MAINTENANCE OF HIGH AROUSAL LEVEL BY VOLUNTARY DRIVING MANEUVER USING SENSORY FEEDBACK

Tetsuro, Shirakata

Hiroyuki, Koike

Automotive R&D Center / Honda R&D Co., Ltd.

Japan

Yutaka, Hirata

Dept. Computer Science / Chubu University College of Engineering

Japan

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ABSTRACT

In order to prevent car driver sleepiness that may cause a serious accident, various stimuli have been proposed and tested to date. Although some of these stimuli have been proven effective, their effectiveness is limited and cannot be expected to last long enough. In this study we propose a new method to keep car drivers awake for a long period of time, and demonstrate its effectiveness by using driving simulation (DS). The proposed method lets the car driver perform a voluntary driving maneuver, which is lane-keep control with auditory or haptic feedback. In the DS, our subject was asked to drive on a straight road with a monotonous visual scene by following a car running in front at a constant speed. During the DS, recorded road noise was played back or the steering wheel was vibrated such that its intensity was altered in proportion to the amount of deviation from the center of the driving lane. This maneuver helps subjects keep to their driving lane without disturbing the focused attention required for safe driving. It was expected that the decrease of the road noise or the steering wheel vibration would work as a reward, while the increase would work as a disincentive. Pupil diameter, vestibulo-ocular reflex (VOR) and subjective sleepiness were monitored as measures of the subjects' sleepiness. We demonstrate that the steering wheel vibration is effective. Namely, when the proposed voluntary maneuver stimulus was initiated just after subject's sleepiness was predicted by using the physiological measure (VOR), the duration of the awake period was prolonged. This DS experiment employed only straight road driving, and lane-keep control should be more difficult on real roads. Thus actual driving situations require greater maneuvering that should result in greater effectiveness in maintaining a high arousal level. We conclude that to prolong the period of car driver's high-level alertness, the proposed voluntary driving maneuver is significantly more effective than conventional passive sensory feedback stimuli alone.

INTRODUCTION

When drivers operate a vehicle in a low arousal state with reduced physiological activity, oversights and operation errors occur with regard to predicted behavior and reaction speeds [e.g., 1][2]. When drivers in such a low arousal state face the danger of an impending collision, there is a likelihood that they will be unable to reduce speed of the car sufficiently and that may result in a serious accident. In order to prevent those accidents caused by drowsy driving due to low arousal, various means have been proposed for maintaining or heightening the degree of arousal by stimulating the five senses. For example, loud alarm, scent, and vibration. In cases when a lowered arousal is sustained over long periods of time, however, drivers may accustom to such sensory stimulus and soon it cannot be expected to have the same effect as it did immediately after the stimulus began to be applied. One way to resolve this problem is to prepare multiple sensory stimuli that are potentially effective, and apply them alternately so as to avoid sensory habituation. However, depending on the environment they are to be used, there may be limits on the number of devices that can be prepared, and a sufficient arousal effect may not be readily obtainable. Here we propose a method for sustaining the arousal effect for long periods of time by using a single sensory feedback stimulus. The method applies a sensory stimulus whose intensity is correlated with the vehicle's deviation from the center of the driving lane. To keep the sensory feedback stimulus small, the driver has to maintain the car position close to the center of the driving lane as much as possible. We expect that this voluntary maneuver not only activates sensory processing system but sensory-motor transformation and motor control systems in our brain as well, which then results in helping maintain high arousal level. Reducing annoying sensory feedback stimulus by the voluntary maneuver might work as reward, and be expected to activate reward system as well. In the present study, we employed auditory and haptic stimuli for such a sensory feedback stimulus, and evaluated the effectiveness of the method in driving simulation.

METHOD

A. Experimental Setup

A driving simulator (DS) system was made up of a projector (EPSON ELP-73) for projecting a driving simulation scene on the screen, a driver’s seat (Logicool PRC-11000) equipped with a steering wheel, brake and accelerator pedal, two speakers for auditory stimulus, and a steering wheel vibrator for haptic stimulus. A schematic diagram of the experimental setup is shown in Figure 1. A subject sat comfortably in the driver’s seat. The seat was set so that the head of the subject faced the center of the screen. The distance between the subject’s eyes and the screen was 2470 mm, and the screen size was 100 inches (horizontal visual angle: ±39.1 degrees, vertical visual angle: ±26.3 degrees). A device for adding seat motion that induces the vestibulo-ocular reflex (VOR) was also installed in the lower part of the driver's seat [3]. This device was modified from a commercially available health appliance (Daito Electric Machine Industry FD-003) so that it can generate similar head perturbations to those occurring during highway driving. The steering wheel was adjusted to maintain the subject in a comfortable position. The experiment was conducted in a dark room and the DS image was designed monotonous to easily lower subjects’ alertness. The DS image projected on the screen remained unchanged except for the traffic lane and road shoulder that gave visual cue concerning the direction and speed of the vehicle. The brightness and contrast of the projector were adjusted so that the pupil diameter of the subject stayed within the medium range (about 6 mm).

B. Measured Data

During the DS experiment, we measured vertical and horizontal eye positions, pupil diameter, 3 axes angular head velocities, and 3 axes linear head accelerations together with subjective arousal levels (Table 1). The eye movements and pupil diameter were extracted in real time by image processing of eye image taken by an eye tracker (NEWOPTO ET-60-L) at a frame rate of 29.97 fps (NTSC). This real time image processing was

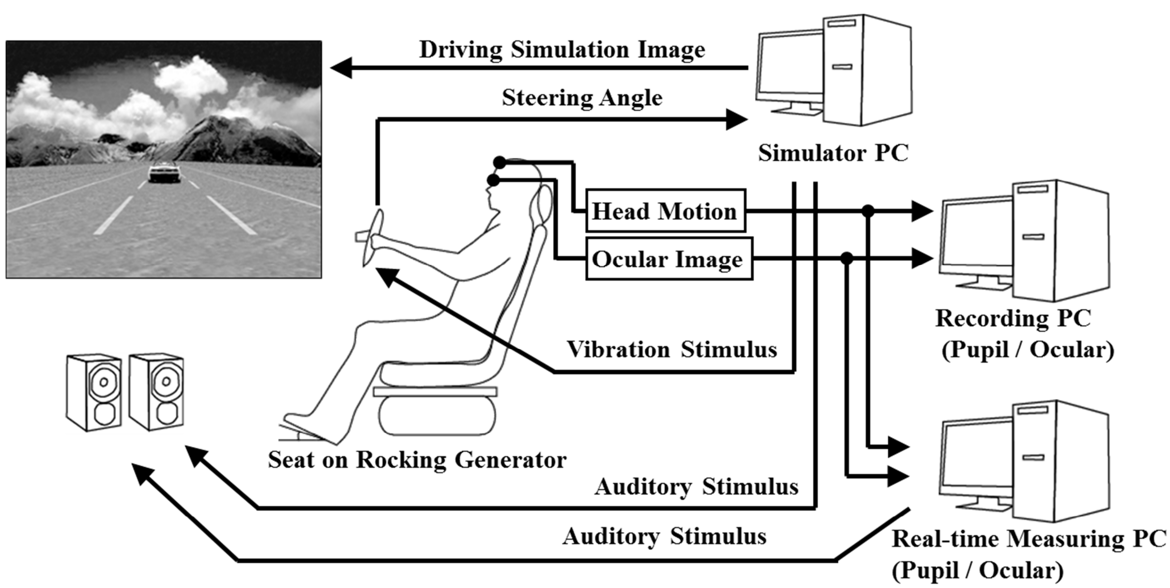

Figure 1. Schematic diagram of the experimental setup.

performed on a PC by using LabVIEW (National Instruments). The head movements were detected by an accelerometer (BestTechnology BTE071) and a gyroscope (BestTechnology BTE070) that were attached to the eye-tracking device, and their output were also fed into the PC running LabVIEW to evaluate VOR performance. These biological signals were synchronized with the eye tracking images using Spike2 software (Cambridge Electronic Design), digitized at the sampling rate of 1 KHz by an AD/DA device, Power1401 (Cambridge Electronic Design), and stored in another PC for off-line high precision data analyses (data not shown in this manuscript).

C. Subject

A total of 18 healthy subjects (mean ± SD: 22.8±7.1 years old) participated in the experiment. All of the subjects had given their informed consent prior to their participation to the experiment. Experimental procedures were considered with caution based on previous similar studies [3][4], following well-established methods. Careful attention was paid to prevent simulator sickness or any other pain to subjects during the experiment. The subjects made introspective reports on their sleepiness before the experiment to confirm that they were not sleepy. Farsighted and nearsighted subjects wore contact lenses to correct their vision.

D. Experimental Procedure

After having the eye-tracking device attached, each subject sat in the driver's seat in a natural comfortable posture, and practiced the driving simulator operation for one minute. Additional ten minutes were taken for each subject to adapt to the room light condition. During this period, subjects did not manipulate the DS system, and participated in ordinary conversation to maintain their arousal level. Following these preparations, the following task was given to the subjects.

The subjects were instructed to drive at a constant speed in the center lane of a monotonous straight 3-lane road, and keep their gaze on the rearview mirror of the vehicle. The position of the rearview mirror did not change as a result of steering operation. Seat motion to induce the VOR was applied from 20 seconds after the start of the experiment up to its end. In order to monitor the subjects' subjective degree of sleepiness, they were asked to make introspective reports (Table 1) verbally at a two-minute interval. That is, an arousal state with no sleepiness is level 0; a state unsure if perceiving sleepiness or not is level 1; a state that subjects have begun to perceive as sleepy is level 2; when the sleepiness is greater than level 2, it is level 3; and thereafter, the subjects were instructed to raise the level each time when their sleepiness increased, to 4, then 5, and so on, without placing an upper limit on the sleepiness level. In this measure, sleepiness level 2 is the state in which subjects first become aware of their sleepiness during the experiment. They reported only a number corresponding to their sleepiness state after moderate beep sound played every 2 minutes to prompt the verbal introspective report. The beep sound had a minimal effect on the subjects' sleepiness level.

Table 1. Subjective sleepiness level.

Level	Subjective sleepiness
Level 0	Not sleepy
Level 1	Not completely aroused but not sleepy
Level 2	Sleepy
Level 3	More sleepy than level 2
Level 4	More sleepy than level 3
Level 5	More sleepy than level 4, and so on

During the DS experiment, the subjects were presented with auditory stimulus so that they could perform lane-keep control as a voluntary driving maneuver. Namely, recorded road noise was played back as the auditory stimulus so that its volume was altered in proportion to the amount of deviation of the car from the center of the driving lane. This maneuver helps the subjects keep their driving lane without disturbing the focused attention required for safe driving. It was expected that the decrease of the road noise would work as a reward, while the increase would work as a disincentive. As an alternative, vibration of the steering wheel (similar to that of a cellular phone) was employed. Namely, the intensity of the vibration was increased in proportion to the amount of deviation of the car from the center of the driving lane. In these experiments, disturbance noise of 1/f was added to the vehicle angle in order to prompt corrective steering at the ordinary driving level.

In order to evaluate the effectivness of each sensory feedback stimulus, two timings were employed to initiate the presentation of stimuli; one when the subjects felt sleepiness, and the other when a premonitor of sleepiness was detected. The former timing was detected when our subjects reported sleepiness level 2. The latter was determined when either VOR gain or variability exceeds preset thresholds value (see below for more details). In the case of the experiment using the former timing (sensory feedback stimulus triggered by subjective sleepiness), the stimulus presentaiton continued until the end of the experiment. In the case of the experiment using the latter timing (sensory feedback stimulus triggered by physiological premonitor of sleepiness), the stimulus was stopped when the premonitor of sleepiness disappeared. Experiments for each subject were conducted within the same time period on different days in a one-week period.

E. Data Analysis

Performance of the VOR and the pupil diameter were used to evaluate the physiological degree of arousal. Fluctuation of pupil diameter is under the control of the autonomic nervous system, and its effectiveness for detecting a subject's sleepiness and a premonitor of sleepiness has been demonstrated [4]. Namely, when subjects perceive their own sleepiness, large low-frequency fluctuation (LLFF) of the pupil diameter occurs, and prior to their awareness of their sleepiness, a monotonic gradual miosis (GM) occurs. It has been confirmed, therefore, that LLFF can serve as an indicator of sleepiness that rises to the level of consciousness, while GM is an indicator of a premonitor of sleepiness. Likewise, it has been demonstrated that the vestibulo-ocular reflex (VOR) induced by head movement indicates behavior that is closely related to sleepiness [5]. When head movements take place, compensatory eye movements are generated as VOR. It is an involuntary eye movement that prevents image slip on the retina. The VOR gain is defined as the ratio of the ideal angular eye velocity, which is the eye movement needed to compensate for head movement in a three-dimensional space, and the actual angular eye velocity. It has been confirmed that this VOR gain begins to diminish before subjects become aware of their sleepiness. The standard deviation of the residual obtained from a regression model of the ideal angular velocity of the eye and the actual angular eye velocity has also been confirmed to start increasing before subjects become aware of their sleepiness. In other words, VOR gain and residual standard deviation (VOR variability, hereafter) can be used to detect premonitors of sleepiness prior to subjects' awareness [3].

RESULTS

A. Awaking from sleepiness

Five subjects participated in this experiment. Figure 2 shows an example result of the monotonous driving simulation with audio feedback stimulus triggered by subjective sleepiness. From the top panel to the bottom, pupil diameter (a), VOR gain (b), VOR variability (c), and the subjective sleepiness level (d) are shown. The audio feedback stimulu was started at 8 min as indicated by a vertical line (Stimulus ON) when the subject’s sleepiness level reached 2. Before that, the pupil fluctuation showed gradual miosys (GM) followed by a patial large low frequency

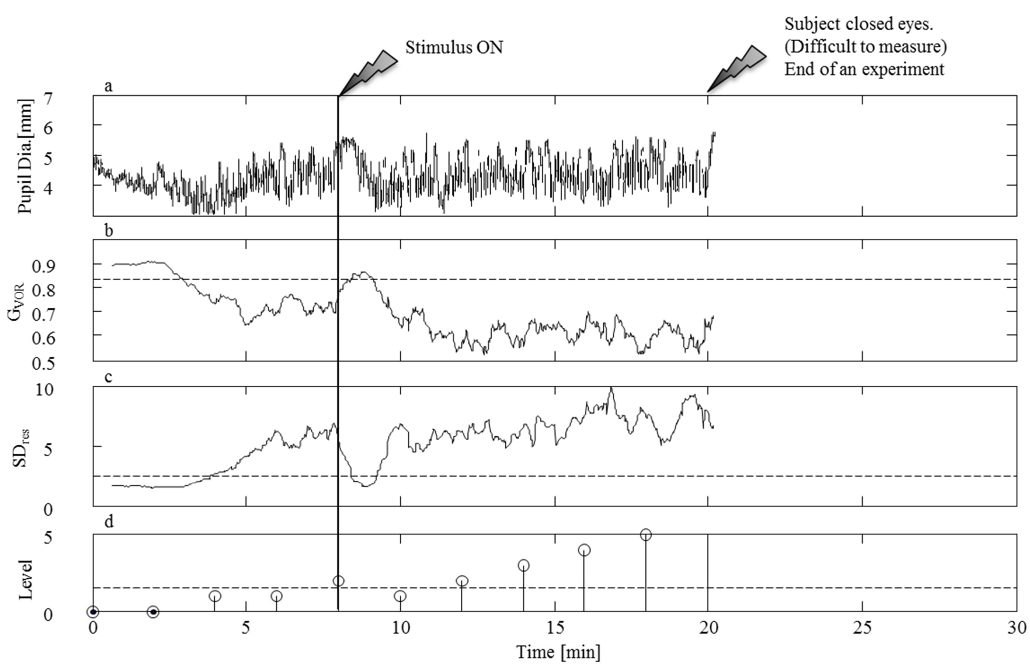

Figure 2. Changes in pupil diameter, VOR parameter and sleepiness level during the driving simulation in the active driving maneuver experiment with the road noise stimulus. a: Pupil diameter. b: VOR gain. c: VOR variability (standard deviation of residual). d: Sleepiness level.

fluctuation (LLFF). Both VOR gain and variability had crossed the preset threshold levels (dotted lines) for the sleepiness prediction as has been reported previously [6]. Two minutes after the beginning of the road noise feedback stimulus, the subjective sleepiness went down from level 2 to level 1, indicating that the subject's sleepiness has improved (see Table 1). Also the LLFF in pupil diameter was stopped, and briefly the pupil stayed dilated as well as the VOR gain and variability went back toward the original values, corssing back the thresholds. This means that the subject's sleepiness has been resolved in terms of physiological indicators. However, this situation didn't last long, and at 12 min (2 min after the initiation of the road noise feedback stimulus), subjective sleepiness came back together with physiological signes of sleepiness.

Figure 3 shows an example result from the expriment in which steering wheel vibration stimulus was employed when subjective sleepiness was reported. The format is the same as Figure 2. In this example, too, the subject reported his self-sleepiness at 8 min (d). In pupil fluctuation (a), GM and an initial part of LLFF were seen. VOR gain and variability have crossed the thresholds before the subjective sleepiness was reported. As soon as the sleepiness level 2 was reported at 8 min, the steering wheel vibration stimulus was initiated (vertical line, Stimulus ON). Although the subjective sleepiness level was not improved (d), it stayed the same and the physiological measures were actually imporoved. Namely, the pupil dilated, VOR gain increased and VOR variability decreased briefly for about one minute or so. After that, the pupil showed GM followed by LLFF, and VOR parameters were gradually degrated accordingly.

Table 2 summarizes the effetive duration of each of the two sensory feedback stimuli, which was defined as the time between the initiation of sensory feedback stimulus and the introspective report in which the subjects reported sleepiness level higher than 2 again. In the case of the road noise feedback, the maximum duration was 6 minutes and the minumum was 4 minutes while in the case of the steering vibration feedback, the maximum was 8 minutes and the minimum was 2 minutes.

Table 2. Time [sec] from initiation of stimulus to renewed increase in subjective sleepiness.

	SY	TK	YT	AM	AO
Road noise	240	360	360	360	360
Steering wheel vibration	360	240	120	480	240

Among those 5 subjects, the number of subjects whose sleepiness level was improved in 4 minutes

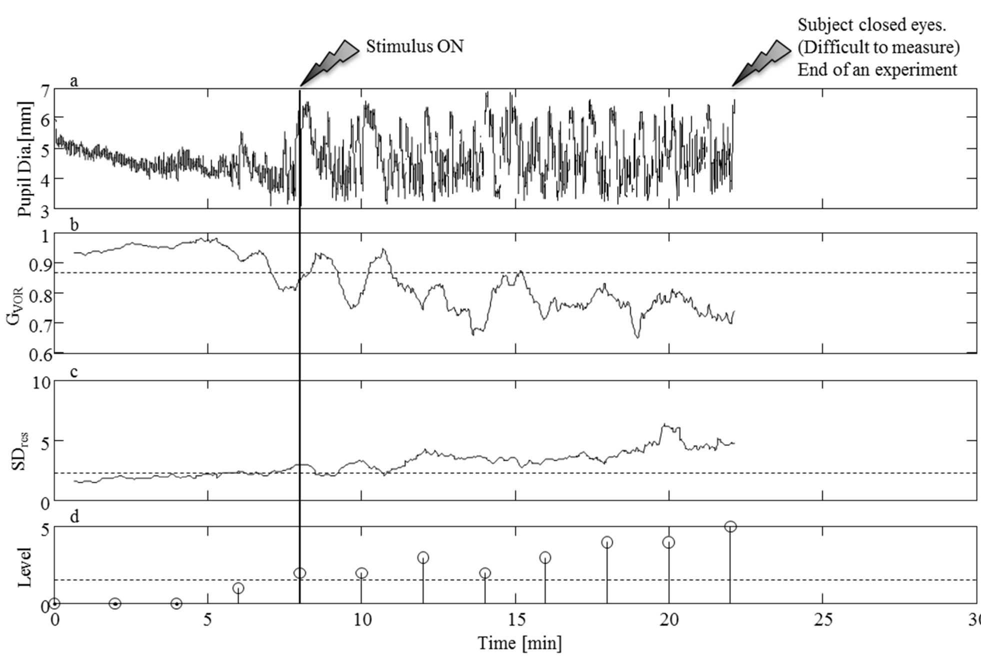

Figure 3. Changes in pupil diameter, VOR parameter and sleepiness level during the driving simulation in the active driving maneuver experiment with the steering wheel vibration stimulus. a: Pupil diameter. b: VOR gain. c: VOR variability (standard deviation of residual). d: Sleepiness level.

after the initiation of the sensory feedback stimulus was 2 for road noise, and 1 for steering vibration. In contrast, the number of subjects whose physiological indicators were either improved or maintained at the levels equal to those of arousal within four minutes after the stimulus initiation was three out of five (60%) for the road noise stimulus, and four out of five (80%) for the steering wheel vibration stimulus. Namely, in terms of physiological indices, the steering wheel vibration seems more effective than the road noise. Thus, we report the results from the steering wheel stimulus in the next experiment in which the stimulus was initiated when one of the physiological premonitors was detected.

B. Inhibiting sleepiness

Eight subjects who are different from those who participated in the experiment A participated in this experiment. Each subject underwent 3 conditions, namely control, subjective sleepiness, and predicted sleepiness. In the control condition, no steering vibration stimulus was given at any timing. In the subjective sleepiness condition, the stimulus was given from when self-aware sleepiness started till the end of the experiment. In the predicted sleepiness condition, the stimulus was started when premonitors of sleepiness are detected, and terminated when it disappeared. Figure 4 shows an example result from the experiment in which steering wheel vibration stimulus was given when premonitor of sleepiness was detected. The format is the same as Figures 3. In this example, the stimulus was initiated at 6 min when VOR variability exceeded its threshold for sleepiness prediction (First prediction of sleepiness. The beginning of the shadowed period). Soon after the initiation of the sensory feedback stimulus, VOR variability dropped back down to the threshold value or lower, thus the sensory feedback stimulus was terminated (the end of the shadowed period). After a while, at about 13 min, VOR gain exceeded the threshold value and the stimulus was initiated in the same way. The VOR gain increased back to the original threshold or higher due to application of the stimulus for 2.7 minutes (shadowed period around 14 min). The pupil diameter showed virtually no LLFF, indicating that physiological sleepiness has been limited by application of the stimulus based on premonitors of sleepiness. On the other hand, subjective sleepiness continued to rise gradually regardless of the application of sensory feedback stimulus. Clear correlation was not found in this case between the physiological measures of sleepiness and subjective sleepiness.

Table 3 summarizes the effecitive duration of the steering vibration feedback stimulus defined as the time between the initiation of the stimulus and the introspective report in which the subjects decleared sleepiness level higher than 2. The condition for the longest effective duration in terms of subjective sleepiness differed from subject to subject, and mean

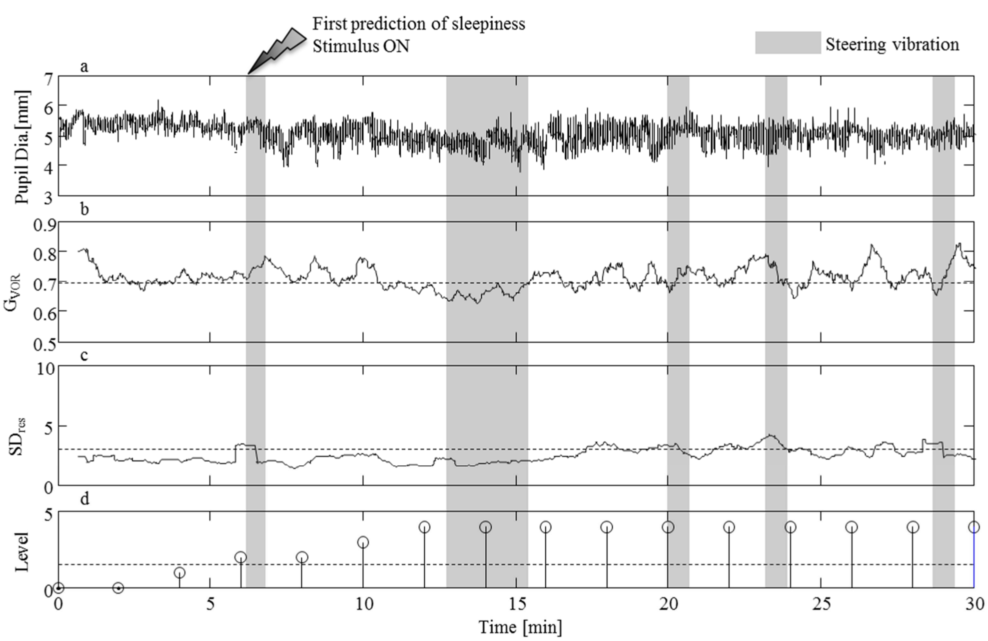

Figure 4. Changes in pupil diameter, VOR parameter and sleepiness level during driving simulation in the active driving maneuver experiment with the steering wheel vibration stimulus. a: Pupil diameter. b: VOR gain. c: VOR variability (standard deviation of residual). d: Sleepiness level.

Table 3. Time [min] from start of experiment to occurrence of self-aware sleepiness.

Subject	AI	KA	KK	YK	KO	SM	TM	SN	Ave.
Control	8	18	12	6	12	8	8	6	9.25
Subjective Sleepiness	6	10	16	6	8	8	6	10	9.25
Predicted Sleepiness	12	8	10	4	8	10	6	6	8.75

Table 4. Time [min] from start of experiment to occurrence of physiological sleepiness (LLFF).

Subject	AI	KA	KK	YK	KO	SM	TM	SN
Control	7.1	None	9.7	None	11.5	None	6.5	11.3
Subjective Sleepiness	8.0	None	19.5	13.9	13.8	None	7.3	9.8
Predicted Sleepiness	8.0	None	6.5	None	None	None	None	None

values over the 8 subjects for the 3 experimental conditions did not show significant differences.

On the other hand, Table 4 summarizes the effective duration of the steering wheel feedback stimulus defined as the time between the initiation of the stimulus and the initialtion of the pupillary LLFF for all the eight subjects in the 3 conditions. LLFF was not seen in two of the eight (KA and SM) under any of the 3 conditions, and they were therefore excluded from the following comparison. Results from comparison of the three conditions showed that in 5 of the 6 subjects (83%) the predicted sleepiness condition yielded the greatest effect on elongating the effective duration. Further, in 4 of the 6 subjects, LLFF was not observed until the end of the experiment, suggesting that these subjects were physiologically aleart during the monotonus DS experiment which easily makes most of our subjects sleepy in 10 minutes [3][6].

These results suggest that the active driving maneuver based on the steering wheel vibration feedback is effective in maintaining high-arousal level for a longer period of time, at least 6.5 minutes in the current experiment if the sensory feedback stimulus is started when physiological premonitor of sleepiness is detected.

DISCUSSION AND CONCLUSION

In the present study, we evaluated the effectiveness of voluntary driving maneuvers to maintain high arousal level for a long period of time by using driving simulation. We employed two kinds of sensory feedback stimuli whose intensity is modulated with the amount of deviation of the vehicle from the center of the driving lane. One is road noise and the other is steering wheel vibration. The voluntary maneuver that our subjects performed was to reduce the intensity of the sensory feedback by manipulating steering wheel to keep the vehicle at the center of the driving lane as close as possible. Thus this driving maneuver helps the driver keep in the driving lane at the same time with reducing somewhat annoying auditory or haptic stimulus, which may be regarded as a reward for the driver. In the first set of experiment, we compared the two sensory feedback stimuli by referring to our physiological sleepiness indices and showed that the road noise was effective in 3 out of 5 subjects while the steering wheel vibration was effective 4 out the same 5 subjects. Thus in the second set of experiment, we employed the steering wheel vibration, and evaluated the effective timings of initiation of the feedback stimulus in 8 new subjects, namely when subjective sleepiness was perceived or when a premonitor of sleepiness was detected. The prediction of sleepiness was done by referring to physiological measures (VOR gain and residual variability) that have been proposed previously [3]. As the result, it was demonstrated that initiating the steering wheel vibration feedback when the physiological predictor of sleepiness was detected was the most effective timing. Thus we conclude that the voluntary driving maneuver prompted to reduce the steering wheel vibration feedback stimulus is an effective novel method to prolong high arousal level during vehicle driving.

REFERENCES

[1] Tränkle U: Geschwindigkeitsbeschränkung und Fehlverhalten. Faktor Mensch im Verkehr, Heft 28. Darmstadt: Tetzlaff, 1978.

[2] Tanida K, Pöppel E: A hierarchical model of operational anticipation windows in driving an automobile, Cognitive Processing, 7, pp. 275-287, 2006.

[3] Hirata Y., Nishiyama J., Kinoshita S: Detection and prediction of drowsiness by reflexive eye

movements. Proc. IEEE EMBC2009, pp.4015-4018, 2009.

[4] Nishiyama J, Tanida K, Kusumi M, Hirata Y: The pupil as a possible premonitor of sleepiness. Proceedings of the 29th Annual International, Conference of the IEEE EMBS, pp. 1586-1589, 2007.

[5] Hirata Y., Highstein SM: Acute adaptation of the vestibuloocular reflex: signal processing by floccular and ventral parafloccular Purkinje cells. J Neurophysiol., 85(5), 2267-2288, 2001.

[6] Lowenstein O, Feinberg R, Loewenfeld IE: Pupillary movements during acute and chronic fatigue. Invest Ophthalmol Vis Sci. 2(2), 138-157, 1963.

Driver's drowsiness warning system based on analyzing driving patterns and facial images

Jinkwon, Kim
Samyong, Kim
Hochoul, Jung
Byoung Joon, Lee
Euiyoon, Chung
Driver Assistant System Development Team, R&D Division for Hyundai Motor Company
Republic of Korea
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ABSTRACT

Development of technologies to monitor the state of the driver is essential in order to provide appropriate services for various driving situations. For the last decade a variety of driver state monitoring techniques have been proposed from many studies. Driver state monitoring systems generally work based on driving patterns, driver's video or physiological signals. Driver's video or driving patterns are convenient to acquire, but to assess driver state accurately is difficult because these methods assess the driver state indirectly. On the other hand, the analysis based on driver's physiological signals can monitor the state of the driver directly, but the sensors are not adopted due to the sensor's low usability in vehicle environment.

