tous conduit avec trois pare-brises différents. Les sujets ont subit deux obstacles au cours de chaque conduite. Après la conduite, ils ont été invités à exprimer leur opinion sur l'expérience. Ils ont évalué à la fois l'environnement simulé, y compris la simulation du soleil et si la tâche de conduite était réaliste. Les variables dépendantes mesurées sont les suivantes : vitesse, puissance de freinage, angle du volant, position latérale du* *véhicule et la longueur de vue. Les résultats montrent une réduction de la durée de vue lors de la conduite avec le pare-brise très usés. Lorsque les sujets ont évité un obstacle placé sur la route, ils ont découvert les obstacles plus tard, ils ont utilisé une puissance de freinage plus grande et ont effectué une action plus efficace pour éviter l'obstacle en dépit du fait que la vitesse moyenne a diminué d'une manière significative. Aucune collision ne fut observée lors de la conduite avec le nouveau pare-brise. Les résultats indiquent que le comportement des conducteurs et des marges de sécurité sont largement influencés par l'état des pare-brises. La lampe halogène utilisée dans cette expérience c'est avérée suffisante pour simuler un soleil de faible altitude.*

Introduction

Visual information is one of the most important factors influencing driving performance. The driver's vision can deteriorate due to dazzling. This may occur because of low lying sun. During the dark hours dazzling is most often caused by oncoming vehicles. Dirty and worn windscreens may cause more light to be refracted into the drivers' eyes, thereby increasing the problem of glaring and impairment of the driver's visibility. In Mace *et al*. (2001) an overview with particular emphasis on headlight glare is given. The traffic safety problems of dazzling and worn windscreens have been observed in several studies (Pronk *et al*., 2001). Field studies by Lundkvist and Helmers (1993) showed that the sight distance decreases with the degree of windscreen wear. The test subjects drove in the dark and were dazzled by oncoming vehicles. Studies where glare is simulated in a driving simulator are relatively sparse. In Fullerton and Peli (2009) a method is described for creating a moving (on-coming vehicle) dazzling light source, using a LED matrix and a beam splitter. Moreover, in Rompe and Engel (1984) a study was conducted with different windscreens, in order to measure detection rate of projected symbols, while being dazzled.

The study presented in this paper is, as far as the authors know, one of the first to measure dazzled drivers' behaviour in critical situations and with different degree of windscreen wear. The aim of this study was both to create dazzle in the simulator and to perform an experiment on driver behaviour, in order to evaluate the possibilities to study the effect of dazzling when driving with worn windscreens.

Methods

In this study VTI's driving simulator III was used (Figure 1). This simulator is equipped with a passenger car cabin and an advanced motion system for realistic simulation of forces felt when driving (Nordmark *et al*., 2004; VTI, 26.03.2010). The surroundings of the driver are shown on a main screen with 120 degrees field of view, as well as in three back mirrors. A vibration table, which simulates road irregularities, is situated under the cabin and provides vibration movement relative to the projection screen. The motion system also provides high performance linear lateral acceleration, as well as roll and pitch movements of the entire platform.

Figure 1. VTI Simulator III

Experimental setup

In order to evaluate the effect of dazzling a within-subjects experimental design was used with a 3x2 setup (three windscreens and two critical events) and 24 test subjects. Only drivers that normally did not use lenses or glasses during driving were chosen. They were between 23 and 64 years old. Both men and women participated. Three windscreens were used; one new (windscreen 0); one worn, driven 150 000 kilometres (windscreen 15), and one very worn, driven 350 000 kilometres (windscreen 35).

In order to assess how worn the windscreens were, SLI (Stray Light Index, defined in German standard DIN 52298) was measured. Two instruments (DMO/Iris) were used. Each instrument gave considerable variations for each windscreen but repeated measurements, nevertheless, showed differences in the SLI values between the three windscreens. Windscreen 0 had a SLI value of approximately 0.05, windscreen 15 approximately 0.8 and windscreen 35 larger than 1.0.

Each driver drove with all three windscreens. They were instructed to drive as they would normally do under similar conditions. Between each drive the windscreen was replaced according to an experimental scheme with a balanced order. All windscreens were thoroughly cleaned in order to measure only the effect of the wear of the windscreen.

A road section of approximately 10 kilometres was created in the simulator. Two obstacles were placed by the roadside. One was a passenger car and the other an excavator. Both obstacles required an evasive manoeuvre. There were also some oncoming vehicles which occurred in predetermined places. The drivers had to pass each obstacle once during each drive. The distance between the two obstacles was 5 kilometres. In order to reduce the risk of the test subjects learning where the obstacles were placed, the starting point differed between the three drives. This resulted in different order of the obstacles and the distance to the first obstacle encountered.

