Night Vision - Reduced Driver Distraction, Improved Safety and Satisfaction

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Abstract. Accidents in the dark in non-urban areas result in disproportionately high rates of pedestrians injuries (Hülsen 2003).

This paper describes the methods and results of test drives with 39 test persons for the assessment of driver behavior in interacting with different Human-Machine-Interfaces (HMI) for Night Vision systems which inform drivers about the presence of pedestrians.

Data of driver eye movements was analyzed to evaluate the different HMI designs of pedestrian alerts, in a passenger vehicle with Head-up-Display (HUD), regarding the ergonomic suitability and safety benefit.

All systems were compared in field tests on public roads and on a test track.

Keywords: night-vision, head-up display, eye tracking, driver distraction.

1 Introduction

Night Vision with pedestrian detection supports drivers' cognition. The examined systems try to decrease the high rates of pedestrians injuries through visual assistance (Hülsen 2003). On the other hand, due to the increasing number of driver assistance systems in today's vehicles, there is a need to evaluate the potential risk of increased driver distraction caused by additional displays before they are available for end users. Especially with Night Vision systems, which generate, regarding to Green (cited in Jones 2006), the problem "that these systems demand that the driver take his or her focus from the road".

To enhance perception of pedestrians Scheuner et al (2005) and Fardi et al. (2005) already studied pedestrian detection using infrared sensor based Night Vision systems. This study focuses on drivers' behavior and the allocation of drivers' attention comparing different HMI designs of pedestrian detection using Head-up-Display technology to visualize the information. Three different HMI designs for pedestrian detection were compared with two baselines, where one baselines was "without Night Vision" and the second one a "conventional Night Vision" without pedestrian alert.

The study examines different objective and subjective appraisals of HMI-Systems depending on the environment and drivers' task with a focuses on drivers' distraction.

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2 Description of Methods

2.1 Experimental Design

The Institute of Ergonomics (IAD) of the TU Darmstadt developed a method to test different implementations of the pedestrian warning of the Night Vision HMI. Three different HMI designs were compared with two baselines (see table 1). The baselines were “without Night Vision” and a “conventional Night Vision” without pedestrian alert. The examined HMI implementation was varied by the level of abstraction and the duration of the presented information. The drivers were able to test all systems and baselines with several pedestrians before they used the system on public roads. During the field test each subject had the chance to experience each night vision system and baseline with two pedestrian events.

Table 1. Experimental design

		3 Systems		
		System 1	System 2	System 3
2 Baselines	Baseline 1			
	Baseline 2			

A BMW E60 with far infrared Night Vision was used as basis for the experiment. It was equipped with brightest Xenon-technology available to ensure best preconditions for the drivers’ vision.

To test Night Vision systems under lifelike and reproducible conditions, tests were carried out on public roads and on the test track of the TU Darmstadt.

The driver’s job was to drive the given route according to their habits. The route bypassed eight positioned pedestrians. The subject was neither asked to look out for pedestrians nor was he asked for any response, in the case he detects a pedestrian. However there was a questionnaire after the subject passed a pedestrian, weather he had detected him or not. The subjects had to drive 22.5 km (approx. 14 miles) on public roads.

After the field test on the public road the variants were compared again on the test track. There, the driver’s job was to drive 50 km/h (approx. 30 mph) and to reduce speed to 30 km/h (approx. 20 mph) once they saw a pedestrian. The location of the pedestrian was altered.

The passenger car trials were carried out with 39 female and male test persons in two age groups. The younger age group included drivers aged 25 to 40 years, and the older age group included drivers from 50 to 65 years. The trials were carried out comparable terms of visibility after sunset. The subjects drove 50 to 60 minutes. The overall duration of the experiment was 1½ to 2 hours.

2.2 Methods of Measurement

Eye tracking is an important tool for evaluating different HMI designs in passenger vehicles. Because of a correlation of eye movement and observed information

(SEIFERT et al. 2001, RÖTTING 2001) the recorded data exposes the allocation of drivers' attention. The recorded data was analyzed based on the Eye-Mind Assumption and the Immediacy Assumption of JUST AND CARPENTER (1980) and the Sequence Assumption. The sequence assumption postulates that the sequence of fixations allows for the drawing of conclusions to the subjects' sequence of information processing.