The proposed driver state monitoring system aims to assess driver's drowsiness, fatigue, and distraction accurately while achieving high usability through analyzing the driving patterns and video of the driver together. The driver state monitoring system based on driving patterns is able to see the trend of driver state, but it is difficult to determine exactly when the driver is in a dangerous situation, like a microsleep. On the other hand, the video based driver state monitoring system makes it easy to determine the moment of falling asleep, but it needs an additional logic limiting the detection range to prevent increasing a wrong detection rate. The proposed logic finds drowsy driving sections by analyzing the driving patterns, and determines exact time when the alarm is triggered by analyzing the driver's video. This configuration makes the proposed logic decide driver state with a high accuracy and provide an alarm within an appropriate time. This study is preliminary to validate a possibility of the proposed algorithm. The proposed driving pattern based algorithm was validated by comparing with the self-assessment and driver's physiological signal. And the facial image based algorithm achieves a high accuracy of detecting face direction and eye blink.

INTRODUCTION

Sleepiness behind the wheel is the major contribution on fatal accidents. Especially in Korea, drowsiness is the number one cause of fatal accidents on the road. Sleep or drowsiness was a contributing factor in 27.4% of all accidents in 2010. Many different driver state monitoring (DSM) methods, such as driver facial image processing, driving pattern analysis, or biometric methods, have been proposed to detect dozing off at the wheel.

R Sayed et al. [1] developed a drowsy driving detection algorithm using datasets from a driving simulator. The algorithm relies on steering angle signal only, and used an artificial neural network as a classifier to detect drowsiness. They achieved a high accuracy on classifying the driver's state whether drowsy or awake. J Krajewski and his colleagues [2] also analyzed drowsy driver's steering wheel behavior. They proposed some feature sets to capture drowsy steering patterns, and compared five machine learning methods (linear kernel Support Vector Machine (SVM), radial kernel SVM, k-nearest neighbor, decision tree and logistic regression). They reported in a recognition rate of 86.1% based on a simulator database. M Rimini-Doering's study in 2005 [3] analyzed the relationships between drowsiness and lane departure events to figure out the effects of lane departure warning system (LDWS) on drowsy driving. According to the results of the study, 85% of the lane departure events caused by sleepiness could be prevented by LDWS. As well as these researches, there are many other existing researches on developing a drowsy driving detection system based on driving pattern, but most of them were conducted using databases acquired from a driving simulator. It makes difficult for the results of the researches to be used in practical environment.

Driver video analysis is another ordinary method for detecting drowsy driving. The eye blink is considered to be a suitable indicator for fatigue or drowsiness diagnostics. PERCLOS [4], the percentage of eyelid closure over a certain time period (usually a minute), is the most commonly used estimating method of drowsiness. P.C. Philipp and his colleagues [5] proposed several parameters of the eye blink which can be used as a drowsiness measure. They reported that blink duration, reopening time and the proportion of long closure duration blinks are closely related to drowsiness. P. Ilkwon et al. [6] developed a simple illumination compensation algorithm and a novel eyelid movement detection method for drowsiness detection systems using a single camera. The system achieved over 98% of the eye detection rate under various illumination conditions.

R N Khushaba et al. [7] acquired electroencephalogram (EEG), electrooculogram (EOG) and electrocardiogram (ECG) from subjects during a simulation driving test. They analyzed the signals using fuzzy mutual information based wavelet packet transform to get drowsiness-related information. L. Chin-Teng et al. [8] developed a drowsiness estimation system using EEG. They evaluated the relationship between ICA (independent component analysis) component of EEG and driving errors. M. Szypulska et al. [9] developed an algorithm based on heart rate variability (HRV) for detecting the moment of sleep onset. They asserted that HRV could be an indicator for detecting sleep onset, and represented the changes of HRV at the moment of sleep onset.

This study proposed a DSM system based on driving patterns and facial images. These signals are able to be acquired unobtrusively, and therefore the proposed system makes no inconvenience coming from the acquisition of signals. The next section gives a detailed account of the proposed drowsy driving detection system. And the results and discussion section represents the evaluation of the system comparing with the self-assessment and the results from the physiological signal.

METHOD

In this section, the detail configurations of the proposed system are described. The proposed system evaluates the trend of driver's drowsiness using driving patterns, and determines the exact time of microsleep based on detecting long blinks.

Driving pattern based DSM

The proposed system detects three driving patterns related with drowsy driving. The first driving pattern is high lateral speed event. The event is detected when the current lateral speed exceeds the reference lateral speed. The lateral speed, the blue line in the figure 1, means an average lateral speed over a short period of time. And the reference lateral speed, the red line in the figure 1, is calculated as adding the average and a certain times the standard deviation of lateral speed over a long period of time. Excess of the lateral speed over the reference lateral speed is considered as the loss of lane keeping ability.

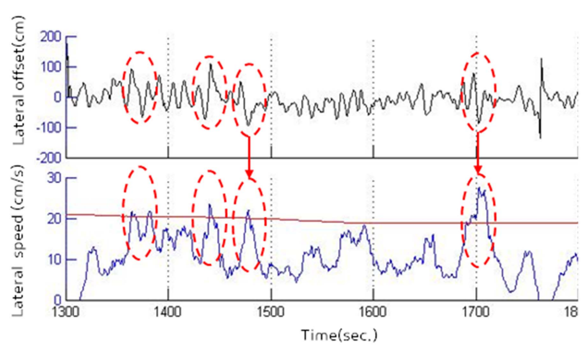


Figure 1. Examples of the high lateral speed drowsy driving patterns

The second driving pattern detects an abrupt counter-steering near the edge of the lane. As shown in Figure 2, steering value remains nearly constant during the driver is drowsy, and then over-reactive correction of steering value is occurred when the driver recognizes he is in danger. The detection logic of the second driving pattern examines three criteria. The three criteria are 1) the steering value changes less than a threshold during a few seconds, 2) the amplitude of the counter-steering value is greater than an ordinary counter-steering, and 3) the center of the car is far away from the center of the lane.

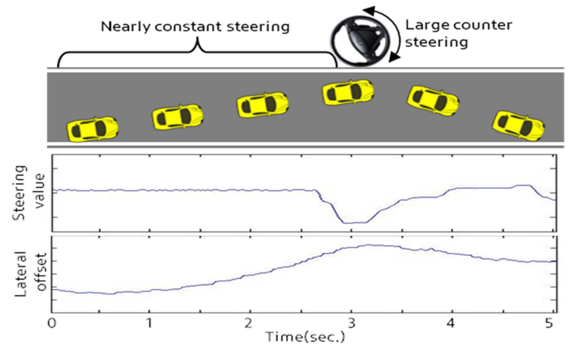


Figure 2. Examples of the over-reactive correction of steering based drowsy driving pattern

During getting sleepiness most of the driver is getting lost their hand from hold the steering wheel, and the last driving pattern measures tighten of hand to check whether the driver is under normal condition. When driver is drowsy, steering signal shows little change around zero because of weakening the gripping force. The detection logic of the third driving pattern checks that 1) the steering values changes less than a normal range around zero during a few seconds and 2) the lateral speed during that same period exceeds the reference lateral speed.

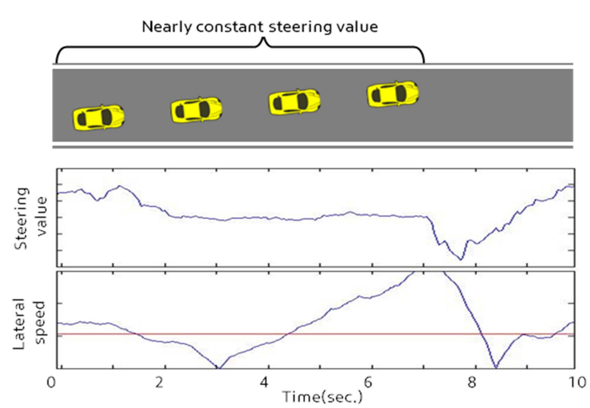


Figure 3. Examples of the excessive lack of steering based drowsy driving pattern

Facial image based DSM

Camera based DSM system detects the driver's face direction and the eye closure by using IR camera and image processing ECU. As shown in Figure 4, the IR camera is comprised of a image sensor, a MCU for controlling a image sensor, and a IR pass filter for preventing the interference of sunlight. The specification of the IR camera is as follows. The IR camera was installed on the steering column cover and its view angle is 45° in the horizontal direction. The image sensor is VGA level, and its dynamic range is more than 100 dB. Two IR-LEDs and IR pass filter were equipped for reducing the disturbance such as reflection from glasses and strong sunlight. The ECU including image processing DSP controls the synchronization between the image sensor and LEDs, and communicates with the image sensor and the vehicle CAN. And it also processes the DSM algorithm.

Figure 5 shows the configuration of the proposed camera based DSM algorithm for detecting face direction and eye blink. First, facial area detection is performed. The facial area detection adopts Modified Census Transform (MCT) [10] as a feature extraction method, which can get robust features against changes of illumination, and cascaded AdaBoost [11] as a classifier. Training database includes 300,000 non-face images and 300,000 face images.

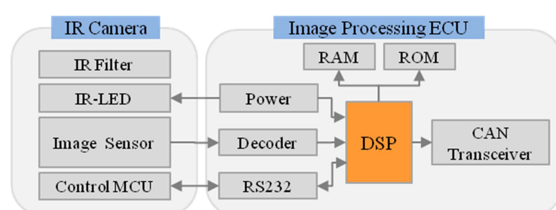


Figure 4. The block diagram of the IR camera

After the facial area detection, left and right face contour were detected through the projection of the binary image of facial area onto the horizontal axis. Next, face direction is defined according to the position of eyes, nose and mouth. The algorithm for detecting eyes, nose and mouth is also composed of MCT and AdaBoost. The face direction would be determined according to the face contour and facial parts position. For dealing with changes of illumination and glasses wearers, eye blink detection was performed by detecting upper and lower eyelids detection and applying

AdaBoost. Lastly, driver's inattention and drowsiness level are estimated by the analysis of face angle and eye blink pattern.

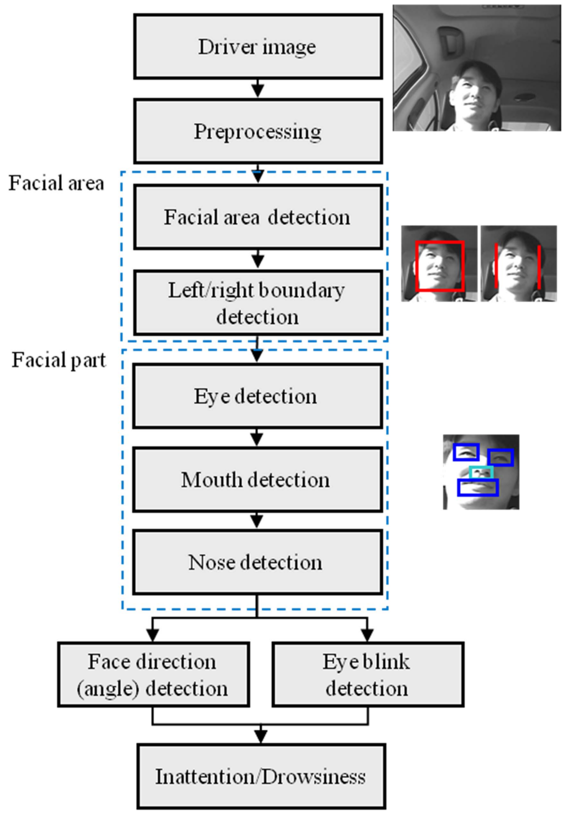


Figure5. The configuration of the image based DSM algorithm for detecting face direction and eye blinking

RESULTS & DISCUSSION

The driving pattern based DSM and the facial image based DSM are separately evaluated for safety reasons. The results of the driving pattern based DSM was compared with the drowsy level of self-assessment and the results of physiological analysis. As shown in Figure 6, a test car equipped with CAN data logging tool and biosignal acquisition tool was used for the evaluation of driving pattern based DSM. The recorded CAN signals included velocity, steering value, and lateral offset from LDW, etc. And ECG was recorded through a Biopac ECG 100C system. HRV is analyzed based on the recorded ECG signal to assess the state of the driver. Two drivers are involved in this evaluation experiment. They drove 100 km on highway course after lunch, and it took about an hour. During the experiment the driver was supposed to assess self-drowsy levels, and they could input the self-assessment signal through a button on the wheel. And using radio and talking are prohibited.

The evaluation results of the driving pattern based DSM is shown in Figure 7. The high lateral speed events, over-reactive correction of steering related events, and excessive lack of steering related events are respectively represented as red lines, blue diamonds, and red diamonds. The amplitude of red line means time duration when the current lateral speed exceeds the reference lateral speed. The self-assessment drowsy level has 4 levels; awake (level 0), slightly drowsy (level 1), extremely drowsy (level 2), and micro-sleep (level 3). The blue line in figure 7 represents LF/HF signal of HRV.

Figure6. The configuration of the test car for evaluating the driving pattern based DSM; 1) LDW, 2) facial image based DSM (IR-camera), 3) CAN data logging tool (Labview), and 4) Biosignal acquisition tool (Biopac)

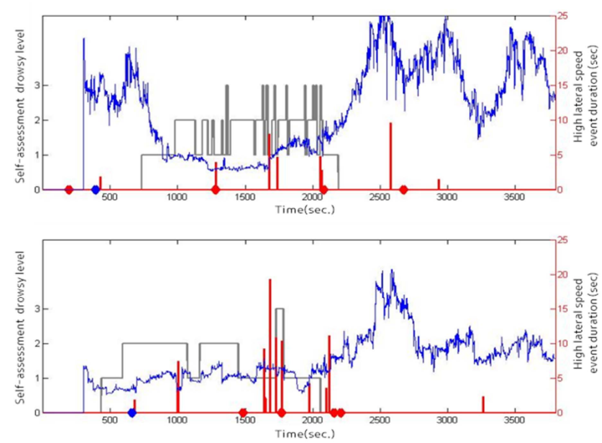


Figure7. The evaluation results of the driving pattern based DSM.

The LF/HF generally has low value when the subject is drowsy [9]. As can be seen in Figure 7, the LF/HF shows an inverse relationship with the self-assessment drowsy level. And the detected drowsy driving pattern events more frequently appear when the driver feels drowsy.

The evaluation of the facial image based DSM was performed using testing dataset acquired from 100 subjects in a standing car. Among them, 25 subjects were wearing glasses and the others were not. The subjects were supposed to blink at predefined interval and look nine different sites in the car, such as cluster, side mirror, AVN etc. As shown in Table 1, the performance of facial image based DSM achieved over 95% in a detection rate.

Table1.
The performance of the facial image based DSM

Detection rate of face direction (%)		Detection rate of eye blink (%)	
Wearing glasses	Without glasses	Wearing glasses	Without glasses
96.8%	96.3%	97.2%	90.3%

CONCLUSIONS

In this study, we proposed a drowsy driving warning system based on analyzing driving patterns and facial images. Although the proposed algorithm shows possibilities for detecting driver state and delivering an alarm at microsleep, i.e. long blink, farther experiments are necessary to develop a robust DSM system. The future work will be concentrated on the improving and validating the performance of the algorithm with large dataset to deal with a variety of environment.

REFERENCES

[1] R. Sayed and A. Eskandarian, 2001. “Unobtrusive drowsiness detection by neural network learning of driver steering.” In Proceedings of the Institution of Mechanical Engineers. Part D, Journal of Automobile Engineering, 215, 969-975.
[2] J. Krajewski, D. Sommer, U. Trutschel, D. Edwards, and M. Golz. 2009 “Steering wheel behavior based estimation of fatigue.” The 5th international driving symposium on human factors in driver assessment, Training and vehicle design, 118-124,
[3] M. Rimini-Doering, T. Altmueller, U. Ladstaetter and M. Rossmeier, 2005. “Effects of lane departure warning on drowsy drivers' performance and state in a simulator.” Proceeding of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 88-95.
[4] D.F. Dinges and R. Grace, 1998 "PERCLOS: A Valid Psychophysiological Measure of Alertness As Assessed by Psychomotor Vigilance.” Federal Highway Administration, Office of Motor Carriers
[5] P.C. Philipp, E. Udo and U. Peter, 2003, "Experimental evaluation of eye-blink parameters as a drowsiness measure." European Journal of Applied Physiology, Volume 89, Issue 3-4, 319-325
[6] P. Ilkwon, A. Jung-Ho and B. Hyeran, 2006, "Efficient Measurement of Eye Blinking under Various Illumination Conditions for Drowsiness Detection Systems." Pattern Recognition, ICPR 2006
[7] N. R. Khushaba, K. Sarath, L. Sara, and D. Gamini, 2011. “Driver Drowsiness Classification Using Fuzzy Wavelet-Packet-Based Feature-Extraction Algorithm.” Ieee Transactions on Biomedical Engineering, 58, 121-131
[8] C.T. Lin, R.C. Wu, S.F. Liang, W.H. Chao, Y.J. Chen, and T.P. Jung, 2005, "EEG-based drowsiness estimation for safety driving using independent component analysis." IEEE Transactions on Circuits System vol. 52, no. 12, 2726–2738
[9] M. Szypulska and Z. Piotrowski, 2012, “Prediction of fatigue and sleep onset using HRV analysis.” Mixed Design of Integrated Circuits and Systems.
[10] B. Froba, and A. Ernst, 2004, “Face Detection with the Modified Census Transform.” In Proceedings of the IEEE Conference on Automatic Face and Gesture Recognition, 91-96.
[11] Paul Viola and Michael Jones, 2004, “Robust Real-Time Object Detection.” International Journal of Computer Vision (IJCV)

IN CITY TRAFFIC EVALUATION OF VARIOUS CRASH AVOIDANCE FEATURES WITH CHINESE DRIVERS

Bing Deng
Raymond Kiefer
Wende Zhang
General Motors Safety Electronics & Innovation
U.S.A.
Paper Number 13-0181

ABSTRACT

This in-traffic study examined the performance and driver acceptance of various Crash Avoidance (CA) features with Chinese drivers on Shanghai urban, city roads. The test vehicle was a production 2011 Cadillac DTS equipped with Forward Collision Alert (FCA), Lane Departure Warning (LDW), Side Blind Zone Alert (SBZA), Front Park Assist (FPA), and Rear Park Assist (RPA) features. In addition, an "add on" camera-based FCA feature was installed on this test vehicle. Participants experienced the FPA and RPA features in a parking lot while approaching traffic cones, and then commenced a 25 km drive during normal traffic hours on urban roads. This drive included a variety of arterial, minor arterial, and branch roads. After this test drive, participants completed a series of questionnaires corresponding to each of the features they experienced. Overall, the RPA feature received generally more favourable ratings relative to the other features under these testing conditions. Furthermore, although undesirable false alarm activations associated with these features were observed, results generally indicated that the CA features evaluated appear promising in the China market.

INTRODUCTION

Various CA features are emerging in production vehicles offered in China. Given the unique traffic conditions and driver behavior characteristics in China, research is needed to examine the extent to which production crash avoidance features offered in other countries/markets (e.g., the United States) are well-suited, or at least readily adaptable, to these unique conditions. This in-traffic study provided an initial evaluation of the acceptance and performance of various CA features with Chinese drivers (primarily GM China employees) on Shanghai urban roads. The study employed a production 2011 Cadillac DTS (imported from the United States) equipped with a high level of crash avoidance feature content. Test participants were asked to drive the test vehicle on Shanghai urban surface roads and then provide subjective ratings on the various features that they experienced. The results reported here are part of a broader multi-study effort to gather feature performance and driver behavior data with crash avoidance features with Chinese drivers on China roads.

METHODOLOGY

Test Vehicle and Features Evaluated

To support this testing, a 2011 Cadillac DTS Platinum was imported from North America (see Figure 1) that was equipped with production FCA, LDW, SBZA, FPA, and RPA features. In addition, an "add on" prototype camera-based FCA feature was also installed on this test vehicle. (The vehicle was also equipped with Adaptive Cruise Control; but this feature was not used by participants in the current effort.) The radar-based production FCA feature lets the driver know when the feature detects a vehicle ahead, and warns the driver when following a vehicle directly ahead much too closely or when the driver may be in imminent danger of crashing into the vehicle ahead (Figure 3). In the latter case, a series of high-pitched warning beeps are sounded out the front speakers. The feature operates above 20 mph or 32 kph. The camera-based prototype FCA feature used an "add on" forward-looking camera sensor located on the windshield ahead of the rear view mirror. The feature also operates above 20 mph or 32 kph. The "add on" FCA display was located on the top of the dashboard to the right of steering wheel (Figure 3). Similar to the production radar-based FCA feature, when a vehicle is detected ahead, a green vehicle ahead display is lit. Furthermore, when the feature determines the vehicle is following too closely to the vehicle ahead, this display turns amber. When the feature determines that you may be in imminent danger of crashing into the vehicle directly ahead, this display turns red and flashes and a series of high-pitched warning beeps are sounded from the front.

The LDW feature operates above 35 mph or 56 kph, and requires at least one visible lane marking to operate. The LDW display is located in the instrument panel. When lane markings are detected ahead, a green LDW symbol is lit (Figure 4). If the vehicle drifts out of the lane without the turn signal activated, this symbol will turn amber and flash, and three low-toned beeps are sounded. These beeps are played out of left front or right front speaker, depending on the direction of the lane departure.

The SBZA feature operates at all speeds when moving forward. The SBZA warning symbol is located in both outside side mirrors. When a vehicle is detected in the left/right blind zone, this symbol is lit in the left/right mirror. If the turn signal is activated in the direction of a detected blind zone vehicle, the SBZA warning symbol flashes to give the driver extra warning not to change lanes (Figure 5).

The FPA feature assists the driver in avoiding objects directly ahead of the vehicle while moving forward during low speed parking (i.e., below 5 mph or 8 kph). The object distance display for this feature is located on the top of the dashboard to the right of steering wheel in the center of the vehicle. This display uses two amber indicators and one red distance indicator light to warn the driver (Figure 6). When the vehicle is within 0.3 meters of a detected object, all three lights will flash and repeating high-pitched beeps are played out of both front speakers.

Similarly, the RPA feature assists the driver in avoiding objects directly behind the vehicle while backing during low speed parking (i.e., below 5 mph or 8 kph). The object distance display this feature can be viewed in the rear of the vehicle as the driver looks over their right shoulder. This display may also be visible in the rear view mirror. This display uses two amber and one red distance indicator light to warn the driver (Figure 7). When the vehicle is within 0.3 meters of a detected object, all three lights will flash and repeating low-pitched beeps are played out of both rear speakers.

Figure 1. Production 2011 DTS test vehicle

Figure 2. Forward Collision Alert (FCA) display

Figure 3. Camera-Based Forward Collision Alert (FCA) display

Figure 4. Lane Departure Warning (LDW) display

Figure 5. Side Blind Zone Alert (SBZA) display

Figure 6. Front Park Assist (FPA) display

Figure 7. Rear Park Assist (RPA) display

Data Acquisition Systems

The vehicle operational data was logged through the CAN bus. The operational and alert data from the “add on” prototype camera-based FCA feature was recorded and synchronized with vehicle data.

Test Participants

Test participants included 17 males and 6 females between the ages of 25 and 43 years old, with a median age of 33 years old. Figure 8 provides an age breakdown of the test participants. 70% of the test participants were between 25 and 35 years old, which corresponds well to Shanghai statistics indicating that more than 75% of driver license holders are younger than 35 years old [1]. Twenty of the 23 test participants were GM China employees, who had between 1 and 13 years of driving experience (with a median value of 6 years of experience). The remaining three test participants were company drivers who had 8, 11, and 16 years of driving experience.

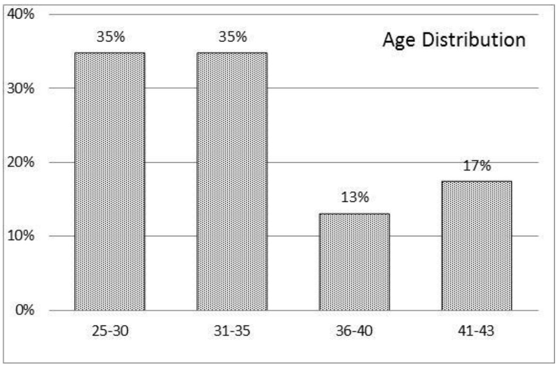


Figure 8. Age Breakdown of Test Participants

Test Procedure

A detailed PowerPoint and video description of each of the features evaluated (both available with Mandarin Chinese translation) was used for the initial training of all test participants. This training occurred as part of a "question and answer" workshop that occurred a few weeks before formal testing commenced.

On the day of a participant's test session, they were required to read and sign an Informed Consent Statement prior to participating in the study. Next, participants viewed the same feature-by-feature training video using in the previous workshop training. Participants then drove the test vehicle (accompanied by an experimenter), and initially were exposed to the FPA and RPA features in a parking lot while slowly approaching traffic cones.

Next, the test participants drove a 25 km (or 15 mile) test route between either between 9:30 and 11:30 am or between 2:00 and 4:00 pm. Participants drove on one of two urban surface road routes in Shanghai. These test routes included a variety of surface road types, including arterial, minor arterial, and branch roads.

It should be noted that on Shanghai arterial roads, 42% of traveling distance occurs at speeds of less than 40 kph (or 25 mph) [2]. Consistent with these traffic congestion-related findings, the 25 km (or 15 mile) test route took approximately 1-2 hours to complete (depending on traffic conditions). At the completion of the test drive, participants were asked to complete a series of 2-page questionnaires (translated into Mandarin Chinese) that addressed their perceptions and impressions of each of the features they experienced during testing. The questionnaires were designed, to the extent possible, to ask the participants the exact same set of questions for each feature. This questionnaire strategy was employed in order to enable direct comparisons across features, as well as shorten the time needed for the driver to complete the entire set of questionnaires.

RESULTS

The features evaluated were exposed to a rich set of "objects to be detected" (e.g., pedestrians, bicyclists, electric bicycles, motorcycles, and over-loaded carts) under driving conditions that are felt to be more dense, less orderly (with respect to drivers consistently following traffic rules), and more aggressive (e.g., frequent cut-ins and lane changes) than those typically found under United States (US) driving conditions. Figure 9 illustrates various aspects of the challenging China traffic environment, including unusual-looking vehicles, over-loaded vehicles, and complex busy intersections.


Figure 9. Challenging China traffic environment

All FCA questionnaire results reported below are associated with the FCA camera feature, since the logged vehicle operational data indicated no alerts were issued by the production radar-based FCA feature. The lack of FCA warnings observed from this FCA feature tentatively suggests that the associated production FCA timing approach would not be false alert prone under the test conditions evaluated.

Comparison among different systems was conducted using the eight rating dimensions listed below. Each dimension employed a 5-point rating scale with labeled points of 1= Disagree Strongly, 3=Neutral, and 5= Agree Strongly.

OVERALL: Overall, how would you rate your driving experience with the system?
PURCHASE INTEREST: I would like to have the system in my next vehicle
PLEASEABILTY: I was pleased with the system
HELPFULNESS: I think the system would help me in my everyday driving
SAFETY: I think the system would increase my driving safety
CRASH AVOIDANCE: I think the system would help me avoid relevant crash type
UNDERSTANDABILITY: The alerts came on, I understood why

ANNOYANCE: The alerts were annoying

The overall mean rating for each dimension is shown in Figure 10. The RPA feature received generally more favorable ratings relative to the other features evaluated under these testing conditions, suggesting that the RPA system (including the human machine-interface approach) evaluated appears well-suited for the China market. The remaining features evaluated yielded similar subjective ratings by the test participants, with overall mean ratings generally ranging between "3" (neutral) and "4" on the 5-point scale (where "5" corresponds to "strongly agree"). (Note, for the annoyance dimension, a lower number is a more favorable rating.) In addition, the ratings surrounding the "add on" prototype camera-based FCA system are promising.

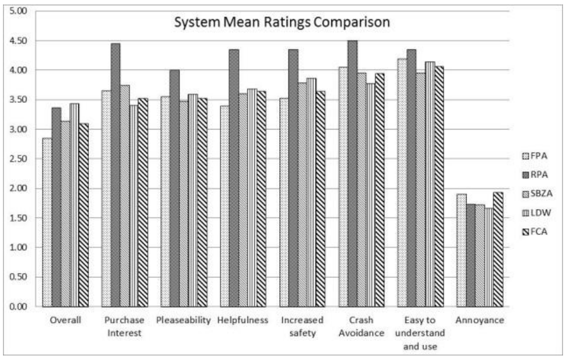


Figure 10. Mean ratings across various crash avoidance systems

When interpreting these results (in particular the SBZA and LDW findings), it is important to note that frequent lane change and prolonged "lane hovering" (i.e., driving on lane boundary for prolonged periods of time) are common strategies drivers use to gain a traffic queue advantage in China. In addition, as in other countries, some drivers may not use turn signals or scan their mirrors as part of their lane change behavior (note turn signal activations are used to suppress LDW alerts in the LDW system that was evaluated).

Another important caveat of these results is the relative low levels of driving experience test participants had with the features evaluated. Indeed, the relatively high RPA ratings could be attributed to driver's greater familiarity and experience with this particular feature. Hence, it should be noted that with increased exposure to CA features, the acceptance ratings of Chinese drivers could change (and hopefully become more positive).

Figure 11 provides results and the rating choices from the following alert timing question:
TIMING: Please rate the timing of when alerts came on.