Each drive was concluded with a measurement of the sight length. This was carried out on a completely straight road without other traffic. The test subjects were instructed to drive at 40 km/h and press a response meter button as soon as they discovered an orange cone placed on the hard shoulder.

Between each drive the driver answered survey questions.

Effect measurements

The drivers' subjective experience of driving in the simulator with the different windscreens was collected using questionnaires.

The behavioural data which has been collected in this study refers, above all, to speed, braking, movements of the steering wheel, position on the road and sight length. Average speed was calculated for two stretches, one before each obstacle. This gave the common basic level of speed.

All data were analyzed using T tests. A significance level of 5 percents has consistently been used. Detailed information about data can be found in Bolling and Sörensen (2009).

Results

In order to achieve dazzling from a low lying sun in the driving simulator, a lamp was mounted in front of the windscreen. The angle chosen between the horizon and the lamp was approximately 13 degrees. The glare shields were lowered during the experiment in order to prevent direct dazzling from the lamp. Figure 2 shows dazzling in the simulator from the driver´s perspective. Figure 3 shows the halogen lamp throwing a shadow and casting a reflection on the projection screen. The distance between the lamp and the driver was 2.8 metres and the lamp was positioned 0.65 metres to the right of the middle of the driver's field of vision.

Figure 2. Driver's perspective of dazzling in the simulator. Photo: VTI

Figure 3. The lamp with shadow and reflection on the screen. Photo: VTI

The light intensity from the lamp was adjusted before the experiment in such a way that the contrast was perceived realistic. This was mainly done by subjective ratings from VTI researchers. Measurements of illuminance in the simulator, with and without the halogen lamp Halospot 50W 24º, and with the use of windscreen 0, gave the results shown in Table 1a and 1b.

Table 1a. Illuminance [lx] in the simulator, lamp on, windscreen 0

Position	**Illuminance [lx] lamp on**
On the windscreen, outside the cabin in front of the driver's face	260
Driver's eyes, glare shield down	4.4

Table 1b. Illuminance [lx] in the simulator, lamp off, windscreen 0

Position	**Illuminance [lx] lamp off**
Driver's eyes, glare shield up, only projector light	2
Light green grass on the projection screen	18
Dark green trees on the projection screen	10
Different road surfaces on the projection screen	16–23
Blue sky on the projection screen – good weather, daylight	60
White clouds on the projection screen – good weather, daylight	90

As can be seen in the two tables the illuminance close to the driver's eyes was 2.0 lx without lamp and glare shield, but 4.4 lx with lamp on and glare shield down. Thus, using a simple fixed halogen lamp an effect of low lying sun was achieved in the driving simulator. Hence, the possibilities to study dazzling and the impact of windscreen wear were given.

The results of the experiments show that the effect of dazzling varied depending on the degree of windscreen wear. Several driver behavioural variables supported this conclusion. The driving performance deteriorated with the two worn windscreens, compared with the new one. However, the results did not seem to follow a linear function, since the driving performance was rather similar with the two worn windscreens, but differed from the new windscreen, see Figure 4.

For example, the drivers reduced their basic level of speed by 7–21 km/h with worn windscreens. When the driver had to make way for an obstacle on the road, this was more difficult with a worn windscreen, despite the lower speed. When driving with windscreen 35, the drivers on average discovered the excavator 60 ± 37 metres later, started to brake 139 ± 50 metres later, and then used a somewhat harder braking power. They also took a more powerful action to avoid the obstacle. When passing the excavator, the average distance to this obstacle was 1.6 metres with the new windscreen and 0.9 metres with windscreen 35. None of the obstacle passes while driving with the new windscreen led to any collision, whereas two obstacle collisions occurred with windscreen 15 and four with windscreen 35. .

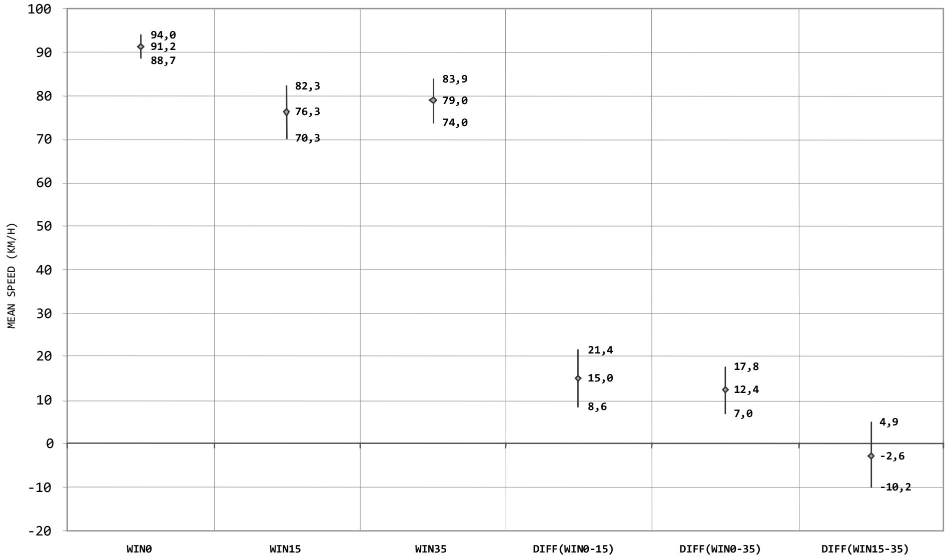

Figure 4. Average speed and difference in average speed before obstacle B (the excavator) for windscreen 0, 15 and 35, and confidence interval for the average speed and differences