The drivers' eye movements were recorded with a modified head mounted SMI eye tracker (resolution: 0.5° – 1.0°, 720 x 576pixels at 50 Hz; 8000Kbps; measurement range ±30° horizontally, ±25° vertically). The recorded data was analyzed manually.

Besides eye tracking, various other data was collected such as car speed, steering wheel angle, braking pressure and the videos of the driver and the environment. Questionnaires were used to collect subjective data.

The subjects had to complete questionnaires before the trial and were interviewed after they passed a pedestrian. After the trial they had to complete another questionnaire.

3 Results

In this study, visual distraction of different HMIs was analyzed by the percentage of the accumulated durations of fixation, the maximum durations of fixation and the frequency of the fixations on different areas of interest (AOI) during the driving task. The scene video was divided in the following AOI: Street, HUD, instrument cluster, interior, pedestrians, miscellaneous and measurement error.

3.1 Response Time

The duration period of cognition (Te) is defined as the time difference between the first fixation and the passing of the pedestrian. It is a factor of the time which remains for the driver to handle the situation appropriately. Longer Te's are better. A comparison of the medians in figure 1 illustrates, that Subjects with "system B" had, on average, more time to react appropriately to the presence of a pedestrian after they detected him.

The difference of the mean-values of Te was verified in a t-test for paired samples. The significant results are shown in table 2. This demonstrates that "system B" gives drivers significantly more time to react appropriately compared to "baseline 1" and also significantly more time for an appropriate reaction compared to "system C".

The results of the duration period of cognition (Te) were compared with the response times which were measured in a track test that followed the field test where the drivers were asked to slow down as soon as they saw a pedestrian on the test track.

The graph in figure 2 shows the distance of the drivers to the pedestrians at the moment they utilized the brake pedal. A longer distance is superior, because it leads to a longer time span to react appropriately to the presence of a pedestrian.

The comparison of the medians in figure 1 and figure 2 reveals that temporary renditions of the information, ("system B" and partially "system A" as well as "system C") which showed excellent results in the realistic field test, did not perform as well in the test field when the driving task tempted drivers to focus on the secondary task, the HUD.

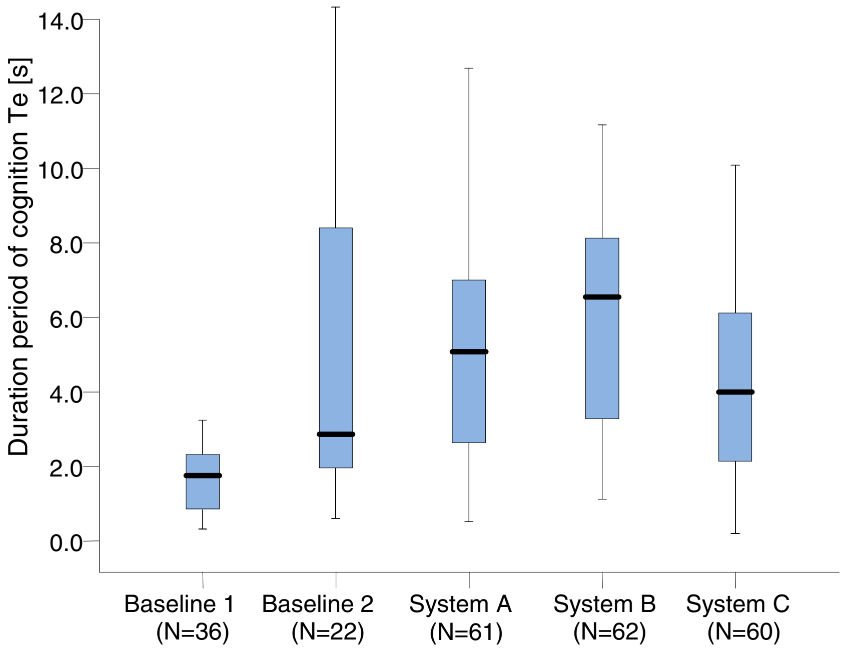

Fig. 1. Box plot: Duration period of cognition (Te in seconds): difference between the first fixation and the passing of the pedestrian

Table 2. Significant results of t-test for the duration period of cognition (Te)

Version	p	T
Baseline 1 – System A	0.000	5.825
Baseline 1 – System B	0.000	6.803
Baseline 1 – System C	0.001	3.822
System B – System C	0.002	3.284

Furthermore, a response time T1 was defined. It is the difference between the first HUD warning and the first HUD fixation of the subject. A shorter response time T1 gives more time to the driver to react appropriately to the presence of a pedestrian.