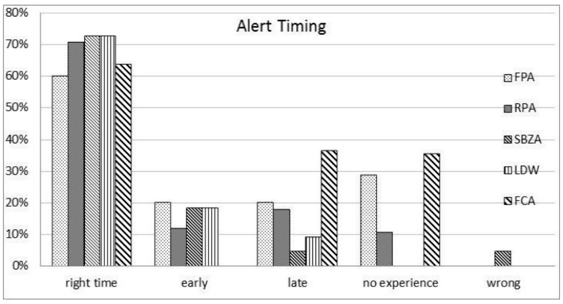


Figure 11. Alert timing ratings across systems

As shown on the right side of Figure 11 (under the "no experience" category), all drivers reported experiencing LDW and SBZA alerts, and the percentage of participants reporting no experience with the FPA, RPA, and (prototype camera-based) FCA alerts were 29%, 11%, and 35%, respectively. Even though all participants were given the opportunity to experience the FPA and RPA features in a parking lot while slowly approaching traffic cones, some did not provide the FPA and RPA alert timing ratings. These alert timing results indicate that the "right time" category received the highest percentage of ratings for each of the features evaluated, and that no "unacceptably late" ratings were observed. In addition, overall, the incidence of "unacceptably early" ratings was relatively low across features.

Figure 12 provides results from the following "anticipated system usage" question:
ON/OFF IN OWN VEHICLE: If I had the system I experienced on my own personal vehicle I would leave the system ON or OFF.

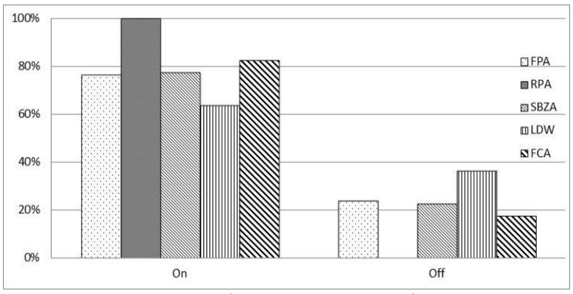


Figure 12. ON/OFF feature usage preferences across various crash avoidance features. (Note "ON" ratings combined results from the "ON all of the time" and "ON most of the time" categories, and "OFF" ratings combined results from the "OFF all of the time" and "OFF most of the time" categories.)

Results in Figure 12 indicate that that the percentage of drivers reporting they would leave these features ON (either all or most the time) ranged from a low of 64% for the LDW feature to a high of 100% for the RPA feature. This pattern of "anticipated system usage" findings is consistent with the pattern of mean ratings of "purchase interest" shown in Figure 10.

Figure 13 provides results from the following two system-performance oriented questions:
FALSE ALARMS: Did you notice any instances when the system alerted when it should not have done so?
MISSES: Did you notice any instances when the system did not alert when it should have?

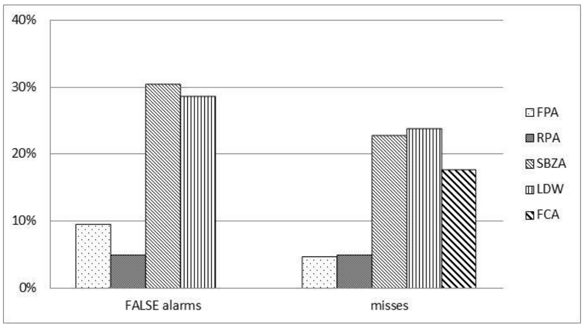


Figure 13. Reported false alarms and misses across various crash avoidance features

As shown in Figure 13, some test participants reported experiencing false alarms with the RPA, SBZA, and FPA features. In addition, some test participants reported experiencing misses with the LDW, SBZA, and (prototype camera-based) FCA features. It should be noted that these subjective data do not necessarily correspond to intended system performance, and that these subjective reports could be due to test participant's incorrect understanding of feature operation (particularly given their limited experience with these features under the current test conditions).

Given these important caveats on this subjective data, reported experiencing relatively higher levels of false alarms and misses with the LDW and SBZA features. Reported LDW false alarms tended to be associated with curves and freeway ramp scenarios, whereas reported misses for this feature tended to be associated with poor lane markings. Reported SBZA false alarms were associated with structures being very close to road edges (e.g. guardrails, barriers, trees), whereas miss issues were associated with the feature failing to detect other vehicles when stopped.

CONCLUSIONS

The results reported here are part of a multi-study effort to gather system performance and driver behavior data with crash avoidance features with Chinese drivers on China roads. Overall, the GM production and prototype "add on" crash avoidance features evaluated appear reasonably well-suited for the China market. It should be noted that the test participant's (aged 25 to 43) had extremely limited experience with these features relative to a feature owner (with the possible exception of the RPA feature). With respect to the relatively young age of the test participant's, the reader is reminded that 75% of driver license holders in Shanghai are less than 35 years old [1].

The RPA feature employed was particularly well-received by test participants, and appears well-suited for the China market. The preponderance of low speed travel on urban roads in China coupled with the close proximity and dense clusters of "objects of interest" (vehicles, pedestrians, and bicyclists) are consistent with the observed subjective ratings. In addition, the China driving environment and driving conditions more generally suggest that other "near field", low speed operation features (e.g., "distance to object" graphical displays, Rear Vision Camera, 360 degree camera-based surround-view feature, pedestrian/bicyclist detection) would similarly be well-received by Chinese drivers.

The LDW feature received the lowest anticipated driver usage ratings under these "limited experience" testing conditions, and the LDW and SBZA features had the highest levels of subjectively "reported" false alarms and misses. It is hypothesized that potentially the relatively high frequency of lane changes (and lane hovering), lower use of turn signals, and/or lower use of mirrors could have played a role in these subjective LDW and SBZA ratings. Hence, efforts should be pursued to attempt to better accommodate these features to the China market (which may benefit other markets as well), in order to help ensure drivers leave these features on.

Finally, multiple sensing and sensor fusion approaches (e.g., mono/stereo camera, radar, lidar, laser, and ultrasonic sensing) should be considered to improve feature performance under the challenging dense, dynamic, and generally less predictable vehicle, bicyclist, and pedestrian traffic conditions characteristic of urban China. These approaches may have particular importance for features that automatically control (e.g., brake and/or steer) the vehicle in order to avoid or mitigate the impact of potential crash.

REFERENCES

[1] Shanghai Statistics: http://www.stats-sh.gov.cn/ (2009 to 2011)
[2] Xuesong Wang, Haobing Liu, Xiaohong Chen, and Bing Deng, "Exploring Speeds on Urban Arterials using Floating Car Data: A Case Study in Shanghai", Journal of Transportation Engineering, 2012.

A TECHNIQUE FOR EVALUATION OF PEDESTRIAN WARNING CONDITIONS WITH HIGH DRIVER ACCEPTANCE.

Jan-Erik Källhammer
Autoliv Development AB
Sweden
Hanieh Toghyani
Linköping University
Sweden
Kip Smith
Naval Postgraduate School
United States
Paper Number 13-0229

ABSTRACT

This paper discusses a research method used to evaluate the design of the alerting logic of automotive active safety systems and presents an example of how this method can be used to support the design of pedestrian collision warning alerts. Three questions therefore arise: First, how can we collect a measure of the acceptability of an alert to a wide variety of situations? Second, how consistent is that measure across contrasting samples of drivers? Finally, how to use the measure in designing alerting logic?

We describe an empirical approach to quantifying the relative level with which drivers are likely to accept pedestrian alerts by a night vision system. The study had two parts: a field operational test (FOT) that gathered a set of 302 video clips of pedestrian alerts with a night-vision system, and a post-hoc or retrospective ratings experiment in which volunteers viewed the clips and rated the relative acceptability of the alerts. We document the consistency of these subjective ratings across groups of raters with different levels of experience with the system. This finding supports the argument that laboratory reviews of FOT data are likely to generalize across the population of drivers.

The derived measure of acceptance was then used to investigate a range of contextual and quantitative factors likely to influence driver acceptance of alerts to pedestrians issued by a night vision active safety system. Least squares regression revealed that nominal characterization of pedestrian location and motion and two quantitative measures – minimum separation and time to closest approach - explain almost 70% of the variance in driver ratings and do not interact. We discuss the implications of this finding for the specification of the system's alerting strategies.

INTRODUCTION

A pre-requisite for a good pedestrian alerting system is reliable detection of pedestrians in a wide variety of ambient conditions, but reliable detection is not sufficient to ensure a system is widely accepted by drivers. The system must also implement alerting strategies that determine whether an alert should be issued to warn the driver about a potentially dangerous situation. The number and level of errors caused by unreliable detection will likely shrink with the evolution of technology, while the levels of other unwanted alerts for accurately detected pedestrians are likely to remain, since they are dependent on factors such as the driver's attention and predisposition.

The safety benefits of any active safety system can materialize if and only if the system will be used. Promoting system acceptance must therefore be a major goal. Accordingly, designers of pedestrian alerting systems need a method that can help them determine the factors that influence driver acceptance of alerts. However, the development of active safety systems has often taken an engineering perspective that emphasizes system accuracy, rather than a human factors perspective that emphasizes concordance with the driver's expectations of system performance.

We have taken the human factors approach to develop a metric of driver acceptance of system alerts to traffic situations. Our approach to evaluating system performance is predicated on the belief that system design should seek to maximize driver acceptance of the system, as driver acceptance is likely to improve if the system activates when the driver finds it reasonable.

Driver acceptance or lack of acceptance of a type of alert should never override concerns raised by the basic physics of the situation. An alert should likely always be issued whenever the situation appears to be in the process of precipitating a collision. On the other hand, an alert should not be issued when the risk of a collision is sufficiently low to lead drivers to disregard the alarm. Accordingly, the key to promoting adoption of an active safety system is driver acceptance of system response in situations that lie between the extremes, that is, between situations where there is a clear need for alerts and situations where no alert is justified. Due to the low base rate of actual collisions, most of the alerts issued will be in such in-between situations.

Risk perception is an inherent part of the decision-making process. The quality of the risk assessment depends on the adequacy of the available information (Williams & Noyes, 2007). Risk perception does not have to be associated with the actual risk of collisions. Sheridan (2008) defined safety as conditions where risk is acceptable and points out that risk is partly a subjective factor. An active safety alerting system must therefore take into consideration the driver's assessments of the situations where alerts are being issued.

Wiese and Lee (2004) found a strong correlation between rated annoyance and subjective workload and suggested that perceived annoyance should be used in alert design. They pointed at the important trade-off between improving driver response time through increased alert urgency and the annoyance related to highly urgent alerts. The annoyance trade-off is affected by both the alert type and the frequency of the issued false alarms.

Measuring driver acceptance using field operational tests (FOT) data is a reasonable approach, but is faced with the scarcity and expense of FOT data. A second obstacle is that all FOT data are to some extent unique as their collection is not subject to experimental control. The approach we advocate is to leverage FOT data in the laboratory. This method retains a high level of ecological validity by collecting actual incidents on the road. We then make efficient use of the recorded (and rare) field incidents using within-subjects designs, categorical independent variables, and replicable, quantitative dependent measures.

METHOD

At issue here is the consistency, across groups of drivers with differing levels of driving experience, of the subjective ratings of acceptance obtained in the laboratory. We elicited ratings of the relative acceptability of alerts to pedestrian encounters in a set of FOT video recordings. Volunteers rated the acceptability of an alert to each pedestrian encounter.

FOT data collection

Eight drivers drove instrumented vehicles equipped with a Night Vision system with pedestrian detection software. The drivers were recruited at Autoliv in Vårgårda, Sweden, and applied voluntarily to the study. The system records a continuous 'video' to display to the driver and superimposes an alert icon when pedestrians may be at risk.

The Night Vision system consists of a Long Wave, or Far Infrared (FIR) night vision camera mounted in the grille of the vehicle and a video display mounted on the upper part of the center console. The system contains integrated pedestrian recognition software. The display screen is updated at 30Hz with a black and white FIR image. The image is augmented by a flashing yellow alert symbol and by red rectangle(s) that highlight the pedestrian(s) whom the system has detected. The system was installed in eight recent model year Volvo and SAAB vehicles. A PC mounted in the trunk of the car recorded the video clips in a time window before and after an alert. Each car was used for everyday driving by its owner. Subject participation conformed to the ethical guidelines established by Vetenskapsrådet, the Swedish Research Council (2002).

The eight Night Vision systems flagged a large number of video clips with pedestrian encounters like that shown in Figure 1. Back in the laboratory, we selected clips of flagged events for review. The criterion for selection of clips to be reviewed was that there should not be any ambiguity regarding which pedestrian(s) the volunteers were to rate. Groups of pedestrians were allowed, if they were in the same context, for example walking together. Clips with pedestrians visible at different locations were excluded. Presenting the video clips in a random order contributed experimental rigor to the review.

Figure 1. A typical alert issued by the system.

The product of this selection process was a series of 302 video clips of traffic incidents and situations that were the stimuli used in the table-top laboratory experiment. Each clip shows approximately 5 s of images from the FIR camera. The duration of each video clip was kept short to allow each rater to rate a large number of clips within a reasonable time. Each clip ended a few seconds before the pedestrian encounter at approximately the time that an alert would have to be given to provide the driver enough time to take appropriate action. The amount of time between the end of the clip and the pedestrian encounter varied between 0.9 and 12 seconds. The time to pedestrian encounter was measured as either the time to collision or, if the vehicle and pedestrian were not on direct collision path, to the time when the vehicle position would be adjacent to the pedestrian.

Laboratory experiment

Our method is inspired by the hazard perception test used in U.K. driving tests (Jackson, Chapman, & Crundell, 2009). The experimental procedure consists of viewing and rating: Observers in the laboratory watch the replay of a video clip and then rate the level with which they would likely accept an alert from an active safety system to that event.

A laptop computer connected to a video projector presented the video clips on a wall at a distance of 3 m and a horizontal field of view of 40 degrees. No information about the traffic context other than the FIR video clips was provided to the raters. To avoid response bias, we did not query them on their thoughts regarding their criteria for acceptance.

Immediately following the presentation of each clip, the projector froze the last frame of the clip and the laptop display presented the response screen and its scale bar, Figure 2. The experiment was self-paced. The raters used the Next button in the response screen to queue the next clip. The flashing alert symbol was suppressed to avoid any indication whether an alert was issued and if so, the timing of the alert.

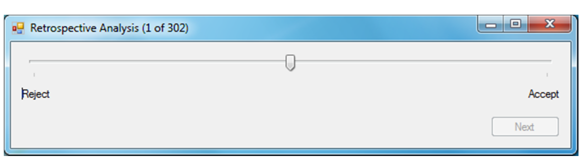


Figure 2. The Response Screen Used in the Experiment.

Instead of the response time collected in the U.K. hazard perception test, our approach quantifies the relative level with which drivers are likely to accept an alert using the approach proposed by van der Laan, Heino, and De Waard (1997). To simplify and clarify the participants' task and to achieve a single measure as in the hazard perception test, we condense the nine scales advocated by van der Laan et al. into a single acceptance score using a continuous scale from 'Reject' to 'Accept'.

The instructions given to the raters were that the scale was linear and that the position on the scale should reflect the degree of rejection or acceptance they had towards an alert to each situation. The raters were asked to provide a rating further to the right on the scale as their acceptance to an alert increased. When they had no objections to an alert they were asked to place their marker at the 'Accept' end of the scale (100%). Likewise, decreasing acceptance to an alert should generate ratings further to the left and would end up at the 'Reject' end of the scale (0%) when they under no circumstances would want an alert to the situation. They were further told that the middle of the scale (50%) was the threshold, above which they would, all things being equal, accept an alert and below which they wouldn't accept an alert. Each rating therefore reflects a judgment by the rater of the relative level at which the situation warrants an alert from the system.

Three groups of participants took part in the experiment. The first was the group of eight drivers from the field study (age: M 53.1 yr., SD 5.8, range 46 to 61). All of the 8 drivers had considerable driving experience (M 34.9 yr., range 27 to 43). They all worked with automotive safety in various capacities. Each of them had experienced some of the reviewed pedestrian encounters. Between them, they had experienced them all.

The second was a group of 42 volunteers (age: M 42.6 yr., SD 10.7, range 24 to 67) recruited from the same facility as the drivers. Most of the 42 had considerable driving experience (M 19.0 yr., range 3 to 48). None of the 42 had experience with the pedestrian alert system in their personal vehicles.

The third was a group of 24 volunteers (age: M 33.4 yr., SD 6.6, range 26 to 52) recruited from a sister company at another location in Sweden. Most of the 24 had considerable driving experience (M 14.2 yr., range 4 to 34). All had experience with the development of the pedestrian detection system. Some were involved with testing and some involved with system and algorithm development. Their experience with the system and inside knowledge of its functionality made them possible candidates for judging the various pedestrian encounters differently.

All participants lived in Sweden and had similar professional backgrounds. The main differentiation is their experience with the system. To make the rating process less of a burden, the video clips where divided into two subsets and each rater was randomly assigned to one of the two subsets. An exception to the randomization was made for the eight drivers who participated in the field study. They wanted to review the events they had experienced on the road. We therefore arranged the two subsets such that all of the events experienced by a given driver were placed in the same subset (together with other clips collected by other drivers).

RESULTS

Here we present analyses of the consistency of the ratings across the participants. With the consistency established, we use the average rating for each event as the response variable (dependent measure) in a regression analysis. The predictor variables in the regression analysis are nominal characterizations of pedestrian location and motion and a pair of quantitative variables previously found to influence ratings.

Consistency or ratings

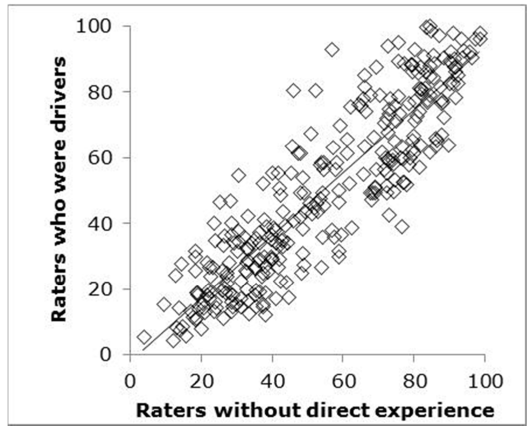
We have analyzed the collected ratings to assess their concordance across three groups of raters. The three groups are (1) the laboratory participants without direct experience with the system, (2) the drivers who drove the cars in the FOT, and (3) the laboratory participants who had experience developing the pedestrian detection system. We expected that the three groups would reflect increasing experience with the functionality of the tested system.

We found driver acceptance of alerts to be highly consistent across groups with differing exposure to the system. The consistency of ratings between the raters without direct experience with the system and the other two groups of raters is shown in Figure 3. The cross-plots compare the mean ratings assigned by the raters without direct experience with the system and the mean ratings assigned by the other raters. In Figure 3a, the other raters are the eight drivers who drove the cars in the FOT. In Figure 3b, the other raters are the 24 participants who had experience developing the pedestrian detection system.

The graphs in Figure 3 also show the best-fit least-squares regression equations for the rating data. The agreement between the ratings by the drivers and the other participants are linear and quite good, $r^2 = 0.79$, $F(1, 302) = 1127$, $p < 0.0001$ for the drivers in the FOT and $r^2 = 0.89$, $F(1, 302) = 2462$, $p < 0.0001$ for the 24 engineers. The larger spread among the drivers who drove the cars in the FOT may be due to the small sample size.

We tested the internal consistency of the ratings by applying the Kendall coefficient of concordance to their ratings. This non-parametric test of inter-judge reliability assesses the degree of agreement in the rank ordering of a set of items (e.g., the 302 video clips) by N judges (Siegel & Castellan, 1988). It imposes no categorical dimensions of similarity on rated items. We found them highly concordant; $W = 0.5702$, $\chi2\ (301) = 6350$, $p < 0.0001$.

a



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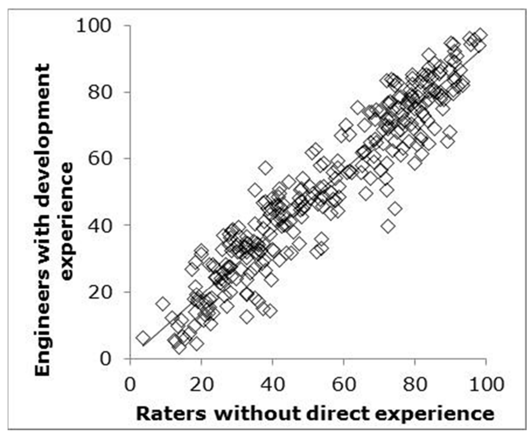


Figure 3. Cross-plots of the average rates of the raters without experience with the system and the average rates of (a) the eight drivers who drove the cars in the FOT and (b) 24 engineers involved in developing the system.

This result encourages us to conclude that the laboratory results are highly consistent. On average, the raters, whether they had experience with the system or not, differentiated among the events in a similar way. This finding supports the contention that the laboratory method of review and rating of events recorded during an FOT study produces data that are consistent between groups of raters with different experience with the system. The high level of concordance implies that the ratings may be aggregated in subsequent analyses of the influence of various parameters on the acceptance of alerts.

Regression analysis

To understand better the influence of pedestrian location and motion on driver acceptance of alerts, we used regression to ascertain the degree to which they explained the observed variability in driver ratings. We created nominal variables that combined categories of pedestrian location and motion, Table 1. Each of these composite categories (e.g., a pedestrian on the left edge of the street who is moving into the street) represents an incursion into the driver's field of safe travel (Gibson & Crooks, 1938). The field of safe travel is an indefinitely bounded field consisting of all unimpeded paths that a vehicle can take at any moment. In a previous study (Källhammer & Smith, 2012), we found some of these incursions to be statistically significant predictors of driver acceptance of alerts.

Table1.
Factors describing combinations of pedestrian location and motion analyzed in this study

Pedestrian location	Combined with pedestrian motion
In Street	None
Right edge	None
Left edge	Same or Opposite Into street
Left side (beyond curb)	Same or Opposite Standing
Right side (beyond curb)	Same or Opposite Standing

We expect ratings to be higher when pedestrians are seen to be within or moving toward the driver's field of safe travel (Gibson & Crooks, 1938). The relative likelihood of pedestrian incursion into the field supports the hypothesis that the acceptance of alerts would be higher when the pedestrian is In the street or on its Right edge than when on the Left edge of the roadway or beyond it on either side.

With regard to Pedestrian Motion, we expect alerts to receive higher ratings when the pedestrian is walking into the street than when standing or walking parallel to the street. The category 'Into street' implies that the pedestrian was walking essentially perpendicularly to the direction of vehicle travel and into its field of safe travel. The categories 'Same' and 'Opposite' are reserved for pedestrians walking in a direction predominately parallel to the vehicle's path in either the same or opposite direction as the vehicle.

When Right edge was used as a separate variable, it interacted with combinations with motion variables and was thus excluded from the combinations. The combinations of Left edge and Standing, Left side and Into street, and Right side and Into street were excluded due to too few cases.

Each of the 302 clips from the FOT was reviewed and categories determined for these factors. Each category was partitioned into a single nominal (dummy) variable at two levels 1 and 0. The categories were the predictor variables in the analyses. The response variable was the average ratings of acceptance of an alert to the events in the video clips.

In addition, the analysis of the motion data used the observed distance in meters between the pedestrian and the car. The observed distance was measured in the direction of the vehicle's travel. By convention, X is positive in the direction of travel. Because the sensor was directed ahead of the car, X distances to pedestrians are always positive. Time to Impact (TTI), measured as time to collision or time to a vehicle position adjacent to the pedestrian if the vehicle and pedestrian were not on direct collision path, was used to describe the time-distance relationship.

The least squares regression equation is shown in Equation 1, the summary statistics in Table 2, and the fit of the model in Figure 4a. The ten parameters explain nearly 70% of the variability in the drivers' ratings of the alerts issued in the 302 video clips. None of their interactions are significant. The ability to explain 70% of the variability in human judgment is both unusual and, we believe, impressive.

$$\text{Rating} = 74.0 + 18.9*L1 + 12.6*L2 - 18.8*M1 - 36.1*M2 - 25.9*M3 + 16.7*M4 - 25.9*M5 - 20.0*M6 - 0.2*\text{Min X} - 0.6*\text{TTI} \quad (1).$$

As expected, factors that indicate that pedestrians are either within or moving toward the driver's field of safe travel prove to be highly significant predictors of alert acceptance. A positive beta weight increases the predicted rating of pedestrians in the path of the approaching vehicle (In street or Right edge) and for pedestrians moving from the Left edge into the street. A negative beta weight decreases the predicted rating of pedestrian motion parallel to the street or pedestrian standing on either side of the street. The weights become increasingly negative the further away the pedestrian is located from the path of the vehicle. The further away the pedestrian is located from the on-coming car and the longer the TTI also reduce the predicted rating.

Table2.
Summary of the Regression Model with 10 Predictors

Variable	Equation symbol	B	t	p
Intercept		74.0	14.6	<0.001
In Street	L1	18.9	3.7	<0.001
Right edge	L2	12.6	2.7	0.008
Left edge and (Same or Opposite)	M1	-18.8	-3.6	<0.001
Left side and (Same or Opposite)	M2	-36.1	-6.8	<0.001
Right side and (Same or Opposite)	M3	-25.9	-5.5	<0.001
Left edge and Into Street	M4	16.7	2.8	0.006
Left side and Standing	M5	-25.9	-4.7	<0.001
Right side and Standing	M6	-20.0	-3.9	<0.001
MinX	Min X	-0.2	-3.6	<0.001
TTI	TTI	-0.6	-4.1	<0.001

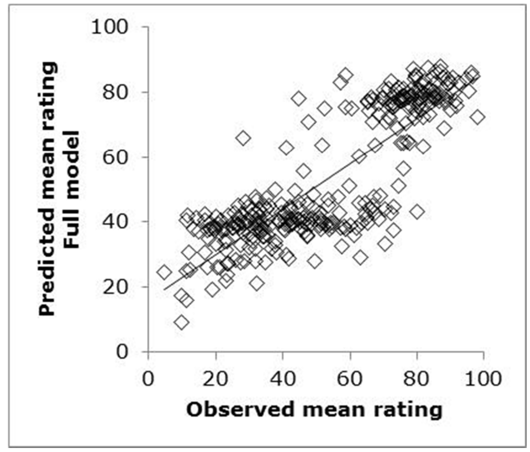
To illustrate the importance of pedestrian location, we tested a reduced model with three predictor variables, one categorical variable that combined two categories of pedestrian location - In street and Right Edge - and two quantitative variables, MinX and TTI. The simplified model explains almost 54% of the variability in the drivers' ratings. As shown in Figure 4b, the reduced model produces two layers or groups of predicted values.

The consistency of model and the average rate by all participants is shown in the two graphs of Figure 4. The graphs also show the best-fit least-squares regression equations for the rating data. The agreement between the predicted and observed average ratings by all the participating raters is quite good, $r^2 = 0.70$, $F(1, 302) = 696$, $p < 0.0001$ for the 10 variable model and $r^2 = 0.54$, $F(1, 302) = 347$, $p < 0.0001$ for the three variable model.

DISCUSSION

A key finding is the consistency of subjective ratings of the acceptance of alerts between groups with different experience with the system. Raters without experience in the field produce reliable and reproducible data that align with the experience of drivers in the field. This lends credence to the method, its reliability, and its application to events recorded by FOTs.

a



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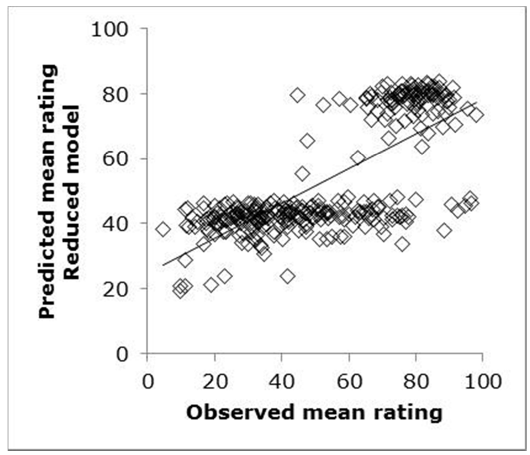

Figure 4. Cross-plots of the average rates of all participants and the modeled rates of (a) the full 10 variable model and (b) reduced three variable model.

A major challenge to FOT studies is that most of the observed events are unique in various ways. The everyday context makes it difficult to experimentally control and accurately repeat trials (Walker, Stanton & Young, 2008). Using recordings of these events in a laboratory environment provides experimental control of the stimuli while retaining much of the original ecological validity. The subjective rating method presented here leverages the scarce and expensive FOT data and help bridges the field and the laboratory. By eliciting responses from a large number of observers, we leverage the high cost of the FOT and generate sample sizes that are amenable to statistical tests of significance.

Although the method was developed to address the analysis of field data, it is applicable to simulator studies as well. Smith & Källhammer (2010) used it in a simulator study to assess the risk posed by intersection encroachments and how that level varies across situations. The method has also been used by Källhammer, Smith, Karlsson, and Hollnagel (2007) to elicit drivers' assessments of a variety of naturalistic traffic situations.

By enhancing our understanding of when and why drivers accept system alerts, we are better able to develop warning strategies that will likely lead to higher levels of driver trust and system acceptance.

CONCLUSIONS

In this paper we have described an empirical approach quantifying the relative level with which drivers are likely to accept pedestrian alerts by a night vision system. Analyses of the ratings data from participants found consensus across volunteers with different levels of system experience about how they rate the acceptability of system alerts to pedestrian encounters. The method will therefore enable us to leverage expensive FOT data. The work demonstrates the utility of subjective driver acceptance criteria as a tool to inform the development of the system's alerting criteria.

System performance optimized based on driver acceptance rather than objective performance criteria should better match driver expectations and thereby promote system acceptance. System use and safety benefits from the systems should increase with higher user acceptance. The derived metric of acceptance can be used to improve alerting criteria and help uncover factors that influence when alerts should be issued.

A nominal characterization of pedestrian location and two quantitative measures of pedestrian location with respect to the approaching vehicle explain almost 54% of the variance in driver ratings. About 70% of the variance in driver ratings can be explained by extending the model with additional factors that refine the description of a pedestrian within or moving toward the driver's field of safe travel (Gibson & Crooks, 1938). Designers of pedestrian crash warning systems need to be aware of the contextual sensitivity of driver expectations and assessments.