The sight length to a cone was also measured and was shorter with a worn windscreen (Fig. 5).

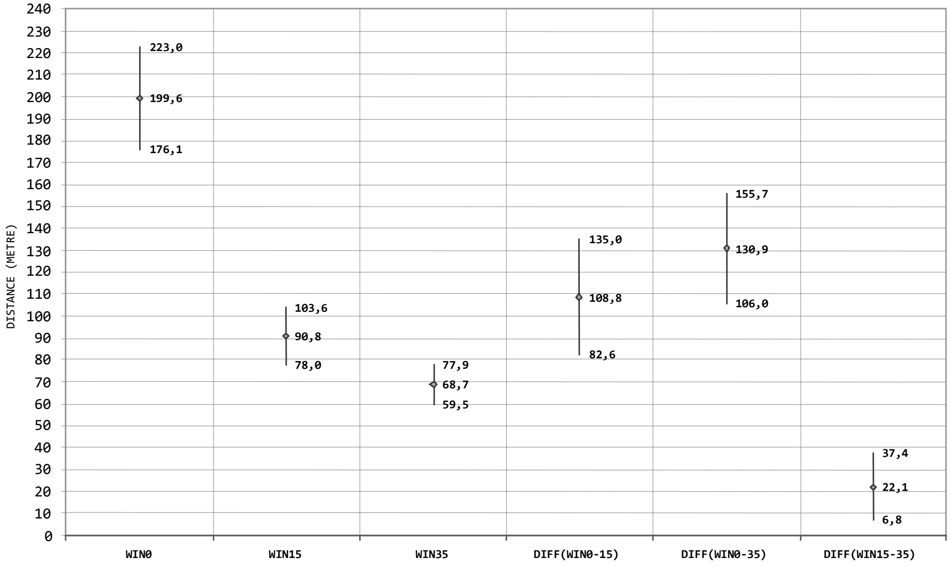

Figure 5. Average values for the distance to the orange cone with windscreen 0, 15 and 35, respectively, and differences in the average value between the windscreens (including the confidence interval for the average values and the differences)

The average sight length with windscreen 0 was approximately 200 metres when dazzled, whereas the corresponding values with windscreen 15 and 35 were 91 and 69 metres, respectively. The difference in sight length between windscreen 0 and windscreen 35 was on average 131 ± 22 metres, implying a reduction in sight length of approximately 65 percent.

The drivers were asked to grade the level of wear and safety of the windscreens on a 7 grade scale. Mean values and confidence intervals are shown in Table 2. The table shows that windscreen 0 was evaluated to be significantly less worn and significantly safer than the two other windscreens.

Table 2. Graded level of windscreen wear (1 = not worn, 7 = very worn) and safety (1 = very unsafe, 7 = very safe). Mean value and confidence interval, *n* = 24

	Graded level Mean value and confidence interval		
	Windscreen 0	Windscreen 15	Windscreen 35
Wear	3.5 ± 0.6	6.2 ± 0.5	6.7 ± 0.2
Safety	4.6 ± 0.7	1.4 ± 0.3	1.2 ± 0.2

After the last simulator drive, the test subjects had to grade how realistic they experienced the simulator environment to be, on the scale from 1 = very unrealistic to 7 = very realistic. The average grades and the dispersion are presented in Table 3. The results indicate that the test subjects experienced the environment and driving in the simulator as realistic, including the new feature of the artificial sun.

Table 3. Experienced level of realism. Mean values and confidence interval (on a 7-grade scale from 1 = very unrealistic to 7 = very realistic), *n* = 24

	Level of realism Mean value and conf. interval
Road environment	5.6 ± 0.5
Artificial sun light	5.6 ± 0.5
Steering function	6.0 ± 0.4
Braking function	4.9 ± 0.6
Driving task	6.2 ± 0.3
Road manners	5.8 ± 0.4

Discussion

This study has shown that dazzle in a driving simulator can be achieved by directing a lamp towards the windscreen, simulating a low lying sun. The test subjects assessed this artificial sunlight as realistic. Furthermore, the results from the experiment show that when dazzled, driver behaviour deteriorates because of worn windscreens. This indicates that driving under such difficult conditions entails an increased risk of accidents.