In figure 3 it is shown, that the median of the subjects focus on the pedestrian warning is significantly earlier in “system B” compared to the systems “A” or “C”. The results of a paired t-test have proven a significant difference of the mean values of “system B” and “system C” (p=0.027; T=2.268). A smaller interquartile range is observed with “system B” compared to “system A” and “system C” Because of the temporary nature of the information presentation in “system B”, the visual stimuli for the driver in “system B” may be more intense compared to “system A” and “system C”.

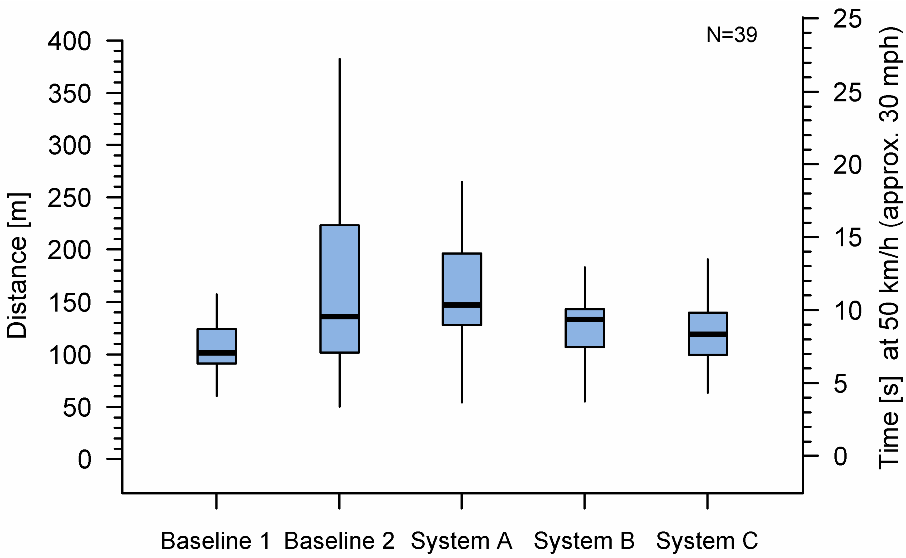

Fig. 2. Box plot: Initiation of slowdown on the test track in meters (left) ahead of the pedestrian and the calculated time to pass (right)

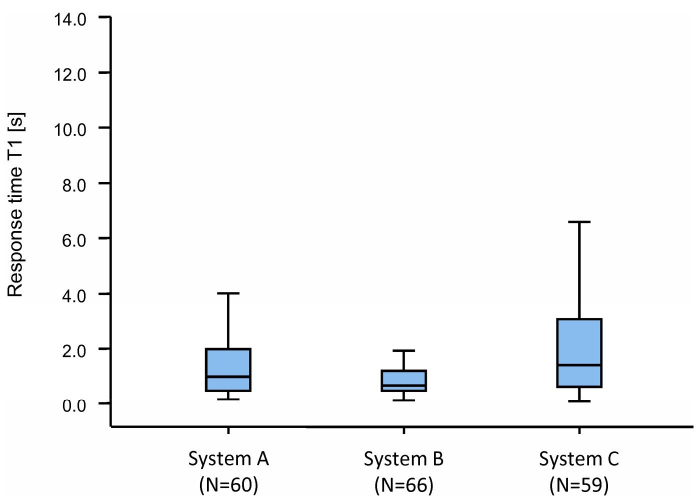

Fig. 3. Box plot: Response time (T1 in seconds): difference between the first HUD warning and the subject's first fixation on the HUD

3.2 Comparison of Subjective and Objective Rating of Distraction

According to Yan et al. (2008) the "drivers' distraction could be the highest risk factor leading to the failure of attempting to avoid crashes". Because of this, one focus of this study was the evaluation of drivers' distraction.

