Psychophysical measurement of headlight glare aftereffects on human contrast perception for optimizing a driving simulator

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Abstract

Visual disorders of drivers, like high glare sensitivity, come to a higher accident risk at night. In contrast, light-based assistance systems, as marking light, try to optimize the perception of the driver by presenting as much light as possible on critical objects. Consequently it is necessary to analyze the influence of glare on contrast perception in order to estimate possible positive effects on driving behavior and perception caused by light-based advanced driver assistance systems.

Simulator studies offer the possibility to analyze critical situations under controlled conditions. However, for analyzing the effects of glare on driving behavior it is not possible to glare subjects while driving in a driving simulator without high technological expenditure. The aim of the presented study is to measure the effects of glare on human contrast perception by using psychophysical methods and to include the results in a driving simulation.

To evoke the level of attention and situational awareness of a normal driving situation and to ensure controlled conditions, the glare of a standard headlight was combined with a simulator study. The recurring contrast perception is recorded by measuring the threshold of perception after glare. The results are implemented in a simulator environment by adjusting the display contrast. Thus the glare effects from oncoming vehicles on contrast sensitivity can be simulated. Hence, in the future, critical scenarios including glare effects can be tested in a driving simulator in order to test the influence of light-based advanced driver assistance systems on human perception.

1. Introduction

During driving about 90% of the information is perceived visually (Rockwell, 1972). From a psychological point of view, a major difference between driving at day and at night is caused by a surplus of information at day and a lack of information at night (Lachenmayr, 1995). This difference has also consequences for accidents, in particular, pedestrian accidents: At daytime, 25 of 1000 road traffic accidents including pedestrians are fatal for the pedestrian. This proportion rises to 70 of 1000 deadly accidents at nighttime (Lerner, Albrecht & Evers, 2005). While at day pedestrians step more frequently onto the street from right-side and are hit by a car, at night significantly more pedestrians are hit while crossing the street from the left side (Wegwerth, Thomschke, Laschinsky & Gonter, 2008). In the dark, the perception of the direction of pedestrian movement and speed is delayed due to a lack of visual information (Wegwerth et al., 2008). Thus, presenting this missing information to the driver at night may support the driver.

Two alternatives have recently been presented: on the one hand Night Vision Enhancement Systems (NVES) support the perception of the driver at night (Rumar, 2003). Here an infrared view of the environment is offered to the driver on a screen in the vehicle interior (Taner, 2007). On the other hand light-based advanced driver assistance systems as the marking light and the dynamic light assist (Wegwerth et al., 2008; Schneider, 2010) are used to illuminate safety hazards in the environment and thus provide the required information to the driver. Especially in the case of glare from oncoming vehicles a better illumination of the environment might increase the perception of the driver. Olson and Sivak (1984) distinguish discomfort glare and disability glare. Discomfort glare describes the unpleasant feeling caused by a glare from oncoming headlights. Disability glare is the objectively detectable impairment of the contrast perception. For accidents, disability glare seems to be more relevant because of the physiological impairment on the human contrast perception ability.

2. Related Work

Glare is only reported rarely as an accident cause in the literature (Hemion, 1969; Mortimer, 1974). Therefore it is necessary to create a database that includes glare from oncoming headlights as possible accident cause (Mace, Garvey, Porter, Schwab & Adrian, 2001). Nevertheless it is not possible to analyze the role of glare effects in accident occurrence. However Lachenmayr, Berger, Buser and Keller (1998) found evidence of a higher accident risk at night if the driver shows visual disorders, like high glare sensitivity. An improvement of the illumination of objects leads to an improved visibility at night. Consequently, an improvement of illumination should lead to an improved perceptibility of objects directly after glare from oncoming vehicles. Therefore it is important to examine which possibilities of perception improvement are offered by light based advanced driver assistance systems directly after glare from oncoming headlights.

In order to examine the influence of glare and light assistance, field tests and simulator studies can be used. While it is easier to present realistic lighting conditions in field tests, the possibility to control the environmental conditions including other vehicles and their lighting is limited. This yields a higher variation in the data. Furthermore, field tests are very sophisticated, expensive, and may also present ethical problems if, for example, real pedestrians should be involved. Thus, driving simulators offer a good compromise between the controlled conditions of laboratory research, which are often lacking in practical relevance, and the practical orientation of field tests, which are interference-prone and often safety-critical.