Limitations

Participants are known to develop expectations for staged events or alerts not only during the course of a simulator study but also when they are exposed to those events in the field (Vogel, Kircher, Alm, & Nilsson, 2003). It is unclear how that may affect the ratings elicited in our experiments.

All of the video clips were collected in Sweden and all participants were Swedish. Additional studies using material collected in other countries and with participants with no experience of Swedish traffic are needed to verify that the method is applicable to the global population of drivers.

Driver state measures such as driver distraction and fatigue are difficult to assess using this method. Further research may test whether the method can be extended to other traffic situations and other types of active safety systems.

REFERENCES

Gibson, J. J. & Crooks, L. E., "A theoretical field-analysis of automobile driving", The American Journal of Psychology, 51, 453-471, 1938.

Jackson, L., Chapman, P., & Crundall, D. (2009). What happens next? Predicting other road users' behaviour as a function of driving experience and processing time. Ergonomics, 52, 154 – 164.

Källhammer, J.-E. and Smith, K. (2012). Assessing Contextual Factors that Influence Acceptance of Pedestrian Alerts by a Night Vision System. Human Factors, 54, 654-662.

Källhammer, J. E., Smith, K., Karlsson, J., & Hollnagel, E. (2007). Shouldn't the vehicle react as the driver expects? Proceedings of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design. Stevenson, WA, 9-15.

Sheridan T. B. (2008). Risk, Human Error, and System Resilience: Fundamental Ideas. Human Factors, 50, 418–426.

Siegel, S., & Castellan, N. J., Jr. (1988). Nonparametric statistics for the behavioral sciences, 2nd Ed. New York: McGraw-Hill.

Smith, K. and Källhammer, J.-E. (2010). Driver acceptance of false alarms to simulated encroachment. Human Factors, 52, 446-476.

van der Laan, J.D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research - Part C: Emerging Technologies, 5, 1-10.

Vetenskapsrådet. (2002). Forskningsetiska principer inom humanistisk-samhällsvetenskaplig forskning. [Ethical principles for research using human participants.] Stockholm: Vetenskapsrådet.

Vogel, K., Kircher, A., Alm, H., & Nilsson, L. (2003). Traffic sense—which factors influence the skill to predict the development of traffic scenes? Accident Analysis and Prevention, 35, 749–762.

Walker, G.H., Stanton, N.A., & Young, M.S. (2008). Feedback and driver situation awareness (SA): A comparison of SA measures and contexts. Transportation Research - Part F, 11, 282–299.

Wiese, E. E. & Lee, J. D. (2004). Auditory alerts for in-vehicle information systems: The effects of temporal conflict and sound parameters on driver attitudes and performance. Ergonomics, 47, 965 - 986.

Williams, D. J. & Noyes, J. M. (2007). How does our perception of risk influence decision-making? Implications for the design of risk information. Theoretical Issues in Ergonomics Science, 8, 1-35.

FIGHTING DRIVER DISTRACTION - WORLDWIDE APPROACHES

Christian Heinrich
Daimler AG
Germany
Paper Number 13-0290

ABSTRACT

Research on telematics applications started in the eighties. The experts realized already at that time the need for appropriate means to reduce driver distraction. The European project Prometheus was the starting point for standardization activities both on national and international level.

On this basis, guidelines have been developed in Europe, Japan and the US. A team of experts tasked by the European Commission developed the European Statement of Principles (ESoP) which was published in the year 2000 and revised in 2006. In Japan, the Japanese Automotive Manufacturers Association (JAMA) published their guideline in 1990 with revisions in 2000 and 2004. In US the Alliance of Automotive Manufacturers (AAM) developed a guideline which was published in 2003 and revised in 2006. Currently, the National Highway Traffic Safety Agency (NHTSA) in the US is also working on a guideline. The final document is not yet publically available.

All guidelines have similar goals and basic concepts to achieve the limitation of driver workload and to avoid risky behavior. The following are the most prominent: Mounting of displays and controls should not interfere with the primary driving task. Necessary information should be easily perceivable with short glances. Dialogs should have a clear structure that can be easily understood and that does not require timecritical input. Complex operation or information should be disabled while driving.

There are some differences between the regional guidelines. The main difference is the determination of the distraction potential. While the ESoP contains only a verbal description (*visual information not related to driving that is likely to distract the driver significantly)*, the AAM guideline offers different objective methods including measurement of gaze behavior and driving performance. The JAMA guideline requires measurement of glance duration.

All these guidelines are voluntary, but only a part of the industry is committed to the guidelines. The driver workload induced by a telematics system depends on many factors. Different stakeholders are responsible for these factors like car manufacturers, device manufacturers, application developer, radio stations and service provider. The guidelines deal differently with this topic. The ESoP addresses all relevant stakeholders but only the car manufacturers which are represented by ACEA are committed to follow these guidelines. The AAM guideline addresses both OEM and nomadic devices but similar to Europe, only AAM members are committed. The JAMA guideline is binding only for JAMA members.

As mentioned above the guidelines are regularly revised by the respective organizations. Up to now, these guidelines have now been applied for a decade. The number of accidents caused by distraction due to the use of vehicle integrated devices is still small despite the increased use of these systems. This shows the effectiveness of the guidelines. Further improvement is only possible on the basis of new scientific data. Naturalistic driving data are a promising approach.

INTRODUCTION

Developing standards for automotive HMI has a history of decades [3].

It started with PROMETHEUS in 1985. This European project was initiated with the purpose to develop the European traffic scenario of the future with improved safety, environment and efficiency. One of the working groups in PROMETHEUS was created to tackle the Human Factors and HMI questions.

Well into the program, the need for standardisation was realised. Within CEN (Comité Européen de Normalisation) the technical committee CEN TC278 was formed in 1991 for this purpose. One of its working groups, WG10, which was entrusted with the task of using new technologies to solve the problems of human machine interaction.

Discussions of lifting the CEN work to an international, ISO, level started early 1993, since it became clear that it is inefficient to have regional standards in the automotive business. ISO TC 22 SC13 WG8 was formed for this purpose and held its first official meeting in Paris in November of 1994.

Many of the standards developed by this group are referenced in the guidelines that will be described in the next sections:

- Dialog management [4]
- Auditory information [5]
- Measurement of visual behaviuour[6]
- Visual presentation of information [7]
- Priority [9]

A standard for driver response task is currently under development.

THE GUIDELINES

These standards have been augmented by voluntary guidelines. They have been developed by different organization and also different groups are committed to comply with the guidelines (Table 1).

Table 1
Development and compliance with the guidelines

Document	Developed by	Signed by
JAMA Guideline	Japan Automobile Manufacturers Association (JAMA)	JAMA
European Statement of Principles (ESoP)	Expert Group tasked by European Commission	European Automobile Manufacturers' Association (ACEA)
AAM Guideline	Alliance of Automotive Manufacturers (AAM)	AAM

There is also a difference in itemization. While the JAMA guideline has only 15 pages including an appendix, the ESoP has 42 and the AAM Guideline 90.

All these guidelines are voluntary. The automotive industry, as shown in table 1, has signed commitments by their respective organisations to comply with these guidelines. But the driver workload induced by a telematics system depends also on factors influenced by other stakeholders. According to ESoP also the following stakeholders are addressed if their products are intended to be used by the driver while driving:

- After-market systems and service producers
- Prividers of nomadic devices,
- Manufacurers of parts enabling the use of nomadic devices (i.e. cradles, interfaces and connectors)
- Service providers including software providers or broadcasters of information, i.e traffic, travel and navigation information, radio programms with traffic information.

The scope of the AAM guideline addresses all suppliers and manufacturers of in vehicle information and communication systems . JAMA referes to OEMs, aftermarket devices are excluded.

Table 2 shows the dates of publication of the guidelines. There are no publications after 2006, despite some discussions about the topic. This is an indication that the guidelines are quite mature and no meaningfull improvement can be done without substantial new scientific data.

Table 2
Publication dates of the guidelines

Document	1. version	2.version	3.version
JAMA Guideline	1990	2000	2004
ESoP	2000	2006	
AAM Guideline	2003	2006	

Table 3 shows a comparison of the guidelines with reference to the respective principles. This list has been developed with colleagues from AAM and CCC (Car Connectivity Consortium) to support HMI developers who have less experience with the requirements of automotive HMI. This seemed to be important because of the upcoming integration of nomadic devices and applications into the vehicle.

It should be noted that some versions of the ESoP use a four digit method of numbering. The numbers used in table 3 are just preceded by 4.3.

Table 3
Comparism of the regional guidelines

Content	Reference		
	ESoP	**AAM**	**JAMA**
Correct installation	2.1	1.1	3.1 (4)
Drivers field of view	2.2	1.2	3.1 (2)
Obstruction of displays and controls	2.3 4.5	1.3	3.1 (1)
Driving posture	-	-	3.1 (3)
Close to the drivers line of sight	2.4	1.4	3.2 Annex 1
Glare and reflections	2.5	1.5	3.2
Display at night			4.1 (3)
Short glances	3.1	2.1A	4.2 (1) 4.2 (2) 5(4) Ann. 2.1
Total glance Time	3.1	2.1A	4.2 (1) 4.2 (2) 5 (3) Annex 3
Visual distraction / driving performance		2.1B	-
Symbols	3.2	2.2/1	4.1 (2)
Legibility			
- Contrast	3.2	2.2/2	4.1 (2)
- Size of characters	3.2	2.2/2	4.1 (2)
- Font dimensions	3.2	2.2/2	4.1 (2)
- Blinking	3.2	2.2/2	4.1 (2)
Audibility	3.2		4.1 (2)
Timeliness and accuracy of information	3.3	2.3	-
Prioritization 4)	3.4	-	-
Information which impairs the safety and smooth flow of road traffic	-	-	4.1(1)
No Uncontrollable Sound	3.5 4.6	2.4	4.3 (1) 4.3 (2)
At least one hand on the steering wheel	4.1	3.1	5 (1)
Chunkibility	4.2	3.3	5 (5)
Resumebility	4.3	3.3	5 (6)
Driver paced	4.4	3.4	5 (8)
Handsfree speech		3.2	-
Timely feedback	4.7	3.5	5 (9)
Visual Information can be switched off	4.8	3.6	5 (5)
No TV or scrolling Text	5.1	4.1	4.2 (2) Ann. 2.3 Ann. 2.4
No functional interference	5.2	-	-
Locked during driving	5.3	4.2	4.2 (2) Ann. 2.2 5 (7)
Malfunction notification	5.4	4.3	-

The following chapters show the detailed comparison with differences and common elements:

Correct installation

The system should be located and fitted in accordance with relevant regulations.

While the ESoP focuses on stable mounting and passive safety, the AAM is more general. JAMA regulates the installation of retrofit systems.

Drivers field of view

The system schould not obstruct the drivers view of the road scene.

The content of all guidelines is the same, AAM and ESoP also reference regional standards

Obstruction of displays and controls

The system should not obstruct vehicle controls and displays required for the driving task.

Same content, in ESoP with reference to ISO 4040.

Driving posture

The system shall not cause the driver to be substantially displaced from the driving posture (JAMA only).

Close to the drivers line of sight

This principle limits the downward angle. JAMA defines a value of 30° for the projection of the line between display and JIS eye point on the xz plane. AAM applies additionally a 3D method that allows greater downward angles if the display is mounted on the passenger side. ESoP does not give a defined value for the downward angle.

Glare and Reflections

Visual displays should be designed and installed to reduce glare and reflections.

Table 4
Different aspects of glare and reflections are handled

Topic	ESoP	AAM	JAMA
Display too bright	X	X	X
Reflections on the wind screen	X		X
Reflections on the display (Reduction of contrast)	X	X	
Reference to ISO 15008	X	X	

Display at night

Within JAMA for the night condition not only excessive brightness is considered, but also properties like contrast and colors.

Short glances

The driver should be able to acquire the relevant information with glances that are short enough not to adversely affect driving.

The ESoP declares this an important item which has to be considered while developing the HMI. JAMA additionally mentions limitations for content regarding maps. AAM limits glance time to 2 sec with precise measurement methods.

Total glance time

AAM offers two methods to determine total glance time:

- Direct measurement of glance time according to ISO 15007 [6]. The device under test is operated while driving on a road, a test track or in a simulator. Total glance time should not exceed 20 seconds.
- Occlusion testing according to ISO 16673 [8].This method uses a special set of google, where the vision can be blocked by a shutter repeatedly for a defined time. Total Shutter Open Time (TSOT) should not exceed 15 seconds.

JAMA defines 8 seconds for total glance time and 7.5 seconds for TSOT.
ESoP has general design recommendations to reduce total glance time.

Visual distraction / driving performance

AAM also offers a method to determine the influence of visual distraction by measuring the effect on driving quality. The experiment can be performed on the road, on a test track or in a driving simulator. While driving on a highway in a car following scenario the test subject operates the application under test. Lane exceedences and variation of headway are recorded as measures for driving quality. The same procedure is done for manual radio tuning as a reference task. Driving performance for the application must not be significantly worse than the reference task to be allowed while driving.

Symbols

All guidelines request the use of international accepted symbols. ESoP and AAM explicitly refer to ISO 2575 [10].

Legibility

The guidelines themselves have only a very general statement. ESoP and AAM refer to ISO 15008 [7] which has very detailed requirements especially regarding contrast and font size.

Audibility

Regarding audibility ESoP and JAMA refer to existing standards, ESoP with explicit reference to ISO 15006 [5]. .

Timeliness and accuracy of information

Information relevant to the driving task should be accurate and provided in a timely manner.

Mentioned in AAM and ESoP, to be verified by inspection. This principle is mainly relevant for navigation.

Prioritization

Information with higher safety relevance should be given higher priority.

This principle is only within ESoP with a reference to ISO 16951 [9].

Information which impairs the safety and smooth flow of road traffic

A system shall not present information that impairs the safety and the smooth flow of traffic.

This principle exists only in JAMA.

No Uncontrollable Sound

The system should not produce uncontrollable sound liable to mask warnings or to cause distraction.

Same content in all guidelines, in ESop with reference to ISO 15006 [5]

At least one hand on the steering wheel

Same basic content in all guidelines. AAM has additional statements :

- operations where both hands are involved, but both hands are on the steering wheel are allowed
- operations with the need to reach through the openings of the steering wheel are forebidden.

Chunkibility

The system should not require long and uninterruptible manual-visual interactions.

Same content in all guidelines.

Resumebility

The driver should be able resume an interrupted sequence of steps at the point of interruption or at another logical point.

Same content in all guidelines.

Driver paced

The driver should be able to control the pace of interaction with the system. The system should not require time critical responses when providing input to the system.

Same content in all guidelines.

Handsfree speech

This principle within ESoP requires handsfree provisions for using the telephone.

Timely feedback

The system's response following driver input should be timely and clearly perceptible.

Same content in all guidelines. AAM additionally sets a time limit of 2 seconds for the response with reference to ISO 15005 [4].

Visual Information can be switched off

Systems providing non-safety-related dynamic visual information should be capable of a means by which that information is not provided to the driver.

Same basic content in all guidelines.

No TV or scrolling Text

Visual Information not related to driving that is likely to distract the driver significantly (e.g. TV, video, continuously moving images and automatically scrolling text) should be disabled while the vehicle is in motion.

Same basic content in all guidelines. In JAMA also a driver induced scrolling is forbidden.

No functional interference

This principle of ESoP requires that the behavior of the system should not adversely interfere with display or controls required for the primary driving task and for road safety.

Locked during driving

System functions not intended to be used by the driver should be made inaccessible for the purpose of driver interaction while the vehicle is in motion.

Same content in all guidelines.

Malfunction notification

Information about current status, and any detected malfunction, within the system that is likely to have an adverse impact on safety should be presented to the driver.

Same content in ESoP and AAM

NHTSA GUIDELINE

In 2010 the NHTSA (National Highway Traffic Safety Administration) presented a project to fight driver distraction [12]. One objective was to develop guidelines for visual manual interactions. Since the final version is not released until now (01.03.2013) the following is based on the draft document that was the basis for public discussion [13]. The NHTSA guideline is in great detail based on the AAM Guideline, but also discusses very detailed seven methods to assess driver workload. It was indicated that only two of these methods will be used in the final document.

EGDS	Eye glance testing
OCC	Occlusion testing
STEP	Step counting
DS-BM	Driving test protocol with benchmark
DS-FC	Driving test protocol with fixed acceptance criteria
DFD-BM	Dynamic following and detection protocol with benchmark
DFD-FC	Dynamic following and detection protocol with fixed acceptance criteria

Table 5
Assessment methods for driver workload within NHTSA Guideline

Method	Description	Acceptance criterion
EGDS	Measuring Eye Glance time in a driving simulator	1) Glance time (85 percentil): < 2sec for any participants 2) Mean glance: < 2.0 sec for 21 of 24 participants 3) Total glance time:< 12.0 sec for 21 of 24 participants
OCC	Occlusion Testing	9 sec TSOT
STEP	Step counting	6 steps
DS-BM	Driving performance in a simulator (lane excceedences and standard deviations of headway)	Not significantly greater than he reference task (radio tuning)
DS-FC	Driving per-formance in a simulator (lane excceedences and standard deviations of headway)	Lane exceedance: 0.06 per second Standard deviation of headway: 0.35 seconds
DFD-BM	Eye glance criteria **PLUS** Visual detection task Reference task: Navigation input	1) Glance time (85 percentil): < 2sec for 85% of the participants 2) Mean glance: < 2.0 sec for 21 of 24 participants 3) Total glance time:< 12.0 sec for 21 of 24 participants **AND** 3 of the 4 following: 1) Standard deviation of lane position significantly less than reference task 2) Car following delay significantly less than for the reference task 3) Percentage of correctly detected events significantly higher than for the reference task 4) Response time is significantly less than for the reference task
DFD-FC	Eye glance criteria **PLUS** Visual detection task	1) Glance time (85 percentil): < 2sec for 85% of the participants 2) Mean glance: < 2.0 sec for 21 of 24 participants 3) Total glance time:< 12.0 sec for 21 of 24 participants **AND** 3 of the 4 following: 1) Standard deviation of lane position significantly less than 1.0 feet 2) Car following delay significantly less than 4.6 sec. 3) Percentage of correctly detected events significantly higher than 80 %. 4) Response time is significantly less than 1.0 sec

After publication of the draft NHTSA faced strong opposition from the automotive industry. The main concerns were:

- NHTSA tightens the criteria very much without a basis of scientific data.
- If, as a consequence of these restrictions, functions of integrated devices are further restricted, users will be inclined to use handheld devices that do not have a user interface developed for use while driving and thus increase the probability of an accident.

Beside these major points there are a number of other concerns. They are not justified from scientific evidence.

- The 30 character rule was taken from the JAMA guideline, ignoring the fact, that a Kanji character is much more difficult to read

than a Latin character because it contains the information of a whole word.
- Moving maps, related to the position of the vehicle, are forbidden. Instead of these quasi-static maps are recommended, that jump every few seconds. Obviously that is more distracting than a smooth scrolling map

Other additional requirements on test subjects, test setup and equipment make the measurement of glance behavior and driving performance more complicated than appropriate without a rationale:
- A vehicle cab is demanded by NHTSA for the test setup. OEMs need to test for all their car types, so a flexible mock up is more useful.
- Definitions of age groups is too detailed
- Requirement for mileage of test subjects (7000 m/a) is too high
- The request that automakers employees are not allowed as test persons is not appropriate. Regarding innovative telematics applications OEM employees are not more knowable about advanced applications than the typical user of innovative applications

Some functions are excluded without a precise definition. As an example social media are mentioned. These applications include features not relevant for driving like general messages and pictures on the 'wall', but others give access to addresses and telephone numbers which can be automatically forwarded to telephone or navigation system and will reduce driver distraction.

CONCLUSION AND FUTURE DEVELOPMENT

History has shown that despite of the concerns in the past there is no increase of accidents due to the use of integrated devices. Current standards and guidelines stand on the solid ground of scientific evidence and are regularly reviewed. New input for these standards is especially expected from naturalistic driving data. For instance, it was surprising that hands free phoning showed an Odd Ratio of 0.5[13] . I.e. it had only half the accident rate of just driving. Data like these can give a deeper inside into realistic driver behavior than simulator experiments. Current guidelines do not consider the frequency of use of a specific application. While texting may occur during the whole travel time, destination input will probably be used only once every second trip.

In contrast to the use of integrated devices the danger of handheld devices is obvious. This holds especially for entering text, a functionality that is generally blocked with OEM installed devices. With nomadic devices there is technically no way to block functions while driving unless the user has installed a special software. This also requires monitoring by e.g. parents or employers. So the main factors to reduce texting while driving is education and enforcement. In addition to that industry can offer save and attractive alternatives for a reasonable price. One approach is the Mirrorlink project. The automotive industry together with the phone companies are spending a big effort in the Car Connectivity Consortium (CCC) to develop a concept where the application runs on a smartphone but uses the large display of the car. By this integration it is also possible to apply all the guidelines described above and block certain functions while driving. This seems to be the next big step to reduce driver distraction.

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REFERENCES

[1] AAM "Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems" accessed February 9, 2012 http://www.autoalliance.org/files/DriverFocus.pdf

[2] European Commision "European Statement of Principles on the Design of Human Machine Interaction", 2006, accessed February 9, 2012. http://eur-lex.europa.eu/ Lex UriServ/ site/en/oj/ 2007/l_032 /l_03220070206 en02000241.pdf

[3] Heinrich, C, 2012 „Automotive HMI - International Standards" in proceedings of the 4th International Conference on Applied Human Factors and Ergonomics, San Francisco, July 21 – 25

[4] ISO 15005:2002 Road vehicles -- Ergonomic aspects of transport information and control systems -- Dialogue management principles and compliance procedures http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=34085

[5] ISO 15006:2011 Road vehicles -- Ergonomic aspects of transport information and control systems -- Specifications for in-vehicle auditory presentation

http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=55322

[6] ISO 15007-1:2002
Road vehicles -- Measurement of driver visual behaviour with respect to transport information and control systems -- Part 1: Definitions and parameters
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=26194
ISO/TS 15007-2:2001
Road vehicles -- Measurement of driver visual behaviour with respect to transport information and control systems -- Part 2: Equipment and procedures
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=32149

[7] ISO 15008 – Road vehicles, Ergonomic aspects of transport information and control systems - Specifications and test procedures for in-vehicle visual presentation
http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm? csnumber=50805

[8] ISO 16673:2007 Road vehicles -- Ergonomic aspects of transport information and control systems -- Occlusion method to assess visual demand due to the use of in-vehicle systems
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=38035

[9] ISO/TS 16951:2004
Road vehicles -- Ergonomic aspects of transport information and control systems (TICS) -- Procedures for determining priority of on-board messages presented to drivers
http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=29024

[10] ISO 2575 Road vehicles -- Symbols for controls, indicators and tell-tales
http://www.iso.org/iso/home /store /catalogue_tc/catalogue_detail.htm? csnumber=54513

[11] Japanese Automotive Manufacturers Association , 2004 “JAMA Guideline”
http://www.umich.edu/~driving/documents/JAMA_guidelines_v30.pdf

[12] National Highway Traffic Safety Administration,
“Driver Distraction Program”, DOT HS 811 229, April 2012

[13] National Highway Traffic Safety Administration,
“Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices”
Docket No. NHTSA-2010-0053

DRIVER HEAD DISPLACEMENT DURING (AUTOMATIC) VEHICLE BRAKING TESTS WITH VARYING LEVELS OF DISTRACTION

Lex van Rooij, Jasper Pauwelussen, Olaf Op den Camp, Robby Janssen
TNO
The Netherlands
Paper Number 13-0403

ABSTRACT

Vehicle occupant behavior in emergency driving conditions has a large effect on traffic safety. Distraction is estimated to be the cause of 15-20% of all crashes. Additionally, the posture of the occupants prior to the possibly unavoidable crash is known to have a large effect on the injury reducing performance of the restraint system. In this study it is investigated whether braking settings as well as driver distraction influence the kinematic response of an occupant during braking events, in order to improve the design of crash avoidance or crash and injury mitigation systems.

A mid-size passenger vehicle was instrumented with an automatic brake actuator and a warning light, which could be operated by the test leader, seated on the passenger side. The motion of the driver's head in six degrees of freedom was recorded via an eye-tracking system, as well as relevant vehicle parameters. A single professional test driver was used, which was driving on a large test track, allowing velocities up to 120 km/h and full braking with 50 km/h velocity reduction in both straights and curves. A total of 61 braking events were generated in a varied order in the following four categories: 1) driver-induced while being attentive, 2) automatic while being attentive, 3) driver-induced after a warning was provided while being distracted and 4) automatic while being distracted. Driver distraction was achieved by asking the driver to type a text message while operating the vehicle.

From 61 braking tests with a single professional test driver, entrance speed, braking deceleration and jerk time histories as well as brake pedal force were plotted in combination with head motion. Head forward displacement varied between 37 and 128 mm, while head forward pitch (relative to vehicle) was in between 4 and 23 degrees. In attentive scenarios, head rearward displacement in anticipation of an oncoming braking event was observed up to 110 mm. Automatic braking for a distracted driver induces on average 123 mm of head forward displacement, which is 67 mm larger than for an attentive driver that applies the brakes himself. Automatic braking for an attentive driver induced substantially higher head motion, which indicates that posture control is dependent on anticipation on the braking pulse.

This study is limited by the fact that tests were performed with one single, professional driver that was aware of the tests to be performed. Wider variation is expected with different drivers and no conclusions could be drawn on habituation. Furthermore, no accurate information is available on timing, such that no information regarding reaction time can be provided.

Sensitivity of driver head kinematic response during emergency braking for various parameters was shown in fairly realistic driving conditions. This information is relevant for the design of safety systems that interface with the occupants, such as a motorized belt pre-tensioner and autonomous emergency braking systems. Obviously this data can also be used for the validation of human models that are used to support the design and functioning of these systems.

INTRODUCTION

Vehicle occupant behavior in emergency driving conditions has a large effect on traffic safety. First of all, the state of the driver can affect the ability of the driver to properly control the vehicle. In 2008, the United States National Highway Traffic Safety Administration (NHTSA) published the results of a crash causation survey in which the cause of over 5,000 crashes was analyzed [NHTSA, 2008]. Driver distraction was a large cause of error, as 18% of the drivers involved in crashes were involved in at least one non-driving activity, the majority of them using cell-phones. In addition, fatigued drivers were twice as likely to make performance errors that ultimately resulted in a crash. A different study based on around 48,000 crashes in the US concluded that 16.5% of all fatal crashes were caused by driver drowsiness, even though officially reported numbers are 4 times lower [Tefft, 2011]. In the Netherlands, it is estimated that annually around 8 to 12% of all traffic fatalities are (partially) caused by drowsiness [SWOV, 2010].

Additionally, the posture of the occupants prior to the possibly unavoidable crash is known to have a large effect on the injury reducing performance of the restraint system. Ejima et al. [2009] performed a series of tests with volunteers seated on rigid seats, restrained by a three-point belt system and subjected to a 600 ms 0.8 G constant deceleration, representative of emergency braking. For a tensed volunteer, kinematic figures indicate that head forward displacement was in the order of 100 mm at 200 ms after impact, while T1 forward displacement was in the order of 25 mm and hip forward displacement around 10 mm. For a relaxed occupant restrained by a lap belt only, the head displacement was in the order of 600 mm at 600 ms after impact with T1 displacement around 400 mm. Bose et al. [2008] used a numerical human model [de Lange et al., 2005 & Cappon et al., 1999] to study the effect of pre-impact posture, as well as levels of muscle bracing in the lower extremities and body mass and stature, on the injury risk in the event a crash was unavoidable. Pre-impact posture was shown to be the parameter affecting the injury risk the most. In an optimization routine it was found that with a seat belt system with adaptive force limiting settings and variable pretensioner firing time, a reduction of injury risk of up to 35% could be achieved.

In this study, the objective is to investigate whether braking settings as well as driver distraction influence the kinematic response of an occupant during braking events, in order to improve the design of crash avoidance or crash and injury mitigation systems.

METHODS

A test series was developed in which an instrumented research vehicle was used. The research vehicle was a mid-size passenger vehicle with the following additional instrumentation:

- An automatic brake actuator was implemented to apply controlled brake pressure on the additional brake pedal at the passenger side. This actuator was controlled by a laptop in the hands of the test leader, which was seated in the vehicle.
- An LED was added as a warning device to the driver. This LED was controlled from the laptop as well.
- A SmartEye Pro [Smart Eye, 2013] eye tracking system was used to track the head motion in six degrees of freedom.
- A video camera monitoring the driver.
- Force sensors on both the driver brake pedal as well as on the actuated brake pedal.
- Vehicle accelerometers recording vehicle acceleration in six degrees of freedom.
- A Trimble RTK-GPS system [Trimble, 2013] tracking vehicle position.

An oval test track [ATP, 2013] with 4 km long straight and 2 km long curves was used to allow highway driving conditions and induce surprise braking events. Test track requirements were that a professional test driver had to drive the vehicle. Therefore, this study is limited to a single professional test driver.

The test driver was asked to drive at a constant velocity of 120 km/h in both straights and curves after which four types of braking events were induced:

1. Attentive – Driver: The driver was attentive and was asked to induce emergency braking himself.
2. Attentive – Automatic: The driver was attentive and the automatic brake actuator was operated while the driver was informed.
3. Distracted – Warning – Driver: The driver was distracted and was instructed to induce emergency braking after the warning light was turned on.
4. Distracted – Automatic: The driver was distracted and the automatic brake actuator was operated at a for the driver unknown moment.

In driver-induced braking events, the driver was asked to make an emergency braking maneuver with a speed reduction of approximately 50 km/h. The automatic brake actuator could apply varying levels of braking force and various rates of force build-up. Driver distraction was achieved by asking the driver to type a text message on a button-operated cell phone while operating the vehicle.

In total, 61 tests were performed with test parameters as shown in Table 1. Test variations were offered in a fairly random order.

Table 1: Overview of tests and test parameters.