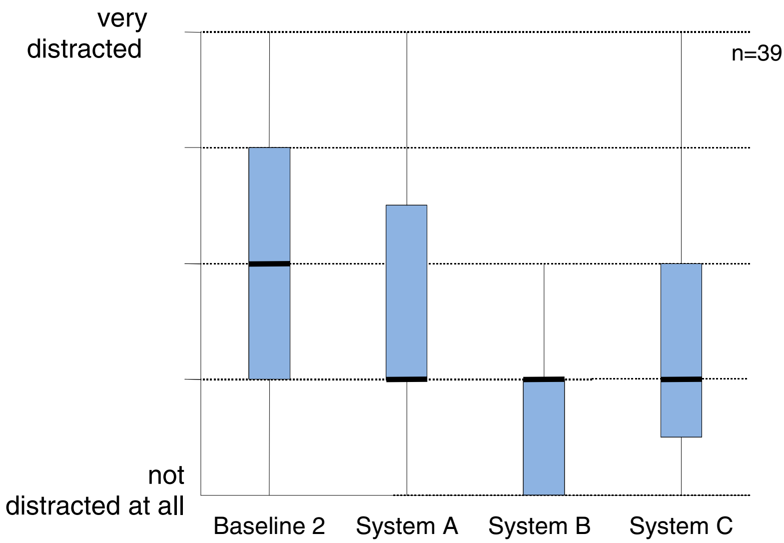

Fig. 4. Box plot: Questionnaire: “How do you rate your distraction by the particular variant?” Scaling from 1 – “not distracted at” all to 5 “very distracted”

Drivers’ distraction was measured in several ways, including a subjective rating of the drivers. The subjective rating of distraction was evaluated with a questionnaire at the end of the test drive. Figure 4 shows the subjective rating of the drivers’ distraction. A paired one-way analysis of variance (ANOVA) was used for testing differences in ranking. An Influence of a factor is shown with the factors F=7.501, df=3, error df=36 and p=0.001. Differences between single groups were calculated using contrasts. There is a significant difference of “system B” compared to “baseline 2” with the factors p<0.001, F=20.030 and df=1. A tendency of “system C” being superior over “baseline 2” is shown factors p=0.051; F=4.063 df=1.

One of the features of “system B” is the temporary display of the pedestrian information.

There were several objective indicators recorded and calculated, which allow to draw conclusions to the drivers distraction, including various response times.

One way to objectively rate the potential driver’s distraction is the maximum duration of the drivers’ fixations of the secondary task. As long as a driver focuses his attention on a secondary task, he is not able to react to sudden changes in the road environment. For example, other road members crossing the road or sudden speed changes of other road users cannot be processed by the driver while they focus on a secondary task. A lower maximum duration of fixations is preferable.

Figure 5 shows the maximum duration of fixations of the HUD during driving task. The drivers’ maximum duration of fixations on HUD are significantly reduced with “system C” compared to “Baseline 2”, as well as compared to “system B”. The results of the t-test for paired samples are shown in table 3.

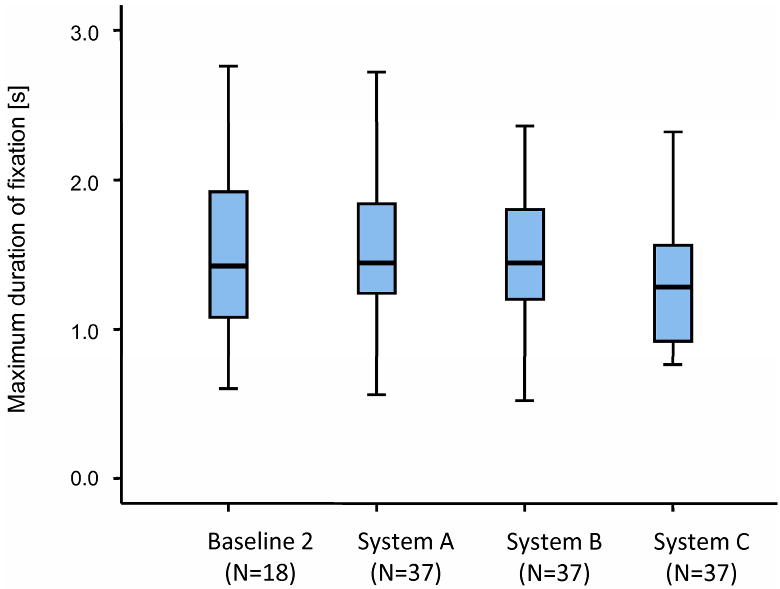

Fig. 5. Box plot: Maximum duration of fixations of the HUD during driving task[s]

Table 3. Significant results of t-test for maximum duration of fixations of the HUD

Version	p	T
System C – Baseline 2	0.037	2.267
System C – System B	0.045	2.079

According to ZWAHLEN et al. (1988) a secondary task is too distracting, if the subject focuses more than approx. 2 seconds a secondary object. However, these limit values were not intended for Head up Displays, where the drivers' eyes don't have to accommodate and adapt, when they focus the road again.