Glare effects have been a study topic of different disciplines for a long time. Most of the studies concerning glare effects on human perception used monochromatic light to glare the subjects and are conducted under controlled conditions in laboratories. Some field tests dealt with the effects of glare from headlights on human contrast perception. Johansson and Ottander (1964) examined glare aftereffects in an experimental study under real driving conditions. They found only small influences of the glare intensity but considerably influences of the glare duration. Olson and Aoki (1989) examined the readaptation of the driver's eyes at darkness after headlight glare in a field test. The subjects were glared by dipped beam headlights and main beam headlights. The subjects should report the point in time after glare, when they could detect a light source in front of them again. A difference between dipped and main beam headlights was reported.

Ranney, Simmons and Masalonis (1999) examined the long-term effects of glare in the exterior mirrors on the driving behavior of truck drivers in a stationary driving simulator. They reported a negative effect of glare onto the detection rate of pedestrians standing at the roadside depending on the driving time of the trucker. A measurement of glare aftereffects was not conducted.

The visualization of human perception is also a research topic by computer graphic science, but only a few publications dealt with the simulation of glares and glare aftereffects. Ritschel, Ihrke, Frisvad, Coppers, Myszkowski and Seidel (2009) as well as Yoshida, Ihrke, Mantiuk and Seidel (2008) visualized different glare intensities. Pattaniaik, Tublin, Yee and Greenberg (2000) as well as Ledda, Santos and Chalmers (2004) visualized indeed the adaptation of the eye under different light conditions but used the perception results of fully adapted subjects. The analysis of

the literature shows that no findings for the simulation of the effect of real glare aftereffects exist by now.
Up to now, simulator studies have hardly been used to analyze the effects of darkness on driving behavior. This is largely because the simulation of night-time scenarios including the lighting is still quite difficult. A suitable light simulation of one's own and the other vehicles and different reflections of surfaces must be included in the visualization. This is necessary in order to present a realistic distribution of light on the one hand and glare effects due to external light sources on the other hand. Moreover, the simulation of glare effects offers the possibility to examine the effectiveness of light based advanced driver assistance systems especially after short glares in the driving simulator. Furthermore, new light-based advanced driver assistance systems can be developed and tested to minimize possible glare aftereffects on driving behavior.

In order to integrate glare effects into a driving simulator, two ways are conceivable. On the one hand, a real headlight could be integrated into the hardware structure of a driving simulator. However, problems will be expected by ensuring the correct blend angle for all subjects and all situations. Also, the dynamic movement of the headlight through the simulator environment in order to implement different headlight positions in the simulation might be difficult. The possibilities of testing more than one subject at the same time as well as the portability of the simulator for demonstration purposes disappear by including a real headlight in the simulator environment. Furthermore, by using a real headlight for glaring the subjects, they are stressed unnecessarily.

On the other hand, an alternative to the use of real headlights in the simulator is the implementation of physiological glare effects from an oncoming vehicle. Monitors are incapable to glare subjects because of the low light level that is produced by the display. Thus it is not possible to generate the biological changes that are comparable to the effects evoked by real headlight glare. Until it will be possible to produce luminosities of monitors that are comparable to the glare of oncoming headlights, another way should be used. Therefore, adjusting the perceivable contrast in the view of the driving simulation might be a possible solution. The picture in the simulation is dimed in order to simulate the effects of glare from oncoming headlights for the driver. For this, the recurring contrast perception after glare needs to be measured and implement to the simulation. Thus the effects of glare on the human contrast perception could be simulated in a driving simulator without the need of additional hardware. Furthermore the problems discussed by using a real headlight in the simulator environment are nonexistent. In the present study the effects of a real headlight on the contrast perception after glare were measured in order to use the results for implementing the glare aftereffects in the simulator by manipulating the visualization. On this way a tool was developed to survey the influence of glare aftereffects on driving behavior by using a driving simulator.

3. Method

In order to test the aftereffects of a real glare from headlights in the simulator, a sample of 18 subjects were examined. Reading (1968) found evidence that the effect of glare on the human contrast perception ability is correlated with the age of the subjects. Therefore, the average age of the subjects participated in this study was limited by using only subjects under the age of 40.