Parameter	Option	Nr. of tests
All tests	-	61 *(100%)*
Driver state	Attentive	24 *(39%)*
	Distracted	37 *(61%)*
Braking type	Driver	6 *(10%)*
	Warning – Driver	13 *(21%)*
	Automatic	42 *(69%)*
Track	Straight	40 *(65%)*
	Curve	20 *(33%)*
	Unknown	1 *(2%)*
Braking force setting (automatic braking only)	360 N	21 *(34%)*
	500 N	21 *(34%)*
Braking rate setting (automatic braking only)	300 N/s	21 *(34%)*
	600 N/s	21 *(34%)*

RESULTS

Occupant kinematics

First of all, the kinematics of the driver are shown from two tests from two braking scenarios.

Figure 1. Occupant kinematics in Attentive-Driver braking scenario, before braking (top) and at time of highest head excursion (bottom).

Figure 2. Occupant kinematics in Distracted-Automatic braking scenario, before braking (top) and at time of highest head excursion (bottom).

In Figure 1, for an attentive driver that induces emergency braking himself, the initial posture just before braking is shown, as well as the posture during braking, at the time of maximum head forward excursion. It can be observed that the head moves forward and that the driver maintains his eyes on the road during the event.

In Figure 2, for a distracted driver with automatically induced braking, the initial posture just before braking is shown, as well as the posture during braking, at the time of maximum head forward excursion. It can be observed that the driver was distracted by typing a text message just before the braking occurred. During the braking, the head moves forward to a large extent and the driver maintains his eyes on the road. Also, the driver is only holding the steering wheel with one hand, since the other hand holds the cell phone.

The driver posture in the other two braking scenarios was comparable to that in the scenarios discussed above, however at different magnitudes. The shown test results are examples of the scenarios. In other tests within the same scenario, the kinematics were slightly different, but in terms of typical characteristics it was the same.

In appendix 1, for the four different braking scenarios time-history plots are shown of four tests, as examples of the four scenarios. In a time-frame of 16 seconds the velocity of the vehicle, the head forward displacement and head pitch angle as well as the braking force is indicated. It is shown that prior to braking head forward displacement and head pitch are fairly constant, except for the distracted scenarios where irregular periods of around 2-3 seconds are shown in which the test driver changes focus between downward looking at the cell phone and looking at the road. It is shown that during braking, typically head forward displacement occurs as well as head pitch. Also, when the braking force is removed, the head typically goes into a rebound, i.e. backward displacement of the head relative to the initial position.

Statistical analysis on head motion

A statistical analysis was performed on head position parameters that were recorded from the Smart Eye system. In Appendix 2 a correlation matrix is shown for all parameters. In Table 2, the results from a one-way ANOVA and a Tukey post-hoc test are shown for peak head forward displacement.

Head forward displacement varied between 37 and 128 mm, while head forward pitch (relative to vehicle) was in between 4 and 23 degrees. In attentive scenarios, head rearward displacement in anticipation of an oncoming braking event was observed up to 110 mm.

It is shown that in all 5 Attentive-Driver tests the mean peak head forward displacement was 57 mm with a standard deviation of 18 mm. In 17 Attentive-Automatic tests, the mean peak head forward displacement was equal to 95 mm with a standard deviation of 21 mm. The Tukey post-hoc test showed that the mean difference of -38 mm was statistically significant (p=0.00). This indicates that automatic braking for an attentive driver induces on average 38 mm more peak head forward displacement than when an attentive driver brakes himself (p=0.00).

It is shown that in all 18 Distracted-Automatic tests the mean peak head forward displacement was 123 mm with a standard deviation of 14 mm. In 12 Distracted-Warning-Driver tests, the mean peak head forward displacement was equal to 54 mm with a standard deviation of 24 mm. The Tukey post-hoc test showed that the mean difference of -70 mm was statistically significant (p=0.00). This indicates that automatic braking for a distracted driver induces on average 70 mm more peak head forward displacement than when a distracted driver brakes himself after a warning was provided (p=0.00).

Additionally, it is shown that no statistical significant difference exists in peak head forward motion between an attentive driver that induces the brakes himself and a distracted driver that induces the brakes himself after a warning (p=0.99).

In Table 3, the results from a one-way ANOVA and a Tukey post-hoc test are shown for peak head forward displacement in anticipation and in rebound. Head forward displacement in anticipation is defined as the difference between the peak head forward displacement in the second prior to the braking and the average head forward displacement in the ten seconds prior to braking. Head forward displacement in rebound is defined as the difference between the peak head forward displacement in the two seconds after braking and the average head forward displacement in the ten seconds prior to braking.

Table 2: One-way ANOVA and Tukey post-hoc test results for peak head forward displacement (95% confidence interval).

Braking event	Braking event	Mean difference	p
Peak head forward displacement [mm]			
Attentive – Driver (μ=57, σ=18, n=5)	Attentive – Automatic (μ=95, σ=21, n=17)	-38	0.00
	Distracted – Warning – Driver (μ=54, σ=24, n=12)	3	0.99
	Distracted - Automatic (μ=123, σ=14, n=18)	-67	0.00
Attentive – Automatic (μ=95, σ=21, n=17)	Distracted – Warning – Driver (μ=54, σ=24, n=12)	40	0.00
	Distracted - Automatic (μ=123, σ=14, n=18)	-30	0.00
Distracted – Warning – Driver (μ=54, σ=24, n=12)	Distracted - Automatic (μ=123, σ=14, n=18)	-70	0.00

A statistically significant difference peak head forward displacement in anticipation is observed between Attentive-Automatic and both Distracted-Warning-Driver and Distracted-Automatic. The difference is 5 mm, which indicates that an attentive driver in automatic braking puts his head 5 mm more backward than distracted drivers do. For an attentive driver that applies the brakes himself, the difference is 3 mm, however not statistically significant.

The analysis on rebound indicates that an attentive driver that applies the brakes himself shows 52 mm less head backward rebound than an attentive driver undergoing automatic braking, as well as a distracted driver undergoing automatic braking. Both comparisons are statistically significant (p=0.00). The same comparison holds for a distracted driver that applies the brakes after a warning, however a lower difference of 37 mm is shown for both cases (p=0.01).

Statistical analysis on braking parameters

Furthermore, a statistical analysis is performed on braking parameters. Braking force in Distracted-Warning-Driver scenarios (μ = 1020 N, σ = 99, n = 13) is significantly lower than in all other events: 265 N, 284 N and 265 N lower respectively (all p=0.00). Braking mean acceleration in Attentive-Driver scenarios (μ = 7.16 m/s^2, σ = 0.51, n = 6) is larger than in all other events: 1.18 m/s^2, 1.11 m/s^2, 1.43 m/s^2 larger (all p=0.00).

Table 3: One-way ANOVA and Tukey post-hoc test results for peak head forward displacement in anticipation and in rebound (95% confidence interval).

Braking event	Braking event	Mean difference	p
Peak head forward displacement - anticipation [mm]			
Attentive – Driver (μ=-3, σ=7, n=4)	Attentive – Automatic (μ=-5, σ=4, n=16)	-2	0.79
	Distracted – Warning – Driver (μ=0, σ=3, n=12)	3	0.52
	Distracted - Automatic (μ=0, σ=3, n=17)	3	0.42
Attentive – Automatic (μ=-5, σ=4, n=16)	Distracted – Warning – Driver (μ=0, σ=3, n=12)	5	0.00
	Distracted - Automatic (μ=0, σ=3, n=17)	5	0.00
Distracted – Warning – Driver (μ=0, σ=3, n=12)	Distracted - Automatic (μ=0, σ=3, n=17)	0	1.00
Peak head forward displacement - rebound [mm]			
Attentive – Driver (μ=-10, σ=10, n=5)	Attentive – Automatic (μ=-62, σ=31, n=15)	52	0.00
	Distracted – Warning – Driver (μ=-25, σ=17, n=6)	15	0.72
	Distracted - Automatic (μ=-61, σ=21, n=16)	52	0.00
Attentive – Automatic (μ=-62, σ=31, n=15)	Distracted – Warning – Driver (μ=-25, σ=17, n=6)	-37	0.01
	Distracted - Automatic (μ=-61, σ=21, n=16)	0	1.00
Distracted – Warning – Driver (μ=-25, σ=17, n=6)	Distracted - Automatic (μ=-61, σ=21, n=16)	37	0.01

Brake force build-up rate in Attentive-Driver scenarios (μ = 3898 N/s, σ = 996, n = 6) is larger than in both Attentive-Automatic and Distracted-Automatic braking events: 1455 N/s and 1474 N/s larger respectively (all p=0.00). Similarly, brake force build-up rate in Distracted-Warning-Driver (μ = 3530 N/s, σ = 512, n =

13) is larger than in both automatic braking events: 1087 N/s and 1106 N/s larger respectively (all p=0.00).

Furthermore, the initial rise of the vehicle deceleration as a result of braking was computed, and here called braking jerk. The braking jerk in Attentive-Driver scenarios ($\mu = 21.8$ m/s^3, $\sigma = 5.6$, $n = 6$) is larger than in both Attentive-Automatic and Distracted-Automatic braking events: 10.5 m/s^3 and 11.0 m/s^3 larger respectively (all p=0.00). Similarly, braking jerk in Distracted-Warning-Driver scenarios ($\mu = 20.9$ m/s^3, $\sigma = 2.7$, $n = 13$) is larger than in both Attentive-Automatic and Distracted-Automatic braking events: 9.6 m/s^3 and 10.0 m/s^3 larger respectively (all p=0.00).

DISCUSSION

This test series was performed in conditions that are different from everyday traffic. First of all, a professional test driver was the driver of the car, who most likely has better vehicle handling skills than an average consumer driver. Test tracking testing, compared to real-world traffic, has some implications as well. There was no other traffic, which could have reduced attentiveness. On the other hand, test track driving involves high responsibilities, which probably elevated the awareness level of the driver. Even though the driver was distracted from his driving task through cell phone message typing, he was aware that somewhere along the 4 km straight an emergency braking event would occur. Therefore, realistic distraction is probably more serious, i.e. causes even slower or later reactions.

In order to make a good comparison between self-induced and automatic braking events, a design emergency braking pulse was used in the brake actuator. In spite of this, the self-induced braking effort was typically higher than the automatic braking effort. Brake force build-up rate was over 30% larger for self-induced scenarios than for automatic scenarios. Closely related, the estimated braking jerk was nearly 50% larger in self-induced scenarios. In Attentive-Driver scenarios, the mean acceleration was above 7 m/s^2 while in other scenarios it was below 6 m/s^2. An additional factor influencing the braking performance were wet road conditions and a vehicle with large additional mass due to equipment. As such, if the driver would have induced lower levels of braking, lower levels of head motion would have been observed as well.

Time synchronization of all measured data was unfortunately not possible. Therefore, no statements could be made on reaction time. The figures in Appendix 1 are derived by overlaying the initial rise of head motion with the build-up of braking force.

The eye tracking system used for computing head motion is sensitive to rapid variations in light conditions, as is shown in the noisy signal in for example Figure 3 just after 470 s. Tests in which this noise occurred during the braking event were excluded from the dataset.

This study has shown that if a driver is attentive and aware of automatic braking about to occur, his head forward motion is 38 mm larger than when he applied the brakes himself. This indicates that a driver is better able to control his body posture if he fully controls the braking action himself.

It is also shown that providing a warning to a distracted driver does not hamper his ability to control his posture, compared to a fully attentive driver, since there was no statistical difference. Possibly, the reaction time of a distracted and warned driver is reduced, but this could not be quantified.

This study quantified a significant difference in anticipation, i.e. the driver moved his head rearward in anticipation of braking, however this was only 5 mm and as such does not have consequences for safety. The rebound of the head once the braking is removed is over 60 mm for automatic braking scenarios, while it is on average 10-25 mm for self-induced braking.

The largest difference in head forward displacement was found between attentive, self-induced braking and distracted, automatic braking. The distracted driver with automatic braking underwent on average 123 mm head forward displacement, compared to 57 mm. Head pitch was observed in this study, but no significant differences between braking scenarios was observed.

CONCLUSIONS

Based on 61 braking tests with a professional driver in four different braking scenarios, the following conclusions regarding head posture can be drawn:

- Automatic braking for a distracted driver induces on average 123 mm of head forward displacement, which is 67 mm larger than for an attentive driver that applies the brakes himself.
- Automatic braking for an attentive driver induced substantially higher head motion, which indicates that posture control is dependent on anticipation on the braking pulse.
- Head rebound after braking was substantial, but head motion as a result of anticipation was not. Head pitch was statistically insignificant.

Recommendations for further study include performing tests with multiple volunteers, extending vehicles motion to lane change emergency maneuvers and by using a vehicle environment that can easily be modeled in a simulation environment, to allow for the validation of human models.

REFERENCES

ATP (2013) ATP test track, website: http://www.atp-papenburg.de/images/Bilder/Testrecken/ATP_ORK_Details_gb.jpg, last accessed March 4th 2013

Bose, D, Crandall, JR, Untaroiu, CD, Maslen, E. (2008) Influence of pre-collision occupant properties on the injury response during frontal collision. IRCOBI Conference on the Biomechanics of Impact.

Cappon, H.J., Mordaka, J., van Rooij, L., Adamec, J., Praxl, N,; Muggenthaler H., (2007) A computational human model with stabilizing spine: a step towards active safety, SAE paper 2007-01-1171.

Ejima, S., Zama, Y., Ono, K., Kaneoka, K., Shiina, I., Asada H., (2009) Prediction of Pre-Impact Occupant Kinematic Behaviour based on the Muscle Activity During Frontal Collision, International Technical

Conference on the Enhanced Safety of Vehicles (ESV), Proc. 21st ESV.

Lange R. de, Rooij L. van, Mooi H., Wismans, J. (2005) Objective biofidelity rating of a numerical human model in frontal to lateral impact. Stapp Car Crash Conference, SAE 2005-22-0020, 2005.

NHTSA (2008) National Motor Vehicle Crash Causation Survey, Report to Congress, DOT HS 811 059, Washington D.C., USA

Smart Eye (2013) Smart Eye Pro, website: http://www.smarteye.se/productseye-trackers/smart-eye-pro-2-6-cameras, last accessed March 4th 2013

SWOV (2013) SWOV Factsheet: Vermoeidheid in het verkeer: oorzaken en gevolgen, http://www.swov.nl/rapport/Factsheets/NL/Factsheet_Vermoeidheid.pdf, last accessed Feb 20, 2013

Tefft, B.C. (2008) Prevalence of motor vehicle crashes involving drowsy drivers, United States, 1999–2008, Accident Analysis & Prevention, 2011 & National Motor Vehicle Crash Causation Survey, NHTSA: National Highway Transport Safety Administration, DOT HS 811 059, July 2008

Trimble (2013): Trimble RTK-GPS, website: http://www.trimble.com/, last accessed March 4th 2013

APPENDIX 1: Time-history plots

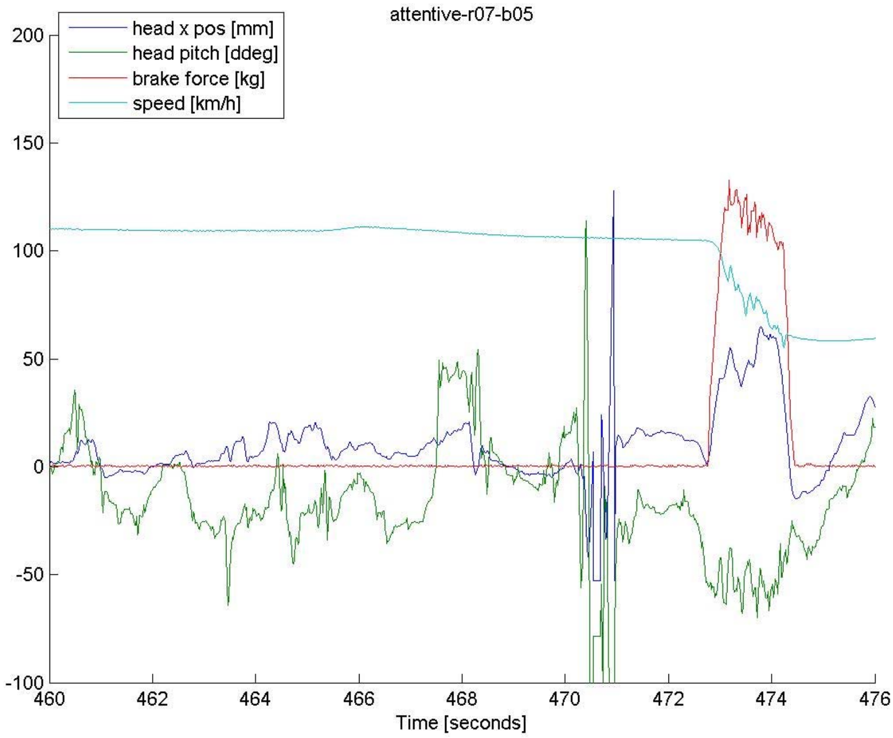

Figure 3. Head forward position, head pitch angle, brake force and vehicle speed in one example test for an Attentive-Driver braking scenario.

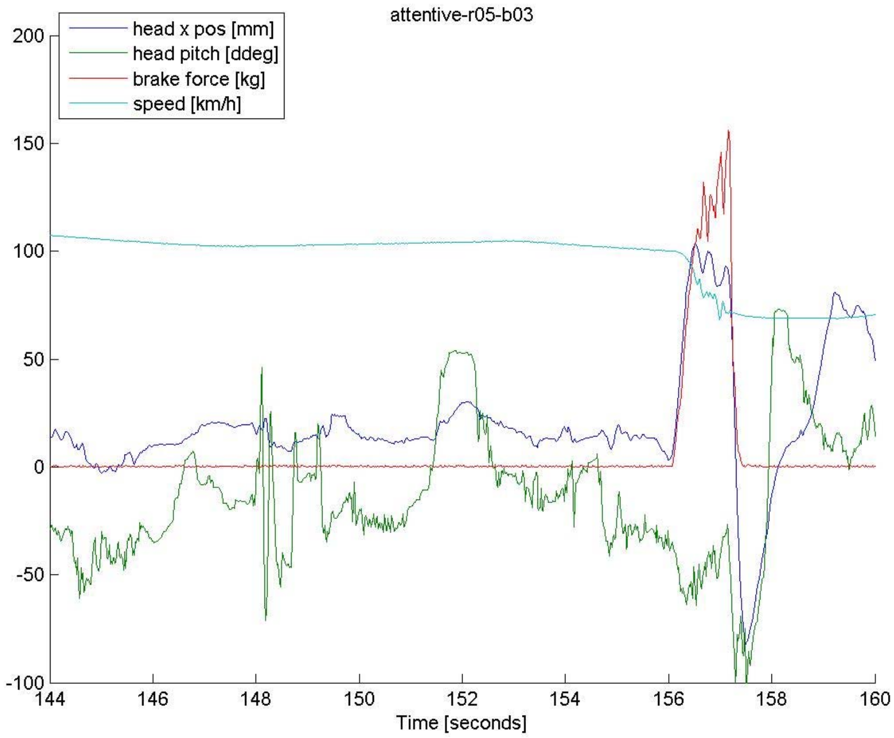

Figure 4. Head forward position, head pitch angle, brake force and vehicle speed in one example test for an Attentive-Automatic braking scenario.

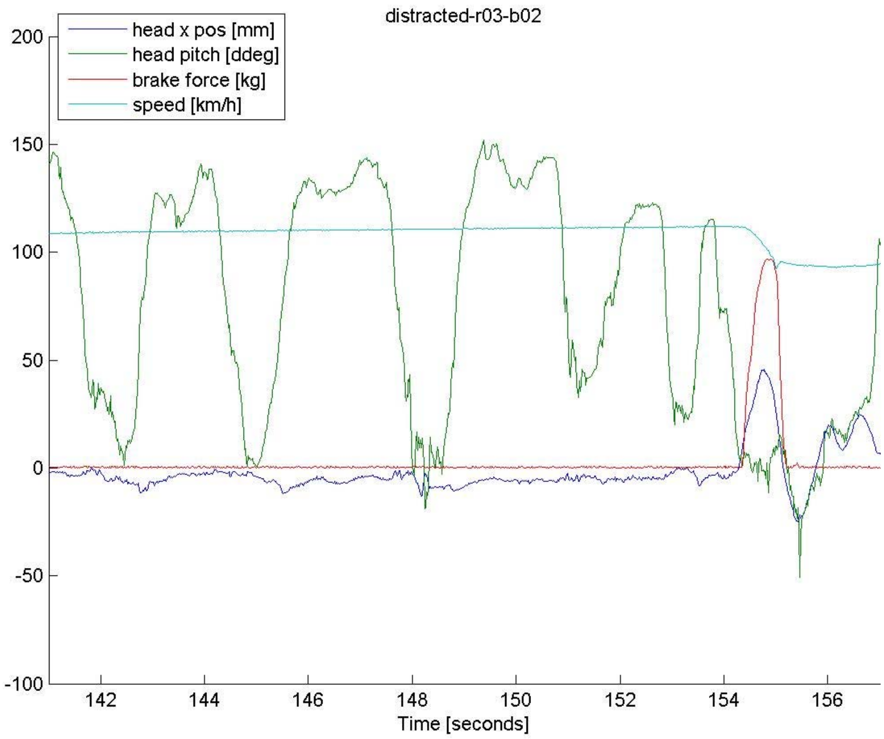

Figure 5. Head forward position, head pitch angle, brake force and vehicle speed in one example test for a Distracted-Warning-Driver braking scenario.

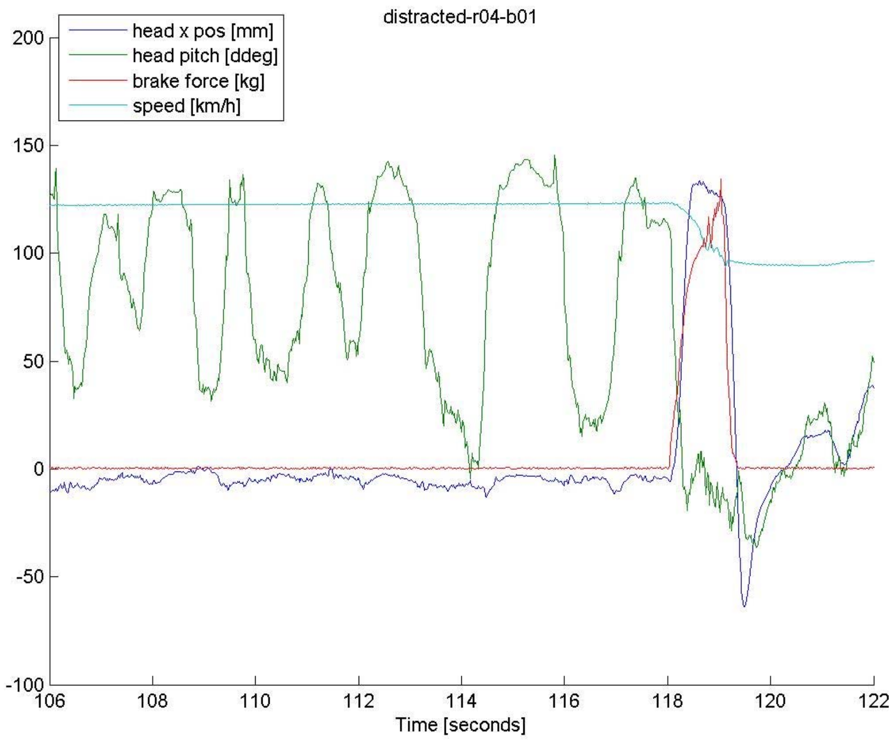

Figure 6. Head forward position, head pitch angle, brake force and vehicle speed in one example test for a Distracted-Automatic braking scenario.

APPENDIX 2: Correlation Matrix

		Peak head forward displacement [mm]	Peak head pitch [deg]	Estimated jerk [m/s^3]	Braking force [N]	Braking jerk [N/s]	Mean acceleration [m/s^2]	deltaV [km/h]	Entrance speed [km/h]	Braking force setting [N]	Braking rate setting [N/s]
Peak head forward displacement [mm]	Pearson Correlation	1	.095	-,644**	.256	-,635**	-.197	.253	,311*	,658**	,512**
	Sig. (2-tailed)		.586	.000	.067	.000	.163	.070	.025	.000	.000
	N	52	35	52	52	52	52	52	52	52	52
Peak head pitch [deg]	Pearson Correlation	.095	1	.113	-.233	.113	-.085	-,375*	.319	-.052	-.041
	Sig. (2-tailed)	.586		.518	.179	.518	.626	.026	.061	.766	.817
	N	35	35	35	35	35	35	35	35	35	35
Estimated jerk [m/s^3]	Pearson Correlation	-,644**	.113	1	-,345**	,926**	,587**	-.097	-.043	-,776**	-,475**
	Sig. (2-tailed)	.000	.518		.006	.000	.000	.455	.745	.000	.000
	N	52	35	61	61	61	61	61	61	61	61
Braking force [N]	Pearson Correlation	.256	-.233	-,345**	1	-.069	.162	,433**	.192	,611**	,581**
	Sig. (2-tailed)	.067	.179	.006		.599	.212	.000	.137	.000	.000
	N	52	35	61	61	61	61	61	61	61	61
Braking jerk [N/s]	Pearson Correlation	-,635**	.113	,926**	-.069	1	,479**	-.168	-.045	-,583**	-.225
	Sig. (2-tailed)	.000	.518	.000	.599		.000	.195	.730	.000	.081
	N	52	35	61	61	61	61	61	61	61	61
Mean acceleration [m/s^2]	Pearson Correlation	-.197	-.085	,587**	.162	,479**	1	,661**	.191	-,371**	-.244
	Sig. (2-tailed)	.163	.626	.000	.212	.000		.000	.140	.003	.058
	N	52	35	61	61	61	61	61	61	61	61
deltaV [km/h]	Pearson Correlation	.253	-,375*	-.097	,433**	-.168	,661**	1	.212	.073	.006
	Sig. (2-tailed)	.070	.026	.455	.000	.195	.000		.100	.577	.965
	N	52	35	61	61	61	61	61	61	61	61
Entrance speed [km/h]	Pearson Correlation	,311*	.319	-.043	.192	-.045	.191	.212	1	.200	.168
	Sig. (2-tailed)	.025	.061	.745	.137	.730	.140	.100		.122	.195
	N	52	35	61	61	61	61	61	61	61	61
Braking force setting [N]	Pearson Correlation	,658**	-.052	-,776**	,611**	-,583**	-,371**	.073	.200	1	,845**
	Sig. (2-tailed)	.000	.766	.000	.000	.000	.003	.577	.122		.000
	N	52	35	61	61	61	61	61	61	61	61
Braking rate setting [N/s]	Pearson Correlation	,512**	-.041	-,475**	,581**	-.225	-.244	.006	.168	,845**	1
	Sig. (2-tailed)	.000	.817	.000	.000	.081	.058	.965	.195	.000	
	N	52	35	61	61	61	61	61	61	61	61

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

PASSENGER/PEDESTRIAN ANALYSIS BY NEUROMORPHIC VISUAL INFORMATION PROCESSING

Woo Joon Han
Il Song Han
Korea Advanced Science and Technology
Republic of Korea
Paper Number 13-0407

ABSTRACT

The physiological studies since the Hubel and Wiesel's experimentation of cat's visual cortex have confirmed the consensus about the brain's intelligence of visual perception. A new way of enhancing the safety of vehicle is proposed by employing the neuromorphic VLSI or processing for mimicking the robust and natural intelligence of visual recognition, inspired by both the Hubel and Wiesel's experimentation of visual cortex and the neurophysiological model of Hodgkin-Huxley formalism. The feasibility of neuromorphic system is demonstrated successfully for the robust recognition of human objects for the safety either in the car or on the road, evaluating the neuromorphic VLSI implementation based on the controlled CMOS conductance for the bio-plausible performance.

The neuromorphic visual information processing is developed for both applications of the driver/occupant analysis in the car and the human object detection on the road. The neuromorphic vision research was motivated by the status analysis of the human posture and safety apparatus for the innovation of the emergency rescue service dealing the crash accidents, and extended its applications to the safety technology of assisting the vehicle drive by detecting nearby pedestrians or human objects. The overall performance is measured with the success rate over 90%, for both the pedestrian detection and the occupant monitoring, in day or night. The most of human object detections are based on the neuromorphic visual information processing using the still image from the video sensor, because of the limited sight condition.

The appropriate use of orientation feature extraction and neural networks ensures the reliability of proposed neuromorphic visual information processing to perform well under various dynamic conditions, such as in the changing ambient light, in night time, or in wet weather which are inevitable for vehicles on the road. The detection of pedestrian or cyclist performs consistently in wide ranges of environment, evaluated in various times and places of Europe and Asia.

The recognition of driver's eye sight is proved as an added function within the framework of proposed neuromorphic system, to match the varying driver's eye sight for controlling the eye-glassless 3D dashboard display. The same principle is applicable to detect any particular part or pose of human object, and the neuromorphic visual processing system can accommodate the enforced adaptation or learning as it mimics the natural brain.

The neuromorphic coupled with neural networks, suggests it as the new feasible and robust device with the convergence of biological neural system and information technology, or as the cost effective and reliable device of vehicle's safety enhancement by using the CMOS neuromorphic VLSI approach.

INTRODUCTION

There have been developed many works of computer vision for the vehicle safety applications using various tools and methodologies such as the camera-based complex computer vision algorithm or a combination of camera and radar to utilize the distance data in calculation to improve the accuracy and reliability. Although, the computer vision algorithms are effective in their condition of usage, they at most times lack the human vision's robustness for the vehicular applications in dynamic environments. Hence, the neuromorphic visual information is investigated to adopt the robust and flexible performance of the primary visual cortex, inspired by the neuron model of Hodgkin-Huxley formalism and the visual cortex experimentation by Hubel and Wiesel [1].

In this paper, the elements of neuromorphic implementation of visual cortex are introduced with the orientation tuned function of synaptic connections and the spiking neuron, based on the electronically programmable MOSFET conductance[2]. The proposed neuromorphic visual signal processing is investgated for enhancing the vehicle safety by the pedestrian detection or the passenger detection.