In simulator studies the experimental situation can be experienced as unrealistic and thereby affect driver behaviour in an unwanted way. The test subjects, however, expressed the opinion that the environment and the task was realistic and that the new windscreen was significantly less worn and significantly safer than the two other windscreens. Nevertheless, it should be kept in mind that the measured driver behaviour in a driving simulator not necessarily transfers directly to driving in real traffic environment. Even though the drivers were instructed to drive as they would normally do, they might on one hand have been influenced by the fact that they were being observed while driving, but on the other hand they may also have been influenced by knowing that they were not driving in real traffic.

A within-subjects design was selected because of the expected considerable variation between test subjects. For instance, scanning ability, eye sight and reaction time may vary with age (for an overview see e.g. Levin *et al*, 2009). It could therefore be of interest in connection with a future study to analyze the significance of the age or eyesight of the driver. This experiment included only drivers that did not use glasses or lenses while driving. Hence, on the basis of this study any effect of glasses or lenses on dazzling and driver behaviour can not be commented on.

As the results from the three tested windscreens did not seem to follow a linear function, it would be desirable to conduct corresponding tests also with windscreens driven, for example, 50,000 and 100,000 kilometres, respectively.

In this experiment dazzling of a low lying sun was simulated. Although the artificial sun was fixed in front of the windscreen and the level of luminous intensity was constant, the results indicate that this set-up is satisfactory for this purpose. It would, however, be of interest to further investigate the possibilities of using moving light sources with adjustable brightness. It would furthermore be interesting to study the effect of the eye's adaptation when exposed to sudden glare.

The problems with worn windscreens and dazzle also arise in other situations than in sun light, for example out of the headlight glare from oncoming vehicles during dark hours. It would be of interest to compare the method used in this study with the method proposed by Fullerton and Peli (2009).

Finally, it would be desirable to validate the different simulator methods, using data from real traffic.

Conclusions

The halogen lamp, Halospot 50W 24º, used in this study proved to be sufficient enough to simulate a low lying sun. The test subjects assessed this artificial sunlight as realistic, despite the fact that this lamp was fixed in front of the windscreen and that the lamp light intensity did not vary. However, the light intensity from the lamp must be chosen with care to match the projected images to achieve a realistic impression.

Even if the present study was performed in a simulator environment, instead of in real traffic, the results indicate that driving in dazzling light with a worn windscreen has negative effects on driver behaviour and safety margins. The problem might be even greater in real traffic, since there are other factors, such as dirt and moisture that cause reduced visibility and increases the level of dazzle.

Keyword: driver behaviour, driving simulator, windscreen wear, windshield, worn, glare, stray-light, dazzling, sunlight, sight length, speed, scattered light, driver's vision, questionnaire

Bibliography

Bolling, A., Sörensen, G. (2009) Worn Windscreens. *Swedish National Road and Transport Research Institute (VTI) VTI Rapport 657A, Linköping, Sweden.*

Fullerton, M., Peli, E., (2009) Development of a system to study the impact of headlight glare in a driving simulator. *Proceedings of the 5th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Montana, USA, 412-418.*

Levin, L Dukic, T., Henriksson, P., Mårdh, S., Sagberg, F. (2009). Older car drivers in Norway and Sweden – studies of accident involvement, visual search behaviour, attention and hazard perception. *Swedish National Road and Transport Institute. Rapport 656A, Linköping, Sweden.*

Lundkvist, S.-O., Helmers, G., (1993) Sight length to obstacles. (Siktsträcka till hinder vid nedsatt syn och/eller sliten vindruta). *Swedish National Road and Transport Institute. VTI rapport 382,Linköping, Sweden.*

Mace, D., Garvey, P., Porter, R., Schwab, R., Adrian, W., (2001) Countermeasures for Reducing the Effects of Headlight Glare. *The AAA Foundation for Traffic Safety 1440 New York Avenue, N.W. Washington, D.C.*

Nordmark, S., Jansson, H., Palmkvist, G., Sehammer, H., (2004) The new VTI Driving Simulator – Multi Purpose Moving Base with High Performance Linear Motion. *In Proceedings of the Driving Simulator Conference 2004 Paris, 45-55.*

Pronk, N., Fildes, B., Regan, M., Lenné, M., Truedsson, N., Olsson, T., (2001) Windscreens and Safety: A Rewiev. *Report No. 183. Monash University Accident Research Centre.*

Rompe, K., Engel, G., (1984) Influence of scattered light in windshields on driver's vision during nightdriving. *Society of Automotive Engineers. SAE technical paper 84 03 85, Warrendale, PA.*

VTI (2010-03-26). *VTI's drivning simulators*. Internet 13:09 2010-03-26 http://www.vti.se/simulator