In average the subjects were 28.6 years old. They were asked to drive a simulated country road at darkness in a stationary driving simulator. The main advantage of this procedure was that the level of eye adaptation, the situation awareness and the feeling of contact with reality was comparable to real driving. For that purpose, the night driving simulation was projected onto a diffusely reflective dark surface and the illumination of the environment suited to a starry night with 0.1 lux. Another advantage of this procedure was that the subjects were able to show normal behavior in case of glare. So behavior effects of avoiding or minimizing the physiological effect of disability glare, like turning the head or focusing the roadside were also included in the measurement. A schematic representation of the setting is shown in figure 1.

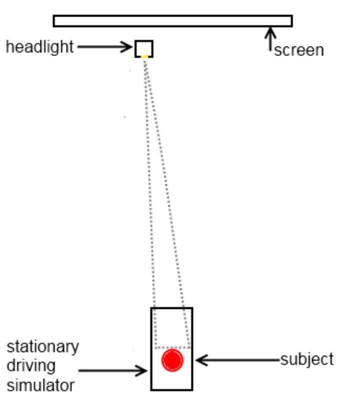

Fig. 1: Schematic representation of the setting

After about three minutes of driving, a headlight standing in a distance of four meters to the position of the driver's seat was switched on and glared the subject. The position of the headlight hot spot was controlled and adjusted for every subject before starting the test. The duration of the glare was varied in the steps 2,5s, 5s and 10s. Furthermore, the headlight sizes as well as the glare intensities were manipulated to resemble headlights positioned in 10, 25 and 50 meters distance.

Of course, in normal traffic the two cars would converge to each other continuously. But the realization of a dynamic variation of the glare intensity would create the necessity to manipulate start and end of the glare stimulus as well as the velocities of the two vehicles. Thus the design complexity of the experiment would increase rapidly. Consequently the intensity of the glare from the oncoming vehicle was realized in a static way in order to receive plausible measurement results.

From these nine possible resulting combinations, two were eliminated. The combination of 50 meters and 2.5 seconds did not evoke disability glare whereas headlight glares over 10 seconds from a distance of only 10 meters seemed unrealistic for headlight glares in real traffic situations.

Accordingly, the subjects drove seven test runs. The sequence of the test runs was generated randomly for every subject. After the glare, the simulation was stopped and a grey square with a reflection coefficient of 13% and a size of about 1° angle of vision appeared in the middle of the lane. The subjects used a shift paddle to adjust the contrast of the square according to their perception. The subjects were instructed to continuously adjust the contrast in such a way that the square was at all times just not visible anymore. With this procedure a graph was generated for the recurring contrast perception of glare aftereffects. The glare aftereffect on contrast perception was measured for 60 seconds for every condition.

4. Results

The single measurement points of a condition were interpolated in order to receive a graph of the recurring contrast perception focusing on the minute after glare for every single subject.

These graphs were averaged over all subjects so that the graphs plotted in figure 2 were received.