The maximum duration of fixations combined with the total duration of fixations and the number of fixations is an indicator that a design gives drivers a better possibility to stop the secondary task easily and focus the attention on the road and other road users again. The medians of "system C" were lower than the medians of the other systems while the duration of fixations was lower and the number of fixations was higher. This leads to the conclusion that it's easier with "system C" to interrupt the monitoring of the assistance system "Night Vision with pedestrian detection" compared to the other systems.

The difference of the results of the questionnaire (figure 4 / figure 5; table 3) and the results of the maximum durations of fixations are founded in the inaccuracy because subjects tend to rate things better, which they like, as well as the challenge to sum all indicators for distractions in one objective item.

3.3 Number of Observed Pedestrians

One important factor for benchmarking the system is the number of observed pedestrians in the field test. Drivers can only react appropriate to perceived pedestrians.

The analysis shows that the design of the HMI has a tremendous influence on the number of observed pedestrians. In figure 6 the number of observed pedestrians is visualized depending on the location, where the subjects observed them first. The drivers showed a 100% success rate in this test while using the HMI of “system B”. Other systems could not improve the number of perceived pedestrians.

With the altered driving task on the test track, there was a 100% success rate with all systems. This might be caused by the predictable, less demanding environment compared to the field study.

This leads to the conclusion that Night Vision systems with an appropriate HMI design can increase road safety also in demanding driving environments at night.

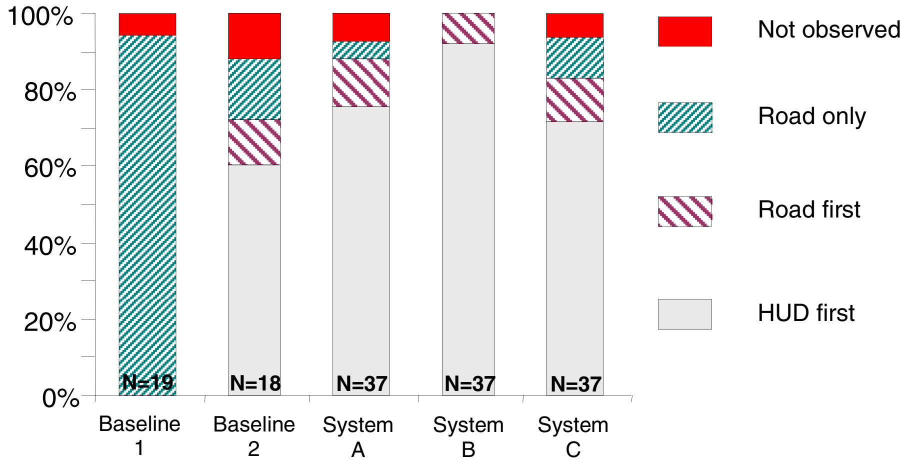

Fig. 6. Number of observed pedestrians (%) in field-test depending on the location of the accommodation of information

The analysis of the drivers’ durations of fixations of the AOI “road” showed no significant reduction. There was also no significant reduction on the frequency of fixations of the AOI “road” observed during these tests.

In addition to the discussed results above, the average speed of the subjects was analyzed. There was no significant speed difference observed between the average speed of the drivers with the different HMI designs, however, a slight trend in a reduced average speed on the road compared to the test track was observed.

4 Conclusion

The results show that vehicles equipped with appropriate HMI implementations of the Night Vision systems, which inform the drivers to the presence of pedestrians, are significantly superior to “non Night Vision” vehicles, which were investigated in the “baseline 1”. The appropriate HMI implementations are also superior to conventional Night Vision systems, as seen in “baseline 2”. “System B” was superior in most analyzed parameters. However, “system C” showed a great potential for the future because its HMI leads to significant less “maximum duration of HUD fixations” compared to the other systems.

With an appropriate HMI design, Night Vision with pedestrian detection increases perception of pedestrians in darkness. This is a contribution to increased road safety. Furthermore, there was no indication for increased driver distraction with an appropriate HMI design.

The study shows that a less realistic driving task and an environment, which needed less attention because of the decreased exposure, can lead to a different rating and to different driver behaviors. Therefore the appropriate choice of environment and tasks is important to generalize the results.

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