NEUROMORPIC VISUAL INFORMATION PROCESSING

The visual signal environment of occupancy detection or pedestrian detection passengers may vary greatly between sensing times and places since the vehicle is in motion. The widely changing environment of the illumination or the background demands the robust human object detection algorithm for the consistent and reliable performance. Much of computer vision algorithms are effective in their specific usage, however they lack the robustness of human vision and for most times will underperform in the varied conditions of illumination.

Primary Visual Cortex

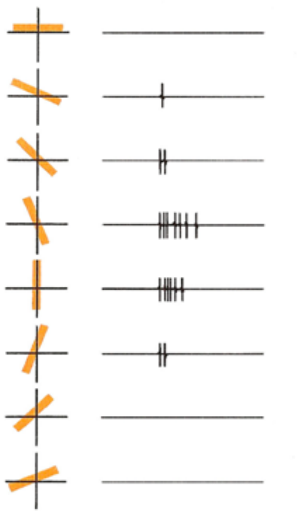

Figure1. Response of the cat's cortex when a rectangular slit of light of different orientations is shown [1].

Although there is not a definite model of visual cortex, Hubel and Wiesel's research on cat's striate cortex confirmed the idea on the functioning of the simple cell. It is from this discovery which motivated various theories of object recognition from characters to complex natural images [3]. The observed orientation based behavior evoked the reflection while the spike-based neuron signal is also an essential feature. These researches on neurophysiology introduced not only the neural networks software algorithm but also the principles of biologically plausible implementation. The neurophysiological model of Hodgkin-Huxley formalism is the most precise spike neuron model requiring complex computing, with the biological plausibility. Two principles of the simple cell and the Hodgkin-Huxley formalism are adopted in the neuromorphic vision together with the linear and controlled CMOS conductance, for the purpose of realizing the robustness of human level and the cost effectiveness of electronic implementation [4].

Neuromorphic Neuron

The neuromorphic neuron of visual cortex can be implemented by simulating the behavior of neuron in the Hubel and Wiesel's experimentation. The spike neural signal is explained by the widely adopted Hodgkin-Huxley formalism in Fig. 2, with the controlled conductance based equivalent model [5]. Hodgkin-Huxley formalism is unlikely used as much in neural networks or VLSI because of uncompromised large demand in computing complexities in its implementation; however the asynchronous spikes are considered as principle element of high level or large scale neural computing system.

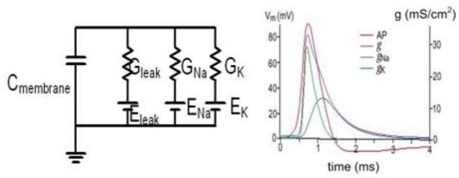

Figure2. (a) An electrical equivalent circuit of a neuron, Hodgkin-Huxley formalism (b) dynamics [5].

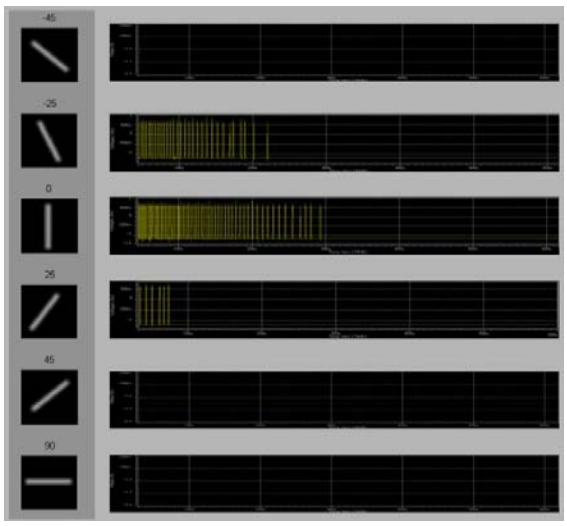

Figure3. Simulated neuron behaviour of visual cortex in Figure 1 by the CMOS neuromorphic neuron based on the model of Figure 2.

The neuromorphic system of neuron and synaptic network was designed for evaluating the feasibility of mimicking the primitive behavior of brain neural system in electronic hardware using the CMOS electronic circuit of [2, 6]. With the neuromorphic neuron formed the various stimuli of six 50 x 50 pixel sized rectangles at different angles are applied as the similar stimulus input to the cat in Hubel and Wiesel's experiment. The simulated result of neuromorphic neuron in Figure 3 shows the consistent outcome as the observation from the Hubel and Wiesel's experiment in Figure 1, where the tuned feature orientations are represented as the spike signal outputs.

NEUROMORPIC VISUAL SYSTEM

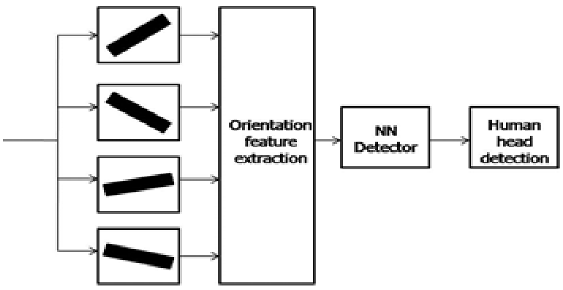

Figure4. Neuromorphic vision for human head figure detection, inspired by visual cortex.

The neuromorphic neuron of simple cell enables the neuromorphic vision system in Figure 4, with the various orientation selective features. The system has three steps in its process which are: 1) orientation feature extraction using neuromorphic neuron, 2) neural network is then applied to the orientation extracted image and finally 3) the human head detection is made to detect the passenger or the pedestrian depending on the system's application.

Pedestrian Detection

One of the major challenges in the pedestrian detection for the enhanced vehicle safety is that the reliability of the detection is strongly affected by illuminace conditions. For example, most pedestrian detection algorithms have significant drop in its detection rate at the night time or indoors compared to the day time or when operating in the bad weather such as rain or snow. The neuromorphic vision system is based on the orientation selectivity of simple cell, instead of the immediate pattern matching or complex figure pattern. The robustness in substantially weak illumination is observed by the successful detection at the indoor parking lot or the night time drive with the head light.

Figure5. Original input image to be processed. Notice the cyclist (red plastic jacket) is uneasy to be recognized by the naked eye.

In addition to the environment of limited illumination, the robustness of neuromorphic visual information processing is demonstrated by the successful cyclist detection in a bad weather and illuminace condition as seen in Figure 5.

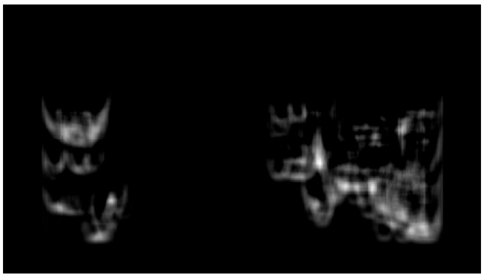

Figure6. Saliency by orientation feature extraction and neural network template of neuromorphic vision system.

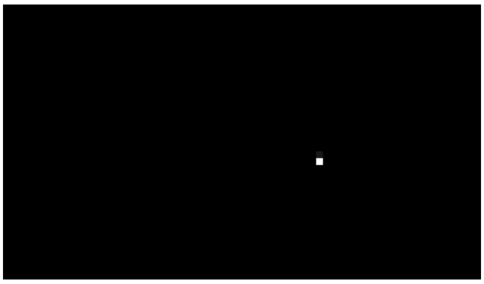

Figure7. Cyclist detection with the post processing applied to the Figure 6.

The saliency after template processing with the orientation features extracted is shown in Figure 6. Due to the extra noise by the snow and limited illumination, the saliency map is shown with extra objects. The characteristics of head detection can separate the large segment in the saliency as it is usually not relevant to human object detection.

The saliency image shows lot of features other than the human object of cyclist. The approaching vehicle’s headlight, vehicle itself, and reflected light on the road, wall and objects cause a lot of noisy components appeared as well. However, once the neural network post processing is applied to the image with the individual feature by head-torso template, most of irrelevant signals other than the single detection signal are eliminated in the resulting image in Fig. 7. The resulting detection is shown in Figure 8 where the cyclist is successfully detected. The test video sample was captured in the snow weather, late afternoon of December, in China.

Figure8. Resulting detection of cyclist from original image of Figure 5.

The performance for pedestrian detection for day or night time is both higher than 90% as illustrated in Table 1 and 2. The detection result in Table 1 and 2 is based on the test video sample captured at the same place, different time, in Korea.

Table 1. Detection rate for daytime

Day Time	Frames including human object	Frames without human Object	Total Number of Frames
Number of frames	18	88	106
Positive Detection	15	88	103
Negative Detection	3	0	3

Table 2. Detection rate for night time

Night Time	Frames including human object	Frames without human Object	Total Number of Frames
Number of frames	99	5	104
Positive Detection	89	2	91
Negative Detection	10	3	13

Passenger Detection

The neuromorphic vision system in Figure 4 is applied to the occupancy detection for new emergency service to reduce the fatality of accidents. There is only the little change for the parameter tuning to accommodate the difference of sensor and object type, where the same template of head-toroso and orientation features are maintained.

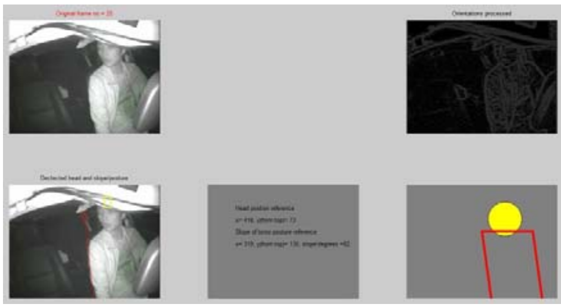

Figure9. Posture detection of passenger. The diagram on the bottom right is represented the posture of the detected passenger.

Similar to the pedestrian detection, same neuromorphic visual system is used to detect the passenger but with minor changes in the processes. For the pedestrian detection, the environment at which the detection must be made is when the vehicle and/or pedestrian is in motion thus there is lot of change in the background such that frame difference cannot be used to reduce noise. However, for passenger detection as shown in Figure 9, the background of passenger is mostly the vehicles stationary passenger cabin with minor variations in the window outlook and so frame difference can be used to minimize noise detected during process.

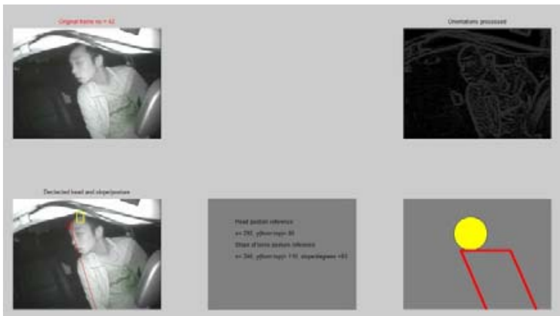

Figure 10. Posture detection of passenger. The passenger is titled further than in Figure 9 and the difference was detected correctly as seen in reconstruction.

To determine the posture of the occupant, the head of the passenger is detected together with the shoulder corner (right arm of driver as in Figure). The straight line is configured to the detected shoulder corner from the edge of driver seat, representing the slope angle of the line. The detected head location and the slope line are used to detect the posture of car occupant as illustrated in Figure 9, 10 and 11. The noisy and unclear image is due to the night time capture by the low cost sensor, while the overall function is reasonable with the consistent head detection.

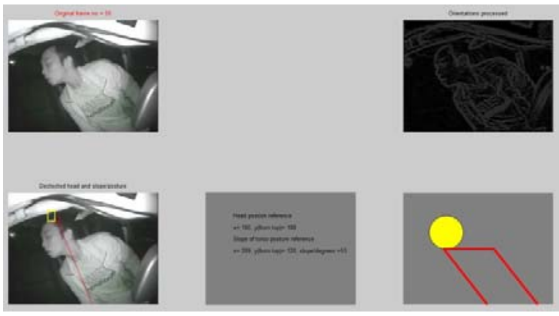

Figure11. Posture detection of passenger. The passenger is titled further than in Figure 9 and 10 and the difference was detected correctly as seen in reconstruction.

Figures 9, 10 and 11 show the posture detection of the passenger. From the detection, the head's x, y position in the image and the angle of its posture is extracted. The extracted information then can be used to visualize the posture of the passenger. This function demonstrates the practical feasibility of sending the information of passenger's posture to the emergency centre without losing the privacy of personal data protection and with the low communication maintenance. The video was captured in night time, in Korea.

Passenger Eye Detection

The demand of the passenger's eye or particular part emerges with the new service or smart devices like 3D dash board without the eye glasses. The monitoring of passenger's facing becomes of interests for the enhanced safety since the information of the face direction or eye status of the passenger is applicable to various advanced service for the attention warning or the smart instrument control.
The fundamental information processing involved in the eye detection is same as for the pedestrian and passenger's posture detection. However, for the robust eye detection, both the nose feature and eye feature are integrated together and the neuromorphic processing is based on the still image after locating the passenger's head. The two stages of processing enhance the image dynamics with localized tuning.

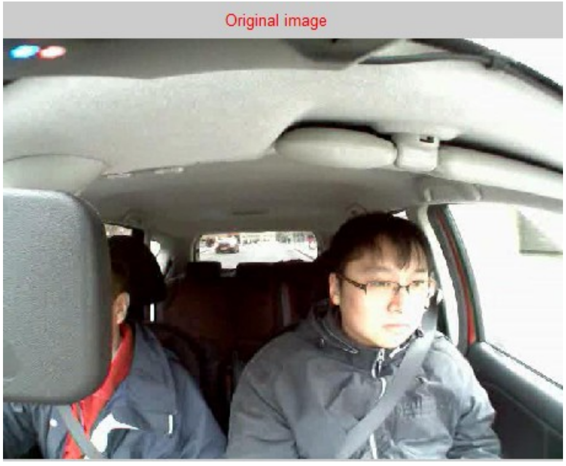

Figure12. Input image

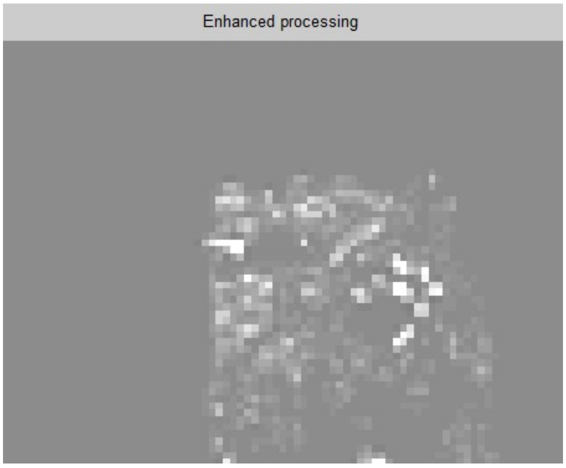

Figure13. Orientation features extracted.

Since the outline of the eye and the nose is distinctively different to that of the head, it is important to detect the head of the passenger to determine the ROI for eye detection. Note that the image used in the detection of the eye and the nose was captured in the different image environment, in the day time, in the UK, even the different vehicle model, but without the change in neuromorphic vision system. The successful detection of the passenger head without calibration or any additional settings to match previous detection shows that the system is robust.

Figure14. Saliency image – resulting image after neural network is applied

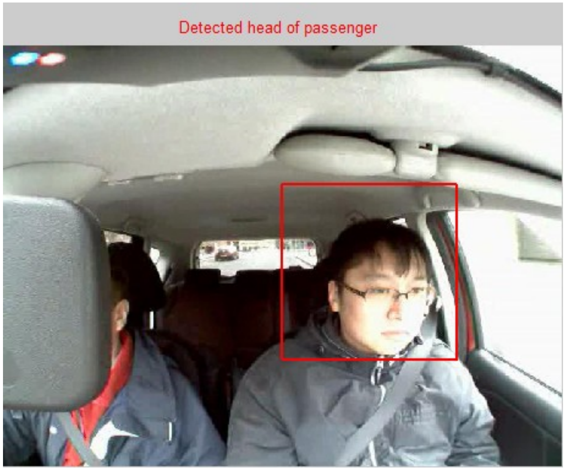

Figure15. Detection of the passenger head to determine ROI for the eye and the nose detection

The orientation features shown in Figure 12 is extracted from the input image, Figure 11. The orientation features were extracted only from the interior of the vehicle, so that the structure of the vehicle and the outside scenery seen through the window is omitted in orientation feature extraction.

Figure 14 is the saliency map after the neural network with human-torso template is applied. From the image it can be seen that the high output levels are concentrated in the center. And the resulting detection in Figure 15 shows the successful detection of the passenger.

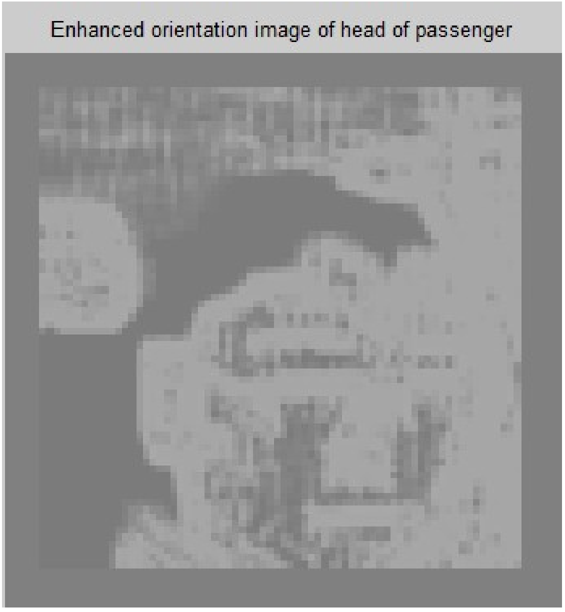

Figure16. Orientation features extracted from the head area.

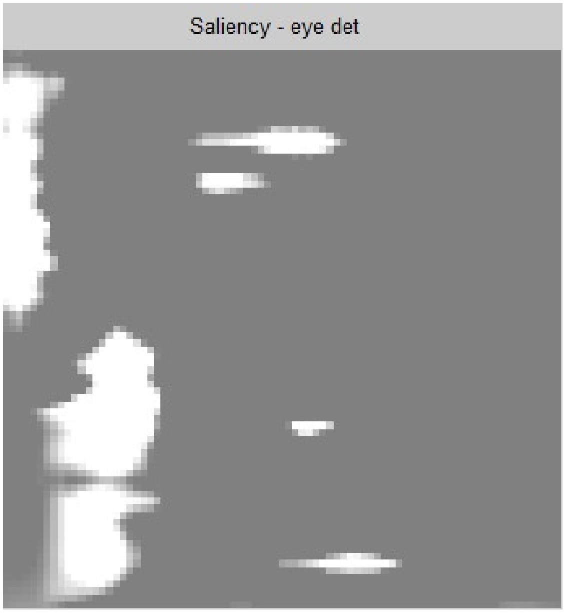

Figure17.Saliency image after neural network with the eye and the nose template is applied

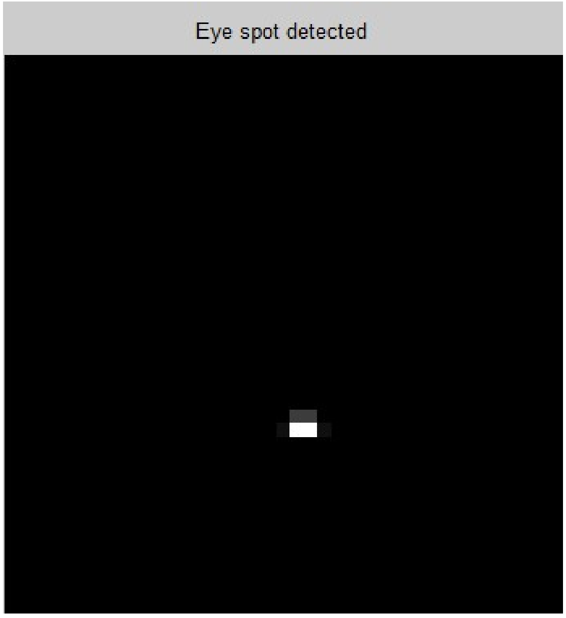

Figure18. Post processing of Figure 16.

Figure19. Detection of the eye

Once the ROI is selected by detecting the head, the process is repeatedly applied with the same orientation feature extractors and the neural network template of eye detection. The Figure 16 is orientation feature extracted from the ROI but it is different to that of Figure 13 since the orientation feature image is enhanced by the locally tuned parameters. Since the outlines of the eye and the nose in Figure 16 are somewhat clearer than the case of frame difference in Figure 13, it is possible to detect an eye of passenger using the appropriate template.

The Figure 17 is the result after the neural network is applied to the Figure 16. There are strong signals detected on the left side of the image possibly due to the noise from other irrelevant object. However, as the detection is specific to the nose and the eye, the valid assumption of small size and isolation is applicable. The detection result of post processing is shown as a single spot in Figure 18, which is represented as the successful eye detection in Figure 19

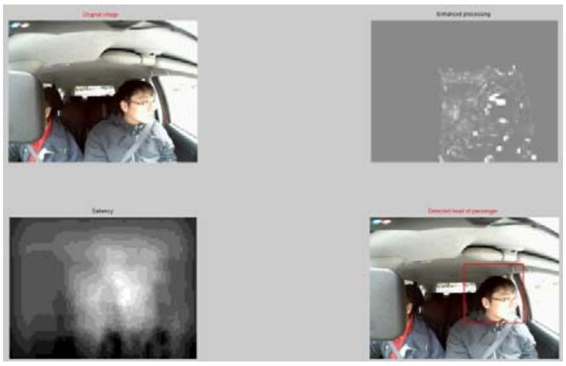

Figure20.Head detection with passenger facing away from the camera

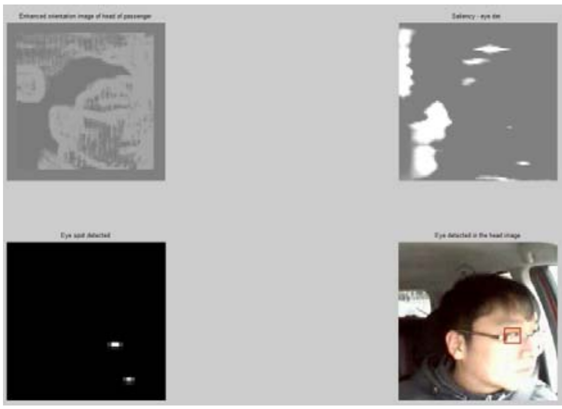

Figure21.Eye detection when the passenger is facing away from the camera.

Figures 20 and 21 show another detection of the eye when the passenger facing away from the camera. The position of the eye detection is different to when the passenger was facing the camera. The difference in these detections can then be also used to determine which direction the passenger faces.

CONCLUSION

In this paper, the pedestrian or passenger detection by neuromorphic vision system is presented with the successful and robust performance in various application environments. The same neuromorphic visual information processing is proven to be applicable to different objects and operation environments, with only the parameter tuning and the addition of necessary template.

The overall performance of the pedestrian detection in both bad weather and illuminace shows that the robustness is sustained without the loss of accuracy as the detection rate was greater than 90%. In addition, the bio-inspired approach involved forming the neuron electronically using CMOS VLSI ASIC technology, which allows for financially advantageous implementation compared to using high-powered chips and computers that the computer vision algorithms requires frequently.

The neuromorphic vision system is demonstrated by using a single camera only compared to other systems which may use stereo-camera or using a IR camera in night-time, which shows promising signs that further use of camera will improve the performance quality even higher.

Acknowledgement

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REFERENCES

[1] D. H. Hubel, T. N. Wiesel, Receptive fields of single neurons in the cat’s striate cortex, J. Physiol., 1959, 148: 574-591.
[2] I. S. Han, Mixed-signal neuron-synapse implementation for large scale neural networks, Int. Journal of Neurocomputing, 2006, pp. 1860-1867.
[3] M. Risenhuber and T. Poggio, Hierachical models of object recognition in cortex, Nature Neuroscience, 1999, pp 1019-1025
[4] W. J. Han and I. S. Han, Tunable linear conductance by two MOSFETs and its application to analogue-mixed VLSI for mobile communication and biologically plausible neuromorphic hardware, Proc. WSEAS, 2009, pp. 86-93
[5] M. Hausser, The Hodgkin-Huxley theory of action potential, Nature neuroscience supplement, vol. 3, 2000, pp. 1165.
[6] W. J. Han and I. S. Han, Bio-Inspired Visual Signal Processing based on Neuromorphic Circuit, Proc. WSEAS, 2010, pp. 131-136.

DEVELOPMENT OF CRASH WARNING INTERFACE METRICS (CWIM)

Eric Nadler
Volpe National Transportation Systems Center
United States
Eric Traube
National Highway Traffic Safety Administration
United States
Neil Lerner
James Jenness
Westat
United States
Timothy Brown
University of Iowa
United States
Carryl Baldwin
George Mason University
United States
Dean Chiang
Dynamic Research, Incorporated
United States
Garrick Forkenbrock
Vehicle Research and Test Center
United States

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ABSTRACT

Based on the findings of a recent field study, Nodine (2011) reported that 88% of forward collision warning (FCW) system alerts in that study were accurate when the lead vehicle was moving. Similarly, 86% of lane departure warning (LDW) alerts activated accurately when the vehicle departed its lane without signaling. However, safety benefits are only realized when the system is both accurate in identifying a crash imminent situation and when the warning presented to the driver elicits a timely and appropriate response (braking or steering). The National Highway Traffic Safety Administration (NHTSA) is conducting studies under the Crash Warning Interface Metrics (CWIM) program to develop valid and sensitive “distracted driver” protocols for the evaluation of the driver vehicle interfaces (DVIs) of FCW and LDW systems on test tracks and in driving simulators as well as examining potential safety-related effects of consistent DVIs for these warning systems. CWIM focuses on distracted drivers because distraction-affected crashes represent a substantial crash risk, including 9% of the fatal crashes and 18% of injury crashes that occurred in 2010 (NHTSA, 2012). The DVI consists of the displays of the warning system, including the warning itself and associated system status displays. Although controls and settings are available for some systems, their usability and effectiveness are outside of the scope of the CWIM program. In this paper, we review some of the prominent results and methodological issues encountered in studies conducted under the CWIM program and describe how they are addressed in the work that is currently underway.

INTRODUCTION

Prominent findings of the CWIM program and their implications for methods to evaluate FCW and LDW DVIs were presented previously at ESV (Robinson, et al. 2011). The prior paper discussed the selection of crash scenarios, the number of warning activations, research participant characteristics, warning system familiarity, crash event expectations, and the secondary (distraction) tasks that were used in CWIM. The present paper considers additional methodological issues that arise with the development of evaluation protocols and with studies of DVI consistency. We review the results of CWIM program research to date and introduce the studies that are currently underway.

BACKGROUND

CWIM began after NHTSA published DVI recommendations for the human factors design of crash warning system DVIs (Campbell, et al., 2007). These voluntary recommendations were often based on expert opinion rather than empirical evidence, but represented the best detailed guidance available. NHTSA then turned to developing a protocol for crash warning DVI evaluation and also began to examine design issues for warning system DVIs that could potentially reduce their benefits.

Evaluation metrics were the first requirement for DVI evaluation. In Phase 1, the CWIM program identified metrics that had been used in earlier research to evaluate the DVIs of FCWs and LDWs. A Federal Register Notice was published to elicit stakeholder feedback about the program (Federal Register, 2008) and follow-up discussions were held.

Phase 2 of CWIM developed test protocols that provided means of obtaining the metrics identified in Phase 1. A protocol was developed in the National Advanced Driving Simulator (NADS) at the University of Iowa. It was then used in a demonstration study to evaluate the effectiveness of two levels of active lane keeping assistance (steering wheel torque) as well as auditory and haptic (steering wheel vibration) LDWs in preventing unintended lane departures by distracted drivers. The protocol permitted sensitive assessment of how quickly drivers responded to the warnings, the amount of lane exceedance that occurred, and subjective assessment of how drivers perceived the warnings. This effort is summarized in Lerner, et al. (2011). A second Phase 2 effort used a test track protocol developed at the NHTSA Vehicle Research and Test Center to compare individual and combinations of visual, auditory, and haptic (seat belt pre-tensioning) FCW DVI. As described in Forkenbrock, et al. (2011), the protocol identified a relatively effective evaluation metric for imminent crash warnings, the end of visual contact with the distraction task.

This test track protocol demonstration and a simulation protocol demonstration with FCWs generated findings that compared driver performance in response to the warnings to a no-warning baseline condition. Additional research questions arose in these studies regarding how some of the test conditions, including the role of incentives, evaluation platform characteristics, and characteristics of the secondary task used to distract the driver when the warning was given, may have affected protocol sensitivity.

In addition to demonstrating test protocols for LDW and FCW, Phase 2 of CWIM examined the potential for inconsistency of the FCW DVI to cause “negative transfer” when drivers encounter an unfamiliar FCW. The results of a simulation study found a sizable negative effect after the drivers became familiar with an auditory/visual FCW “A” and then drove a “different” vehicle with an unfamiliar FCW “B”. Both FCWs were displayed at 85 dB. Other groups of drivers transferred from FCW B to A, A to A (same FCW), and B to B (same FCW) when they drove the “different” vehicle. The simulation included realistic auditory phone alerts (70 dB), an auditory check engine alert, and traffic and road sounds including siren (62 dB). Following transfer, drivers in the A to B transfer condition took twice as long (approximately 1.3 s) to respond by braking than drivers who were familiar with the FCW B (approximately 0.5 s). The corresponding change from B to A did not show this strong effect. Evidence indicated that the traffic and vehicle contextual sounds were perceived as more similar to FCW B than to A, suggesting that the driver may have confused the FCW B with one or more of these other sounds when they were not already familiar with the warning. Additional study is required to clarify whether the negative transfer effect was limited to the specific auditory context used in the study or if it occurs under other conditions (e.g., with haptic or active FCW).

Some of these follow-up investigations have started and are described in more detail in the following section.