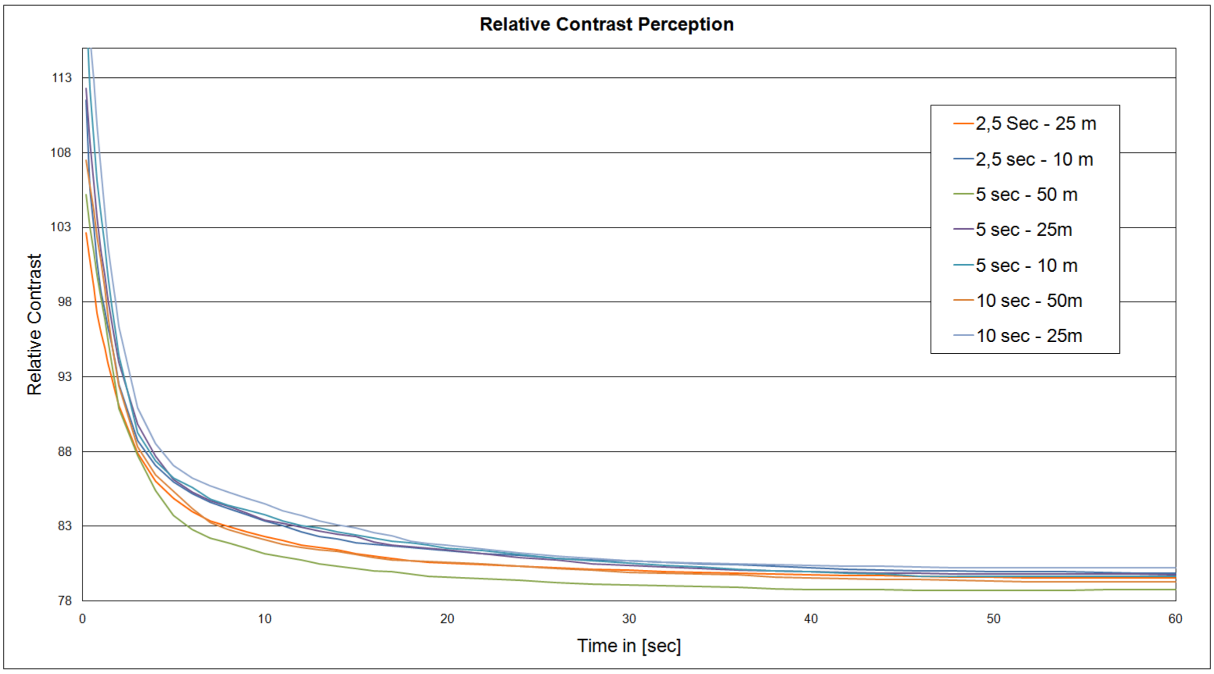

Fig. 2: Averaged graphs of the test results

Figure 2 shows the mean recurring contrast perception as a function of glare duration and glare intensity. The best approximate values are gained from the function type A/(x-B)+C, with *A* being a shearing value and *B* and *C* displacements in x- and y-axis. The parameters do not correspond to physical parameters but describe the data of the measurement conditions as precisely as possible. Interestingly, a logarithmic approximation yields inferior results.

As can be seen in the graph, a higher duration and a shorter distance lead to a later and also slower recurring of the contrast perception ability of the subjects. The combination of 5 seconds - 50 meters shows the smallest effect on the contrast perception whereas the combination of 10 seconds - 25 meters shows the largest effect.

The resulting function was used to implement the glare aftereffects in the simulation by adjusting the visualization of the simulation dynamically according to the recurring contrast perception of the subjects. As mentioned in the method section of this paper, only static glare intensities were tested in this study. At the long run the simulation should be used to test the driving behavior of subjects in safety-critical situations while using new headlight technologies. Thus it is necessary to minimize the possibility of false-positive decisions. Hence the implementation of a single glare situation is conservatively approximated by using the static glare with the highest occurring glare intensity. A sample for the visualization of glare aftereffects is shown in figure 3.

Fig. 3: Screenshots of the driving simulation with integrated glare handling zero (left), two (middle) and five seconds (right) after glare exposure

5. Discussion

The study presented here is a first step in order to make it feasible to analyze the influence of glare aftereffects in a driving simulator. This offers new possibilities to examine light-based advanced driver assistance systems in a more precise way. In particular, it is now possible to focus on the driving behavior and on the detection rate of possible critical objects shortly after glare from oncoming headlights. Thus, novel light functions addressing the critical moments after headlight glare can be developed specially for the time after glare and tested with all advantages offered by a driving simulator. In addition, higher reality proximity of the simulation is achieved by implementing glare aftereffects in a night simulation.

Field tests are still necessary in order to examine light-based advanced driver assistance systems for the time after but the first adjustment of new functions to the needs of the driver can be tested virtually by now.

However, it is necessary to consider that the recurring contrast perception is only one possible parameter for implementing glare aftereffects in a simulation. Certainly the reflection characteristic of different materials and the size of textures must be examined and included in the simulation to optimize the visualization. Furthermore the influence of different weather conditions on glare aftereffects needs to be considered. Also, the effects of discomfort glare on human behavior while driving must be considered for an optimization of the visualization because of different strategies of drivers to avoid glare. A categorization of drivers in different classes of glare avoidance behavior needs to be investigated, before a driving simulation with simulated glare aftereffects can be used for testing light-based advanced driver assistance systems in order to reduce the number of necessary field tests.

Certainly, this study is a first step to include glare aftereffects close to real human perception in a night driving simulation. As a next step a validation of the visualization with data occurring from a field test will be conducted in order to assure that simulation and reality are sufficiently similar. A continuous improvement of night simulations in general and of simulating glare aftereffects in specific is necessary in order to be able to test critical scenarios as realistic as possible in a driving simulator. In this way, new light-based advanced driver assistance systems can be developed and tested in order to reduce the number of accidents at night.

6. Literature

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