CURRENT STUDIES

Common evaluation protocol

The CWIM program is currently conducting empirical studies to address some of the protocol research questions that remain following the investigations that were discussed above and in Robinson et al. (2011). These prior studies included the use of separate FCW and LDW evaluation protocols to examine the effectiveness of DVIs that present the warning in different ways. As Robinson, et al. describe it, their "intent is specifically to have a common method for evaluating the DVI of a commercial system" (p. 11). In the interest of providing a more practical protocol, the current research uses a combined FCW and LDW evaluation drive. Compared to individual protocols, the combined protocol requires only one simulated drive for the evaluation of two different warnings, and it can be used for the evaluation of a combined warning system or either type of warning individually.

In the current Phase 3 CWIM draws upon the findings of the Phase 2 studies to identify potential methodological improvements that will increase the sensitivity and validity of the test protocols, identify sensitive metrics for LDW and FCW timing, and create a framework for DVI assessment that utilizes these metrics. Also, Phase 3 will compare the sensitivity of protocols across test track and simulation platforms that vary in fidelity and motion base to determine the effect of the platform on protocol sensitivity. Full motion may not be necessary to achieve results similar to what can be obtained in a high fidelity simulator (the NADS-1 with 13 degrees of freedom) or test track. Phase 3 will also extend the Phase 2 test track evaluation protocol work to include the development of a test track evaluation protocol for LDWs.

In the current simulation research a combined LDW-FCW evaluation protocol is used to examine a series of additional methodological alternatives that have arisen in the preceding studies.

1. Since the CWIM program has developed test track and driving simulator methods for assessing the effectiveness of FCW DVIs, it is important to determine whether their results are the same. CWIM is approaching this question by conducting a simulation study that compares the sensitivity of the test track and simulation drives by simulating and comparing findings from both situations.
2. The CWIM program assumes that warnings are particularly needed by distracted drivers. The distraction task provides a realistic context for presenting a forward collision and lane departure situations, and it also encourages the drivers to attribute the situation to their own actions instead of to an artificial and arbitrary experimental procedure. The secondary task used for distracting the driver can also produce data loss if the driver is not distracted from the developing collision or lane departure situation and responds prior to the warning. The test track and simulator studies used somewhat different secondary tasks to distract the driver prior to experimentally creating the forward collision situation that triggered the warning (Forkenbrock, et al., 2011; Lerner, et al., 2011). Phase 3 research compares these and other secondary tasks for potential use in distracting the driver. In the current phase, CWIM will also consider the secondary tasks that are emerging from the Connected Vehicles program (NHTSA, 2011) because they may introduce new sources of driver distraction (Lee, et al., 2012) and provide the context within which drivers will encounter FCW and LDW.
3. The protocol can provide an incentive for secondary (distraction) task performance, representing another methodological alternative. If they are unrealistically highly motivated to complete the secondary task, drivers may not respond as quickly to warnings that interrupt performance, in effect setting an unrealistic criterion. In a current investigation, the CWIM program is varying the task incentive to

determine its effects on protocol sensitivity and data loss.

4. The previous test track scenario surprised the participants by not instructing them in advance that the vehicle was equipped with the FCW. The purpose of the surprise protocol is to reduce the effects of artificial factors such as expectancies on their responses. In contrast, the simulation protocol introduced FCW and LDW through PowerPoint training presentations that portrayed the warnings as one of a variety of features that the participants would experience. Currently CWIM is studying how familiarity generated by instructions or prior exposure to the warning affects simulation protocol sensitivity.
5. The timing of the FCW provides a pair of methodological alternatives. The current research directly compares the previously used warning timings with time-to-collision onsets of 2.1 s and 3.5 s.

In each case, the alternative that will be selected for the recommended protocol needs to contribute both to practical goals such as preventing data loss and statistical goals such as enhanced sensitivity.

In addition to methodological alternatives, the CWIM Program has begun to address the current lack of a common test track evaluation protocol for LDW DVIs. Previously, Rudin-Brown & Noy (2002) compared participant responses to LDW on a test track and in a driving simulator, and found similar lane position effects in the two settings. The authors used a secondary task requiring continuous attention to the dashboard and center console to distract the driver and the LDW system generated warnings when the vehicle was 22 cm from a lane boundary. This method would not appear to provide much control over the frequency of LDWs or circumstances in which they are issued. In order to achieve more control over data collection, lateral movement will be created unobtrusively using differential braking of a trailer attached to the rear of the vehicle while the driver is engaged in secondary task performance. It is expected that the driver will in most cases attribute the movement to inattention so that this method will provide a practical, sensitive evaluation protocol for LDW with relatively precise control over data collection and minimal data loss.

Potential safety effects of consistent DVI components

Current research also examines the potential safety effects of consistent DVI components. One study is examining the repeatability and robustness of the "negative transfer" effect, described above, which indicated a slower response when a driver switches to an "unfamiliar" (simulated) vehicle that has a different-sounding FCW. This finding raised several questions that current research is attempting to answer, but the overall aim is to better understand the effect that was observed in the previous experiment. It examines the effect of a rich auditory environment including a siren and an email alert that had to be silenced on the negative transfer finding and whether the effect is found without this environment. It substitutes a peripheral detection task for the centrally located working memory task used in the preceding study to determine whether the effect occurs when attention is required in the visual periphery.

A second study concerns the effect of a less urgent alert on a driver's response to a FCW when the less urgent alert occurs roughly 350 ms or less prior to the warning (Hibberd, et al., 2010). Several simulation studies have found that responses are delayed when the prior alert occurs during this "psychological refractory period". Examples of prior alerts include e-mail alerts that the driver must silence (Wiese & Lee, 2004) and laboratory choice reaction time tasks (Levy, Pashler & Boer, 2006) performed in a driving simulation. The results could suggest the value of muting or delay of other alerts and messages when the conditions are about to trigger a FCW. Studies are replicating the PRP effect with safety-related warnings including verbal and non-verbal auditory alerts and auditory or haptic (automatic braking) FCWs. The verbal alerts are "traffic ahead," "curve ahead" and "construction ahead," and all indicate that the driver should decrease speed.

Acoustic warning research

Further experimental work is planned to define the dimensions and extent to which FCW signals may vary around a prototype FCW signal and still quickly communicate the warning message to drivers, regardless of past experience with other vehicle systems (i.e., eliminate negative transfer). Phase 3 will thus assist warning DVI designers through studies of the auditory warning features that result in the categorical perception of a sound as an urgent warning and of the external auditory environment that could mask the perception of these warnings.

CONCLUSION

The findings of the CWIM program will provide practical guidance for the future design and evaluation of FCW and LDW systems. Although the approach has continued to emphasize the evaluation of the DVI component of crash-imminent warnings, it has adapted to the evolving vehicle (and connected vehicle) environment within which these warnings need to operate. This is seen in the current FCW and LDW evaluation protocol studies that will adapt the protocol to an environment in which drivers respond to connected vehicle alerts and in the PRP research where these alerts may occur in close temporal proximity to FCW onset. In this way NHTSA is attempting to provide research findings that can potentially be applied to the design of future warning systems as well as to systems that are beginning to be implemented in the current fleet.

REFERENCES

Campbell, J., Richard, C., Brown, J. & McCallum, M. (2007). Crash warning system interfaces: Human factors insights and lessons learned. DOT HS 810 697, NHTSA Washington, DC.

Federal Register Volume 73, Issue 42 (March 3, 2008). Notice and Request for Information and Comment on Development and Application of Crash Warning Interface Metrics 73 FR 11459.

Forkenbrock, G., Snyder A., Heitz M., Hoover R. & O'Harra B. (2011). A test track protocol for assessing forward collision warning driver-vehicle interface effectiveness, DOT HS 811 501, NHTSA, Washington, DC.

Hibbert, D., Jamson, S. & Carsten, O. (2010). Managing in-vehicle distractions - evidence from the psychological refractory period paradigm. Proceedings of the Second International Conference on Automotive User Interfaces and Interactive Vehicular Applications (Automotive UI 2010), pp. 4-11. Pittsburgh, Pennsylvania, USA.

Lee, J., Lee, J. D., & Salvucci, D. (2012). Evaluating the distraction potential of connected vehicles. Proceedings of the Third International Conference on Automotive User Interfaces and Interactive Vehicular Applications (Automotive UI 2012), Portsmouth, NH, USA, pp. 33-40.

Lerner N., Jenness J., Robinson E., Brown T., Baldwin C., & Llaneras, R. (2011). Crash Warning Interface Metrics: Final report. DOT HS 811 470a, NHTSA, Washington, DC.

Levy, J., Pashler, H. & Boer, E. (2006). Central interference in driving: Is there any stopping the psychological refractory period? Psychological Science, 17, 228-235.

NHTSA (2011). USDOT connected vehicle research program: vehicle-to-vehicle safety application research plan. Report No. DOT HS 811 373. NHTSA, Washington, DC.

NHTSA (2012). Traffic Safety Facts: Distracted Driving 2010: Report No. DOT HS 811 650. Washington, DC: NHTSA. Retrieved from the Distraction.gov website: http://www.distraction.gov/download/research-pdf/2010FactSheet.pdf.

Nodine, E. (2011). Evaluation results of integrated vehicle-based safety systems (IVBSS). Paper presented at the SAE Government Industry Meeting, Washington, DC. Retrieved from the Bureau of Transportation Statistics website: http://ntl.bts.gov/lib/35000/35800/35867/Nodine-2011_SAE_Govt-Ind_Meeting_1-27-11.pdf.

Robinson, E., Lerner, N., Jenness, J., Traube, E., Brown, T., Baldwin, C., Llaneras, R. (2011). Crash Warning Interface Metrics: Evaluating driver-vehicle interface characteristics for advanced crash warning systems. Paper presented at the 22nd International Technical Conference on the Enhanced Safety of Vehicles, Washington, DC. Retrieved from the ESV conference website: www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000252.pdf.

Rudin-Brown, C. & Noy, Y. (2002). Investigation of behavioral adaptation to lane departure warnings. In Transportation Research Record: Journal of the Transportation Research Board, No. 1803, TRB, National Research Council, Washington, D.C., pp. 30-37.

Wiese, E. & Lee, J. (2004). Auditory alerts for in-vehicle information systems: The effects of temporal conflict and sound parameters on driver attitudes and performance. Ergonomics, 47, 965-986.

UNDERSTANDING AND IMPROVING DRIVER COMPLIANCE WITH SAFETY SYSTEM FEEDBACK

Mikael Ljung Aust
Sergejs Dombrovskis
Volvo Car Corporation
Sweden
Paper number 13-0455

ABSTRACT

Many crashes usually start with a driver inadvertently leaving the lane. These lane departures broadly fall into two categories. One is where kinematic control is lost, e.g. due to icy roads. The other, and the focus here, is when the vehicle in principle remains controllable, but where the driver for some reason temporarily does not exercise that control. Developing safety systems which detect and act on inadvertent lane departures due to e.g. drowsiness and/or distraction, has a large safety potential.

However, in addition to precise threat detection, successful implementation of such systems also requires an understanding of what motivates and controls the driver's response to system feedback. While threat detection has advanced considerably in recent years, there has yet to emerged a common view on how to understand and improve driver compliance with system feedback in imminent lane departure situations.

The objective of the paper is to formulate a theoretical framework for understanding how safety system feedback is received by the driver in different driving situations. The purpose is to enhance the understanding of what is required to achieve high levels of driver compliance in situations where systems indicate risk, for example of inadvertent lane departures.

The framework is based on the dimensions of perceived threat relevance and opportunities for action. Essentially, when system feedback is received (e.g. a lane departure warning), the driver balances the perceived potential gravity of the situation against the effort required to abide by the system's feedback. This aligns with a general human factors trend toward describing human behavior as a balancing act between goal desirability and energy expenditure.

Application of the framework shows that if the driver associates an imminent lane departure with a low level of threat, correctional effort in response to system feedback will be minimal. To increase lane keeping precision under those circumstances, the vehicle must offer an opportunity for action that requires minimal driver effort to realize. Here, strategies like offering to turn on lane keeping aid as soon as lane keeping starts to degrade might be a way forward. If the driver on the other hand associates a lane departure with a high level of threat, any warning that manages to bring the driver's attention back on the forward roadway will be sufficient. The exception is if the driver is incapable of comprehending or acting the warning, in which case radical actions such as autonomously driving the vehicle to the next rest place might be necessary.

To increase road safety, a deeper understanding of driver compliance is just as important as good threat detection. The issue of how to scientifically approach driver compliance needs to be a top priority in driver behavior analysis. The framework illustrates both the need for, and a viable approach to, a systematic view of how safety system feedback influences driver behavior in lane departure situations. While a step forward, much work remains before the principles governing driver compliance in potentially threatening situations are fully understood.

INTRODUCTION

Active safety systems that detect and act on potentially critical driving situations by alerting or warning the driver to e.g. inadvertent lane departures and imminent lead vehicle collisions have a large safety increasing potential. However, for these systems to accomplish what they set out to do, they must influence driver behavior in the way system designers have intended. For this to happen, it follows that implementation of these systems not only requires precise threat detection and an intuitive driver interface. Also, a deep understanding of what motivates and controls driver compliance with the alerts and warnings given is required.

A concrete example serves to illustrate the point. Say a vehicle manufacturer launches a safety function that with 100 % certainty detects when a driver is close to falling asleep behind the wheel, and alerts the driver to this condition. What happens next? From a system design point of view, the desired response would be that the driver almost immediately stops, drinks a cup of coffee and then takes a fifteen minute nap before continuing the drive.

However, as most can testify from their own experiences as drivers, drivers' real world behavior do not always conform with system design intent. Apart from not always having a thermos of coffee ready for situations like these, drivers normally weight in the system's recommendation together with a number of other factors, such as distance to home or the availability of a safe parking place, before deciding whether to go on or to stop, and it's not obvious that the system will have the final word on the matter.

As the example illustrates, the purpose of in-vehicle alerts and warnings is to guide driver behavior in certain ways, and if this guidance is unsuccessful, so is the system. For safety systems general, a lack of compliance means that the benefit one predicts based on installing the system never will come to fruition.

Given this truly central role of driver compliance in the effect of warning based in-vehicle systems, one would assume that the study of compliance would be a large field. However, there are actually relatively few studies in the empirical warnings literature that assess people's compliance behavior [1].

One of the underlying reasons is fairly straightforward. Compared to studies that focus on pre-cursors to compliance such as warning awareness and comprehension, driver compliance is difficult to study. Coming back to the drowsiness detection function exemplified above, when one starts to think about it, operationalizing how to measure compliance with system output is quite difficult. Is it enough to ask drivers whether they stop in response to warnings given, or are more objective measures required? And if they do stop, how soon after the warning need they stop for it to count as warning compliance and not just stopping because they are tired (which is why they get the warning after all)?

Another reason why compliance is hard to understand and move forward is that the available studies to a certain extent contain results that are less easy to interpret and understand. Some very interesting findings that inspired the current paper come from the recently concluded euroFOT project [2]. In euroFOT, the drivers attitude towards, and usage of, several in-vehicle warning systems were studied. The result which concerns us here is that in this study, two systems that in many aspects are very similar were rated very differently by the users. These systems were Forward Collision Warning (FCW) and Lane Departure Warning (LDW). Both warn the driver when driver action is required, either to avoid leaving the lane or to avoid a conflict with the lead vehicle. The difference between them in euroFOT was that while FCW was highly appreciated by most drivers on many compliance related dimensions such as usefulness and warning relevance, LDW received much less favorable ratings. Moreover, at the same time as LDW was rated as less favorable, the intervention system Lane Keeping Aid (LKA), which countersteers when the driver is about to cross the lane marker rather than sounding a warning like LDW, received very positive feedback from the drivers.

It is far from obvious how these findings should be interpreted. Why do drivers like a warning for longitudinal conflicts but prefer a steering intervention when lateral loss of control is at hand? Why not the opposite? It is clear that a larger picture that describes the more basic mechanisms of what makes drivers adhere or not adhere to warnings is missing. There is simply a lack of agreed-upon concepts and principles when it comes to describing the mechanisms that govern driver compliance with different in-vehicle alerts and warnings.

A CONCEPTUAL FRAMEWORK FOR DRIVER COMPLIANCE

A set of principles and concepts that capture the fundamental ideas of a field of science is often referred to as a conceptual framework. That is what is missing from the research field of behavioral compliance, and also what the current paper tries to address. To exemplify more concretely what is meant by a conceptual framework, it helps to consider work in a related field, i.e. injury prevention. Here, William Haddon formulated a conceptual framework through what can be called the energy transfer model [3]. Haddon stated that injuries occur when "energy is transferred in such ways and amounts, and at such rates, that inanimate or animate structures are damaged" [4].

This basic idea, albeit simple in retrospect, had a tremendous impact on work in injury protection. Accident investigators understood they should collect field data on the ways in which sudden and unwanted energy transfers into humans occur. Those who develop countermeasures realized they should focus creating ways of redistributing unwanted mechanical energy in time and space to avoid it reaching humans. All in all, Haddon's framework presented a simple yet scientifically sound model that practitioners in the field could use as a basis for discussions.

The present paper is an attempt to formulate a conceptual framework for driver compliance with warnings and alerts that can describe the effect of in-vehicle warnings on actual driver behaviour in a way similar to how Haddon's energy transfer model explains the injury preventive function of seat belts, etc. The purpose of the framework is to enhance the understanding of what is required to achieve high levels of driver compliance with system recommendations in potentially critical situations. The framework presented here draws heavily upon the conceptual framework for evaluation of active safety systems presented in [5], though here it is tweaked to suit application towards compliance issues rather than warning design.

While the central concept in Haddon's framework is negative energy transfer, the central concept in the currently proposed framework is control. Control in general can be defined as an ability to direct and manage the development of events [6], or more specifically the maintenance of a goal state in face of disturbances [7]. In the domain of traffic safety, driving can be viewed as a control task that involves continuous adaptation to a changing environment, in a way which promotes goal fulfillment [7] .

Moreover, controlling a vehicle normally involves the pursuit of multiple goals. These can often be described as hierarchically ordered, i.e. a high-level goal can be to reach the destination in time, while lower-level goals include avoiding colliding with lead vehicles and driving within the lane. Such hierarchies of goals is reflected in many driving models [6][8] [9][10].

However, while the hierarchical models above can describe the multiple control processes involved in driving, they cannot account for how the goals, or reference values, are selected. They therefore needs to be complemented by an explanation of why drivers choose the goals they do. One early such account is the zero-risk theory by Näätänen and Summala [11], which proposes that driver behaviour is shaped by excitatory "forces". These forces motivate the driver to actively look for and exploit opportunities for action present in the environment. For example, if a driver wishes to travel faster than the vehicle in front, s/he will look for a gap in the left lane to overtake in.

To keep things balanced however, the excitatory forces are kept in check by inhibitory forces. Originally, Näätänen and Summala [11] proposed that inhibitory forces are driven by subjective risk estimates. Vaa [12] developed that general idea by incorporating Damasio's concept of somatic markers [13]. Vaa states that adaptive driver behaviour largely is governed by physiological reactions to threatening situations, i.e. emotions, experienced by the driver as unpleasant feelings. Somatic markers are emotional signals that attach positive or negative values to opportunities for action and their outcomes. Following Vaa's model, [14] proposes a generalization of the zero–risk model where driver strives to maintain a state of zero discomfort rather than zero risk. In this model, the driver's selection of goals in the driving control processes becomes a balance between a desire for goal fulfillment and discomfort avoidance. This results in adaptive behaviour, with the driver responding to changing driving demands (current and predicted) by seeking reference values which will result in goal fulfillment without generating feelings of discomfort.

In terms of which goals are attractive or not, drivers normally seek goals they believe are within a safety zone [14]. The safety zone is defined as the region of all goal states for which control is maintained. For any other state, non-recoverable loss of control will occur. The important point here is that according to Summala, in order to maintain their state of zero discomfort, drivers generally avoid goal states that are close to the safety zone boundary. Rather, they prefer goals with a certain minimum distance, or safety margin, to the boundary.

The region defined by this safety margin can be conceptualized as a comfort zone, i.e. a region of possible goal states for which no discomfort is felt or predicted by the driver, and which the driver therefore prefers to stay within. As long as the comfort zone boundary is not exceeded, the exact goal state that is chosen does not matter very much. However, if the comfort zone boundary is exceeded, a feeling of discomfort will be experienced, and the driver will take adaptive action to reduce that feeling.

These concepts are illustrated in Figure 1 below. The comfort zone contains the speeds for which the driver expects no feeling of discomfort, given the subjective assessment of road friction. The safety margin is the difference between the comfort zone boundary and the safety zone boundary (i.e. between the maximum speed that the driver is comfortable with and the maximum possible speed which does not lead to skidding). In this example, the driver successfully perceives the change in safety zone boundary which occurs when friction is reduced due to for example a sudden snowfall. Since the current speed feels uncomfortable in relation to this change in conditions, the driver adapts by slowing down to a speed well below the safety zone boundary for the new friction conditions, and manages to do so without exiting the comfort zone. The driver thus avoids feelings of discomfort as well as loss of control.

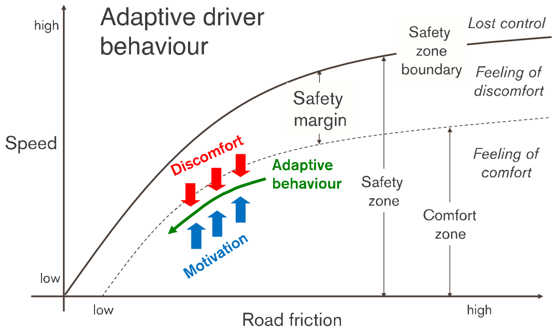


Figure 1: Driver adapting speed when road friction changes

As stated in the introduction, the purpose of a conceptual framework is to capture the fundamental ideas of a field of science. The authors believe that the conceptual framework presented here does exactly that for the field of driver compliance with in-vehicle warnings and alerts, based on the following reasoning.

The design intent of all in-vehicle warnings is to tell the driver that a certain safety margin threshold has been exceeded. The exceedance in itself can be related to many different measures of safety, such as acceptable levels of drowsiness, lateral positioning or kinematic margins to the lead vehicle. Overall however, the one thing all warning and alert systems have in common is that their designers think some safety margin, however defined, should be larger than what it currently is.

Put in terms of the conceptual framework described above, an alert or a warning is principally a sign that the driver has exceeded the system designer's comfort zone boundary, and the designer therefore wants the driver to take corrective action in order to increase the safety margin. From this follows that a key enabler for high levels of driver compliance with alerts and warnings is that the system designers and the driver's view of the situation match, i.e. that they share the same definition of where the comfort zone boundary is. If they do, then all is well. The driver when alerted will realize the safety margin is getting uncomfortably small and will adjust accordingly. If they do not however, the driver will regard the system's output as a nuisance and general source of irritation.
In short, driver compliance crucially depends on how well the system designer's assessment of the comfort zone boundary matches the driver's assessment. This is the key idea of the conceptual framework proposed in this paper.

HOW TO UNDERSTAND WHERE THE DRIVER'S COMFORT ZONE BOUNDARY LIES

In view of the framework, a key research topic for systems designers is to find out how drivers' comfort zone boundaries are set and altered. Here, some key dimensions can be identified.

Expectations about consequences

One very important determinant seems to be the drivers' expectations. Expectations are the anticipatory outcome of a behaviour [15] and are comprised of a person's attitudes and beliefs. The expectations that a person brings to a situation influences whether s/he notices a warning, how s/he processes the warning stimuli, and whether s/he complies. A person's knowledge base, whether accurate or not, will therefore influence behaviors coupled to that knowledge.

In a general context, it is also well known that warning effectiveness tends to increase as a function of perceived hazardousness [16]. Hazard perceptions in turn are generally believed to be based on both the perceived likelihood (probability of experiencing an undesirable outcome) and severity (seriousness of the consequence) of potential incidents [17]. Of these two, severity of injury seems the better predictor of risk perception [18][19]. In other words, people will be more wary of rare events that can do a lot of harm than of more frequent events that do less harm.

This has important implications for warning system design. If the system is able to convey that severe bodily harm is a potential consequence of going beyond the comfort zone boundary as defined by the system designers (even though that outcome may be unlikely), the driver is more likely to comply with the warning. If not, the driver will be less likely to comply, since the current driving state will be perceived as being within the comfort zone boundary.

Familiarity and warnings – the risk of crying wolf too often

In studies investigating the relationship between familiarity and perceived risk, results indicate that increased familiarity with a product reduces it's perceived hazardousness [20]. People may become desensitized to warnings as a result of repeated exposure without immediate consequences [21]. Or put differently, when benign experiences occur, they affect the expectation of risk.

For in-vehicle warning design, the consequence is that repeated warnings in benign situations, i.e.

where nothing bad happens, will lead to a decrease in the perceived hazardousness of the situation. In other words, the further down the timeline of warning exposure that the driver is, the more perceivably hazardous the situation actually has to be in order for the driver to respond as intended. Every benign warning gives the driver reason to believe that the warning is given within the comfort zone, and hence there is no need to regard it as relevant for driving.

Another consequence is that since systems normally are improved over time, applying a conservative warning strategy when releasing new systems is warranted. It seems better to warn rarely at high levels of threat compared to warning more often at lower levels of threat, because if the first warnings are not perceived as relevant, later warnings will not be either. Familiarity will step by step push the warning further inside the comfort zone, unless some transformative (i.e. near crash or crash) experience intervenes.

Illusory superiority and compliance

Another important determinant of the comfort zone boundary is what often is referred to as threat denial. Sometimes people respond to hazard warnings with feelings of personal immunity or overconfidence [22][23].

For example, Svenson [24] surveyed 161 students in Sweden and the United States, asking them to compare their driving safety and skill to the other people in the experiment. For driving skill, about 9% of the US sample and 70 % of the Swedish sample put themselves above the median. For safety, 88% of the US group and 77% of the Swedish sample put themselves in the top half. In a similar study, McCormick, Walkey and Green [25] asked 178 participants to evaluate their position on eight different driving skill dimensions. Only a few rated themselves as below average at any point. When all dimensions were considered together, about 80% of the participants evaluated themselves as being better than the average driver.

For in-vehicle warnings, the implication is that the warning has to be designed to break through what can be called the overconfidence boundary. This means that a warning cannot be presented in a way that primarily appeals to the average likelihood of risk for example, because only average drivers are susceptible to average risk, and oneself is by definition a better driver than average. Instead, for a warning to be perceived as relevant, it has to trigger somatic markers in the driver, making him/her perceive the situation as immediately uncomfortable and requiring corrective action.

INTERPRETING THE EUROFOT RESULTS IN LIGHT OF THE FRAMEWORK

Based on the framework, it can be assumed that when the driver regards system output as irrelevant (i.e. not associated with a threat that can result in serious injury), the correctional effort made by the driver will be minimal. This helps explain the findings from euroFOT mentioned in the introduction [2]. Translated into the framework, the forward collision warning is appreciated because at the point in time when the warning is given, the driver agrees that it could potentially lead to severe bodily harm if s/he does not brake (i.e. a collision with the lead vehicle is close at hand). However, the sense of potential bodily threat when crossing the lane marker is much lower since there normally is a certain portion of road shoulder without apparent obstacles available.

Drivers thus literally do not feel the need for LDWs, because there is no somatic marker that elicits discomfort in the driver if s/he chooses not to act when crossing the lane marker. In the FCW case on the other hand, the possibility of crashing into the lead vehicle does trigger a somatic discomfort response. Drivers thus appreciate the warning and are likely to act on it, or if not, at least agree that it is relevant.

This presents an interesting conundrum for system designers that wish to decrease the number of crashes that are initiated by an inadvertent lane departure. From an engineering standpoint, the chain of events that lead to these crashes start when the vehicle leaves the lane, and logically speaking, the lane marker should thus be equivalent to the comfort zone boundary. However, drivers apparently view things differently. They seem to treat the lane marker more as a useful recommendation about where to drive rather than as an unbreachable boundary. In their minds, they are not afraid of lane departures, they are afraid of road departures. Therefore they show much bigger respect for other vehicles than for lane markers.

System designers therefore probably need to reconsider their approach to the problem of crashes that start with inadvertent lane departures. Since drivers generally are not afraid of the potential consequences of a lane departure, one approach would be to offer an opportunity for action in terms of staying in the lane that requires a minimum of effort to carry out. Automatically steering the vehicle back when an imminent lane departure is detected might therefore be a way forward, and this is indeed what the driver feedback on the LKA system in euroFOT shows [2]. Another approach would be to modify the warning strategy. For example, if the warning comes close in time to the vehicle leaving the road rather than the lane, or if one warns only when there is an oncoming vehicle in the lane you're drifting into. In these cases, the driver's threat assessment is more likely to correspond with the warning, and a higher level of compliance can be expected. To illustrate the point, think about whether you would appreciate a lane departure warning when there is six feet of shoulder followed by a guardrail, compared to when there is a 500 feet drop one foot outside the lane marker and no guardrail.

DISCUSSION AND LIMITATIONS

Application of the framework shows that if the driver associates an imminent lane departure with a low level of threat, correctional effort in response to system feedback will be minimal. To increase e.g. lane keeping precision under those circumstances, the vehicle must offer an opportunity for action that requires minimal driver effort to realize. Here, strategies like offering to turn on lane keeping aid as soon as lane keeping starts to degrade might be a way forward. If the driver on the other hand associates a lane departure with a high level of threat, any warning that manages to bring the driver's attention back on the forward roadway will be sufficient.

To increase road safety, a deeper understanding of driver compliance is just as important as good threat detection, and the issue of how to scientifically approach driver compliance needs to be a top priority in driver behavior analysis. The framework presented here illustrates both the need for, and a viable approach to, a systematic view of how safety system feedback influences driver behavior in lane departure situations. While this is a step forward, there obviously remains a lot of work before all principles that govern driver compliance in potentially threatening situations are fully understood and accounted for.

A limitation of the current framework is that is driver and vehicle centered. There are however certain situations where a high degree of in-vehicle compliance only is the first step toward a good solution. For example, even if the driver intends to comply with an alert from a drowsiness warning system, it may sometimes simply not be possible to do so. The nearest highway exit may be miles away, or rest places that feel safe might be scarce. Certain enablers for compliance thus exist outside the vehicle, and this must not be forgotten in the process.

REFERENCES

[1] Kalsher, M.J, and Williams, K.J (2006) "Behavioral compliance: theory, methodology and results" in Wogalter, M.S. (ed.) *Handbook of warnings*. Mahwah, N.J.: Lawrence Erlbaum.
[2] Sanchez, D., Garcia, E., Saez, M., Benmimoun, M.,, Pütz, A., Ljung Aust, M., Gustafsson, D., Metz, B., Saint Pierre, G., Tattegrain, H., Guidotti, L., Schindhelm, R., Heinig, I., Malta, L., Obojski, M.A. (2012). "Final results: User acceptance and user-related aspects" Deliverable 6.3 of the European Large-Scale Field Operational Test on Active Safety Systems (euroFOT) project. Brussels: European Commission.
[3]Haddon, W. (1968). "Changing approach to epidemiology prevention and amelioration of trauma - transition to approaches etiologically rather than descriptively based". *American Journal of Public Health and the Nations Health,* 58(8), 1431-1438.
[4] Haddon, W. (1973). "Energy damage and 10 countermeasure strategies". *Journal of Trauma-Injury Infection and Critical Care,* 13(4), 321-331.
[5] Ljung Aust, M., & Engström, J. (2011). "A conceptual framework for requirement specification and evaluation of active safety functions". Theoretical Issues in Ergonomics Science, 12(1), 44 - 65.
[6] Hollnagel, E., & Woods, D. D. (2005). "Joint cognitive systems: foundations of cognitive systems engineering". Boca Raton, FL: CRC Press.
[7] Engström, J., & Hollnagel, E. (2007). " General Conceptual Framework for Modelling Behavioural Effects of Driver Support Functions". In P. C. Cacciabue (Ed.), *Modelling Driver Behaviour in Automotive Environments Critical Issues in Driver Interactions with Intelligent Transport Systems*. London: Springer. pp. 61-84.
[8] Allen, T.M., Lunenfeld, H., & Alexander, G. J. (1971) "Driver information needs". Highway Research Record, 366(366), 102-115.
[9]Michon, J.A. (1985). "Critical view of driver behavior models: what do we know, what should we do?" In Evans, L. and Schwing, R. (eds) *Human Behaviors and Traffic Safety*, Plenum Press, New York
[10] Hollnagel, E. (2003). "Handbook of cognitive task design". Mahwah, N.J.: Lawrence Erlbaum.
[11] Näätänen, R., & Summala, H. 1976. "Road-user behavior and traffic accidents". Amsterdam: New York.
[12] Vaa, T. (2007). "Modelling Driver Behaviour on Basis of Emotions and Feelings: Intelligent Transport Systems and Behavioural Adaptations". In P.C. Cacciabue (ed). *Modelling driver behaviour in automotive environments: critical issues in driver interactions with intelligent transport systems* London: Springer. pp. 208-232.
[13] Damasio, A.R. (1994) Descartes' error: emotion, reason, and the human brain. New York: G.P. Putnam.
[14] Summala, H. (2007) "Towards Understanding Motivational and Emotional Factors in Driver

Behaviour: Comfort Through Satisficing". In P.C. Cacciabue (ed). *Modelling driver behaviour in automotive environments: critical issues in driver interactions with intelligent transport systems*. London: Springer. pp. 189-207.
[15] Bandura, A., (1986) "Social foundations of thought and action: a social cognitive theory". Englewood Cliffs, NJ: Prentice- Hall.
[16] DeJoy, D.M. (1991) "A revised model of the warnings process derived from value-expecancy theory". Proceedings of the Human Factors Society, 35, 1039-1042.
[17] Slovic, P., Fischhoff, B. and Lichtenstein, S (1979) "Rating the risks". *Environment, 21*, 14-20, 36-39.
[18]Wogalter, M.S., Brelsford, J.W., Desaulniers D.R., and Laughery, K.R (1991) "Consumer product warnings: the role of hazard perception". Journal of Safety Research, 22, 71-82.
[19] Young, S.L., Brelsford J.W., and Wogalter, M.S. (1990) "Judgments of hazard, risk and danger. Do they differ?" Proceedings of the Human Factors Society, 34, 503-507.
[20] Vredenburgh, A.G., and and Zackowitz, I.B. (2006) "Expectations" in Wogalter, M.S. (ed.) *Handbook of warnings*. Mahwah, N.J.: Lawrence Erlbaum.
[21] Stewart, D. W. and Martin, I. M. (1994) "Intended and unintended consequences of warning messages: A review and synthesis of empirical research". Journal of Public Policy & Marketing, 13, 1-19.
[22] Fischhoff, B., Slovic P. & Lichtenstein, S (1977) "Knowing with certainty: The appropriateness of extreme confidence". Journal of Experimental Psychology: Human Perception and Performance, 3: 552-564.
[23] Slovic, P., Fishhoff, B., & Lichtenstein, S. (1980). "Facts and Fears: Understanding Perceived Risk". In Albers, W.A. (Ed.) *Societal Risk Assessment: How Safe Is Safe Enough?* New York, NY: Plenum Press
[24] Svenson (1981) "Are we all less risky and more skillful than our fellow drivers?" Acta Psychologica, 47, 143-148, North-Holland Publishing Company.
[25] McCormick, I.A., Walkey, F.H. & Green, D.E. (1986). "Comparative perceptions of driver ability – A confirmation and expansion". Accident Analysis & Prevention, 18, 205-208.

Accident Causation Factor Analysis of Traffic Accidents on the Example of Elderly Car Drivers using the Causation Analysis Tool ACAS

Otte, Dietmar
Jänsch, Michael
Accident Research Unit, Hannover Medical School (1)
Germany
Pund, Bernd
Duntsch, Katja
TÜV Technische Überwachung Hessen GmbH, Hannover (2)
Germany
Paper Number 13-0491

ABSTRACT

The need of in-depth accident causation data in accident research is becoming more and more important. The German In-Depth Accident Study GIDAS is well qualified to deliver adequate data to conduct an investigation on this field, based also on identifying the causes of accidents. This led to the development and implementation of a special tool called ACAS (Accident Causation Analysis System) for the collection of such causation data adopting the GIDAS methodology. Using this system, for each accident participant one or more of five hypotheses of human cause factors are formed along the basic human functions active when managing a situation in traffic. These hypotheses are subsequently specified by appropriate verification criteria. To facilitate the analysis of accident causes, the information collected with ACAS is recorded in a structured code of digits. With the help of structured questionnaires for on-scene investigation used to interviews of accident participants it is possible to easily identify human failures and categorize these in the ACAS structure. Internal analysis of the herewith coded accident causation information has proven that with this system it is possible to find causes of traffic accidents with enough details to identify differences of psychological performances categorized by the basic human functions in the situation or the emergence of the accident.

Past studies on identifying typical accident scenarios of elderly traffic participants have shown that it is difficult to find typical circumstances and features of accidents caused by the elderly, based on classic accident research data. With the present study a first step in this direction is done by analyzing the causation coding of accidents with personal damages of n=817 non-elderly car drivers (aged 25-64) with failures of one of the five human causation categories and to n=169 elderly car drivers aged 65 and over (total of 986 for both age groups). The focus of this study lies on identifying the special causes of elderly traffic participants and analyzing the psychological effects which lead to failures in the situation of the accident event. The results of the causation analysis display that with elderly traffic participants the human failures are mostly about perception problems and difficulties with the execution of a desired action. The study also revealed that the causation category of an accident has an influence on the accident severity (injury-outcome) this is an important factor which has to be kept in mind when looking for countermeasures to decrease severe injuries or fatalities.

INTRODUCTION

In recent years methods and systems for the analysis and collection of causal factors in traffic accidents have been developed in Europe which are based on the principle of "real-life Investigation" with a data collection that is conducted at the scene of the accident and as soon as possible after the accident. Beside the method ACAS (Accident Causation Analysis System) presented in this study which was first presented by Otte in 2009 ESV Conference is used in the German In-Depth-investigation for example in the context of GIDAS [1], other European analysis systems such as DREAM (Driving Reliability and Error Analysis Method) in Sweden or HFF (Human Functional Failures) in France work according to the same principle in defining human failures with causation parameter. These analysis systems have in common that they consist of a method of analysis, an accident model and a classification system.

The present study presents the application of ACAS in a special survey on the comparison of young and older car drivers, i.e. how can the method of ACAS reflect differences between younger and older car drivers involved in accidents on one hand and which causation factors are related to younger versus older drivers on the other hand based on the five human functional levels of the model.

The collection of psychological data for the determination of relevant accident causation parameters from accident participants with ACAS is based on the following fundamental methodological requirements that affect the procedure, particularly when collecting human determined accident factors: The human factors analysis is done "on-scene" and "in-depth". The methodological core constitutes the approach in the form of a "real-life Investigation" which means an analysis of the accident causes as close as possible to the occurrence of the accident. The temporal and spatial immediacy of the data collection is regarded as an essential quality criterion for the relevance of accident causation data: The reliability and validity of the data is higher the more comprehensive the available information is, the less traces are "blurred" (this includes memory traces of the interviewed) and the shorter the experienced situation of the participants interviewed at the scene lies back to ensure the highest possible realism. While the technical and medical data collection is widely standardized and therefore holds little potential for economizing time, the temporal variability of the interviews with involved road users is fairly high. Extreme examples are the people that refuse to be interviewed on one hand and "emotionally overwhelmed" interviews with a high need to talk on the other hand. In experience however in most of the cases relevant human causation information can be determined sufficiently economical, if the interviewer proceeds hypothesis guided according to the basis of the classification scheme and the general accident model using a semi-standardized questionnaire.

This means that it is profoundly analyzed which assessments, expectations or intentions played a role and for which reasons. Within ACAS the theoretical framework for this purpose is the classification scheme of five categories of basic human functions that were effective when coping with the driving task. Except for the first step (the objective access to information), the next steps describe in a sequential manner human functional qualities that individually or in combinations were active in the accident development and contributed to the causation: information admission, information evaluation, goal setting/planning and executing the operation/action. With this hypotheses guided methodology an economic interview of accident participants or witnesses is assured, without running the risk that relevant data are not considered.

An accident-explanatory relevance of the human causation data is ultimately achieved by comparing these with the technical, medical and infrastructural data of the accident sampled from the field of accident analysis and the accident reconstruction. Herewith other influencing factors i.e. those related to injury severity can be identified. The accident reconstruction thus represents an important complementary part of an accident causation analysis.

Elderly car drivers in traffic

Before discussing the results of an analysis on causation factors the general situation of elderly car drivers in traffic accidents is displayed.

The demographic change in Germany and in many other countries is a well-known phenomenon which leads to a distribution of population, where the share of older people in society is continuously increasing (according to the official publication of the German statistic office [2]). On the other hand human while life expectancy is continuously increasing, the appearance of age related diseases such as dementia or defects in eye sight is not delayed in the same manner. This situation will expectably have a significant impact on the accident situation in many countries and will be among the future challenges of road safety measures. In publications on the accident rates by road users of different age groups uniformly a typical profile was found: The highest accident rates are found in the age group of the 18-21-year olds, which is due to lack of driving experience, youth typical driving motives and higher risk tolerance. The rate decreases in the other age groups and stays at a low level until the age of about 65. In the age groups 65 years and older the accident rate begins to rise again and reaches the magnitude of novice drivers.

This characteristic of age related causation responsibility is also found in the GIDAS data as so-called “bathtub-curve” when analyzing the ratio of participants causing an accident to participants that were involved in an accident without having caused it for the different years of age (figure 1).

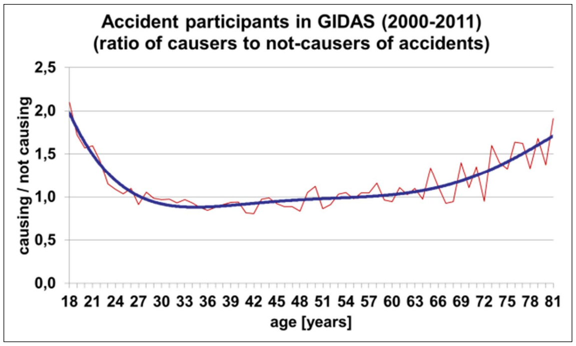


Figure 1: Ratio of causers to non-causers of accidents for different years of age in the GIDAS database (2000-2011).

Here the novice road users are 2 times more likely to cause an accident than to be "innocently" involved in an accident. This ratio quickly falls to less than one for road users in their late twenties and thirties and subsequently begins to rise again. With ages of about 65 years and older the curve begins to rises at a higher rate and reaches a ratio of over 1.5 for road users aged 75 and older. Overall however seniors are not more likely to be involved in accidents than the average car driver [3], [4].

The situation of elderly car drivers and their specific circumstances in the scope of traffic accidents is displayed in this study by comparing the elderly car drivers to the non-elderly car drivers. Thus two age groups were chosen:

• The elderly car drivers can be defined as the group of drivers aged 65 and older. This is consistent with a common age classification found in literature and statistics.

• The age group for comparison consists of drivers aged 25 to 64 years. The young and novice drivers (aged 18-24) were excluded in this survey to leave out their specific features e.g. due to inexperience or a high risk acceptance.

To illustrate the current situation of elderly car drivers in the context of traffic accidents in Germany in a first step the data of the German Federal Statistical Office, DESTATIS was analyzed [5]. Here the most common failures which led to traffic accidents with injuries reported by the police are displayed, comparing the elderly drivers with the non-elderly drivers (Figure 2). It has to be kept in mind that these failures are collected in the context of law enforcement and do not represent the actual causes which led to the accidents. They are rather used in the official national statistics and represent the driving trajectories before the impact.

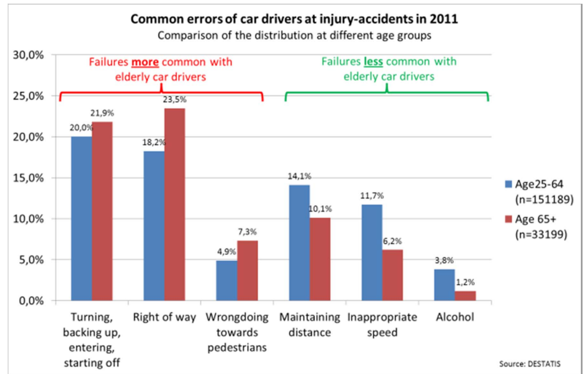


Figure 2: Common failures of car drivers at injury accidents in Germany according to the police, comparing elderly drivers with non-elderly drivers.

The kinds of accidents that are more frequent in the group of elderly car drivers compared to the non-elderly car drivers (turning accidents, right of way accidents etc.) are accidents which occurred in more complex traffic situations like at intersections. These situations require a high capability for orientation in traffic with is more difficult for the elderly road users than for non-elderly road users. On the other hand among the most common failures leading to traffic accidents are failures which are less frequently found with elderly drivers such as not maintaining the distance to other road users, inappropriate speed or driving under the influence of alcohol. These failures often are a result of a higher risk acceptance which is more dominant in the group of the non-elderly car drivers (even though the young and novice drivers are not included in this group). Senior citizens in general have a more pronounced desire for safety in any aspect.

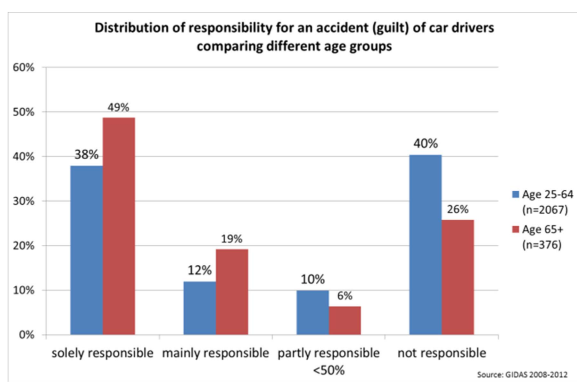


Figure 3: Distribution of responsibility of car drivers for an accident comparing elderly drivers to non-elderly drivers.

An analysis of the GIDAS (German In-Depth-Accident-Study) data from the years 2008 – 2012 shows the share of responsibility for an accident (in the judicial sense) for elderly and non-elderly car drivers (figure 3). GIDAS is based on a in-depth statistical random selection of accidents with injured persons and is representative for the accident distribution [6]. When involved in an accident elderly car drivers are more often solely (49%) or mainly (19%) responsible for the accident occurrence than non-elderly car drivers (solely responsible38%; mainly responsible 12%). This characteristic can be explained by the fact that senior citizen tend to fail more clearly in critical situations.

The initial speed of car drivers at the time of the accident emergence is analyzed in figure 4.

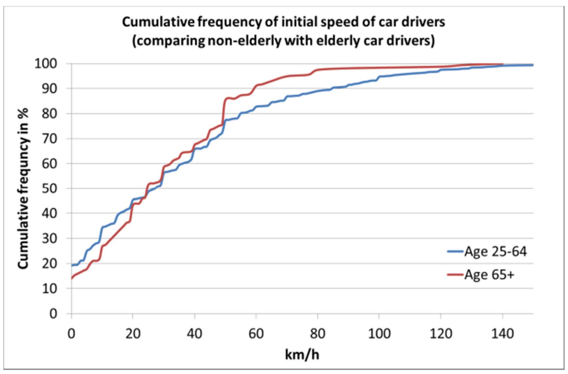


Figure 4: Cumulative frequencies of initial speeds of car drivers for different age groups.

The cumulative frequency for non-elderly and elderly car drivers is about equal for speeds up to 50 kilometers per hour which account for about 75% of the cases of the non-elderly car drivers and about 85% of the cases for the elderly car drivers. For the 25% respectively 15% of cases with higher initial speeds than 50 km/h the non-elderly car drivers were travelling with higher speeds than the elderly car drivers which tend to take fewer risks.

Although the analysis of the Federal German statistical data (DESTATIS) and the common GIDAS data serve to highlight the accident situation of the two different age groups, the exact causes of the accidents are not identifiable. For this reason a causation analysis with the ACAS method was conducted.

Accident causes of elderly car drivers according to ACAS

To identify specific causes of accidents for different age groups the focus clearly lies on the human causation factors as they are influenced by psychological and physiological effects in different age groups and human related causes are with over 90% the most common causes by car drivers. As initially mentioned, the analysis of the human factors with the ACAS methodology is achieved by describing the human participation factors - and failures of these - in a chronological sequence from the perception to a specific action/operation [7]. This is done by considering the logical sequence of basic human functions when reacting to a request for reaction: Information access – Information admission – Information evaluation – Planning – Operation. These functions provide the 5 categories of human factors where failures may lead to an accident.

- **Category 1 (Information access)**: If the participant did not have access to relevant information at the emergence of the accident. An available piece of information cannot be perceived if it was covered / hidden by objects inside or outside the vehicle or if it could not be registered due to physical conditions or disease

- **Category 2 (Information admission):** When the relevant information could have been acquired by the participant, however it was not acquired in time or at all. The participant could have been able to gather the information by reason of adequate perception conditions, however failed to do so.

- **Category 3 (Information evaluation):** The participant has recorded all relevant information but has misjudged or misinterpreted it.

- **Category 4 (Planning):** The information was recorded and evaluated correctly however the participant drew wrong conclusions concerning the action to manage the situation. This concerns no reflex actions - the participant must have had enough time for planning. A further form is the conscious/planned action against well-known traffic rules.

- **Category 5 (Operation):** Errors or difficulties arose during the execution of the planned action. This can cover too late, wrong, omitted or reflex actions. Only usable if the incorrect action was causal for the accident.

A combination of multiple factors can be used if more than one “causation factor” can be assigned to each road user. The causation factors from each of the five categories of the basic human functions can be further specified by subdividing each “category” into specific influence criteria and from there further into specific so-called “indicators” of these characteristics (Figure 5). Due to the hierarchical structure of the accident causation factors they can therefore be recorded in a 4-digit-number, the so-called ACAS-code. These factors are independent from the question of guilt or responsibility of an accident. This means that an accident participant that is not guilty of causing an accident in the judicial sense may well have contributed to the emergence of the accident (e.g. by a late evasive reaction) and thus he may have been assigned with a causation code. For each traffic participant such a code can be given.

Composition of 4-digit-code on accident-causation-factors. In road traffic accidents causes for all fields of interaction can be expected: (1) Human causes, (2) causes from the range of the technology of the vehicle and (3) causes from the range of the infrastructure and/or the environment. The first number of the causation code is describing which field of interaction is addressed with the code. Accordingly with all human causation factors (group 1) the first number of the code is „1 ".

Each of the three fields of interaction is subdivided into specific categories of causation factors (As seen exemplarily for group 1 in Figure 3). These categories are described by the 2nd number of the causation code. Each category is further subdivided into characteristic influence criteria (3rd number of the code), which represent the most frequent factors, which led to an accident. Only in the human causation factors (group 1) each influence criteria can be further specified by specific indicators (4th number of the code)

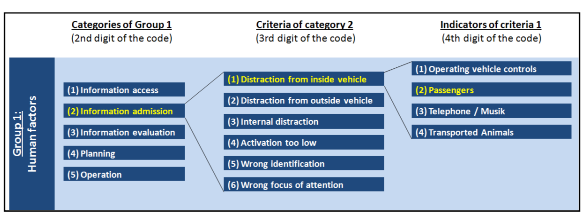


Figure 5: Composition of the ACAS-code – here exemplarily for the Group 1 (human factors)

Example: If someone were distracted by a conversation with a passenger, and thus did not recognize important traffic information, the code of this cause would be:

1 – 2 – 01 – 3 **Code**

Explanation: The accident cause is from the group of human causation factors (first number = 1); Not recognizing something is a failure in the category of the information admission (second number = 2); The influence criterion here is a distraction from inside the vehicle (third number of the code = 1); The distraction in the vehicle occurred due to a passenger (fourth number of the code = 3)

The analysis of the accident data from the GIDAS database was conducted for car drivers taking cases from the years 2011 and 2012 from the Hannover Region. An inter rater reliability check for the quality of the ACAS coding resulted in the best accordance for this sampling unit (about 75%).

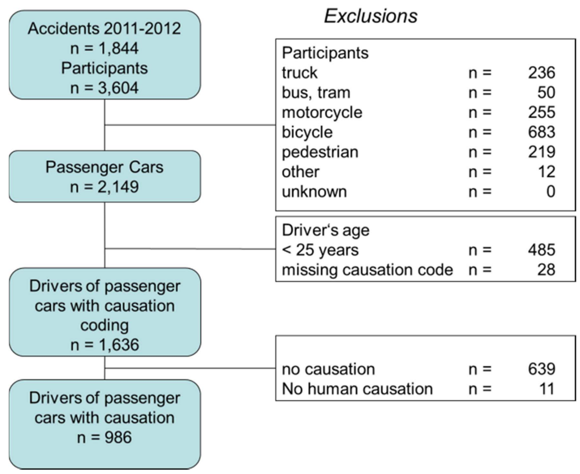


Figure 6: Sample frame for the analysis of accident causes with ACAS in GIDAS.

According to the sample frame (figure 6) the GIDAS dataset provided 1,844 injury accidents with 3,604 participants. The causation coding of these accidents lead to n=817 non-elderly car drivers (aged 25-64) involved in an accident with failures of one of the five human causation categories and to n=169 elderly car drivers aged 65 and over (total of 986 for both age groups). The distribution of car drivers in an accident according to their causation factors (Figure 7) shows different frequencies for elderly car drivers and for non-elderly car drivers.

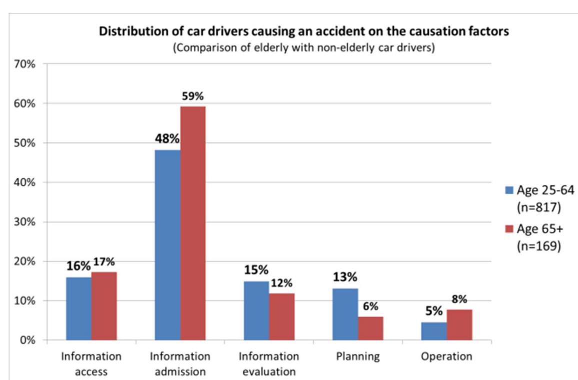


Figure 7: Distribution of car drivers in an accident according to the causation factors.

Even though the amount of cases makes it difficult to conduct a thorough in-depth statistical analysis, tendencies can well be identified: 17 % of the elderly car drivers which have contributed to the emergence of an accident were identified to have had a failure from the category of “Information access”. The frequency in this category is fairly the same as with the experienced drivers with 16%. Elderly car drivers however seem to have more problems with the information admission (59% were assigned with a code of this category while only 48% of the younger drivers were coded with a failure from this category). The following three categories of human failures (Information evaluation, Planning, Operation) in general are less frequent for car drivers. Here the elderly car drivers had fewer failures in the categories “Information evaluation” and “Planning” than the experienced car drivers while “Operation”-failures were more frequently found among the elderly car drivers than among the experienced car drivers.

To explain the different frequencies of the human failure categories between the two age groups the causation information was analyzed on the more detailed level of the subcategories (criteria). Figure 8 shows the distribution of the criteria in category 1 (Information access).

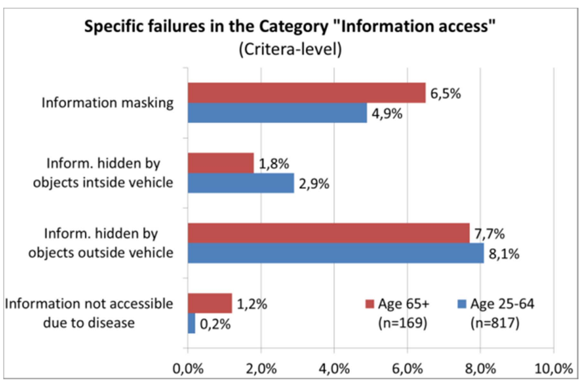


Figure 8: Frequencies of specific failures (criteria) in the human failure category 1 (Information access) comparing the two groups of elderly and non-elderly car drivers.

Category 1 consists of 4 different criteria which are subcategories of “information access”-failures and thus allow analyzing failures from this category in more detail. Even though both age groups (elderly and non-elderly but experienced car drivers) nearly equally often had failures in the “Information access” the specific criteria of this category shows that “information masking” (6,5%) and “Information not accessible due to disease” (e.g. poor eye sight) with 1,2% are more frequent with elderly car drivers than with the experienced car drivers (4,9% respectively 0,2%).

The fact that elderly car drivers more often have failures in the category of information admission becomes clear when looking at the criteria in this category (see Figure 9). Except for the “distraction from inside the vehicle” all other criteria are more frequent in the group of elderly car drivers. This is especially visible in the criteria of “Activation too low”. Here symptoms of illnesses or blackouts which lead to perception problems in combination with a higher fatigability show their effect as they are more common with older people. This finding is congruent with studies found in literature (e.g.[8]) where the symptoms of age related diseases and their impact on the ability to drive a vehicle in traffic are well described. In this scope it has to be kept in mind that the use of alcohol which is also found in this criterion is not a factor which is more commonly found with elderly car drivers (see also Figure 2).

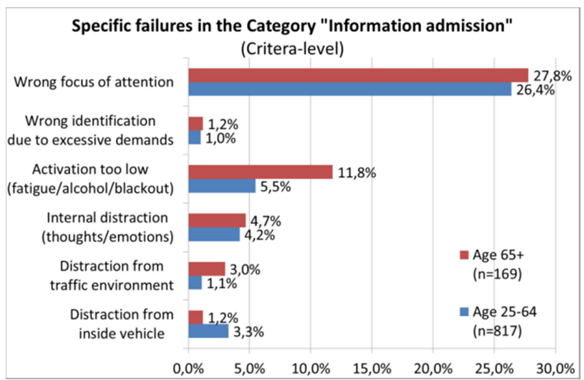


Figure 9: Frequencies of specific failures (criteria) in the human failure category 2 (Information admission) comparing the two groups of elderly and non-elderly car drivers.

The three specific criteria of the category „Information evaluation“ which are based on failures due to a misjudgement or a wrong expectation are less frequently found in the group of elderly car drivers (Figure 10). This explains why elderly car drivers in general have fewer problems with the information evaluation than the group of experienced car drivers where none the less a portion of young drivers with less experience can still be found. Especially failures relating to the misjudgement of the behaviour of the own vehicle are well underrepresented in the group of the elderly (2,4% of drivers that contributed to an accident) when comparing to the non-elderly (4,9% of drivers). If the elderly traffic participants have recorded all the necessary information for accomplishing the driving task they are able to use this information better in the sense of the information evaluation (judgement/interpretation) because the elderly often have more driving-experience and driving–routine and are often more cautious than younger people.

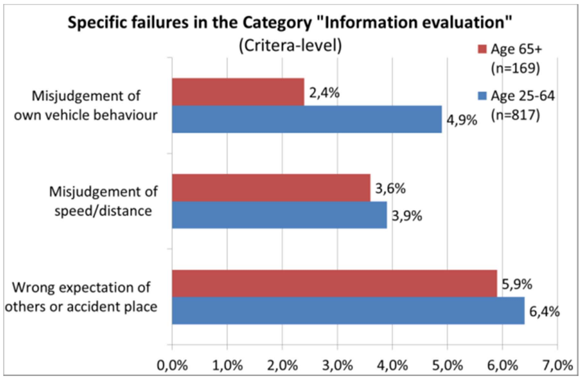


Figure 10: Frequencies of specific failures (criteria) in the human failure category 3 (Information evaluation) comparing the two groups of elderly and non-elderly car drivers.

While 13% of the experienced car drivers had failures from the category of making an adequate plan in a traffic situation (category 4) - based on the recorded and subsequently evaluated information – only 6% of the elderly car drivers were found to have had failures in this category. The criteria of this category are “intentional breach of rules” and “decision errors” based on a correct interpretation/evaluation of the situation. Figure 11 displays that elderly car drivers have noticeably less often intentionally breached the traffic rules (e.g. by speeding, too little distance to vehicle ahead, irregular use of roadway etc.) than the non-elderly car drivers: while 8,6% of the experienced car drivers were attributed with a causation code from this criteria only 3 % of the elderly car drivers had failures based on this aspect. The reason why the elderly car drivers obey traffic rules more than younger drivers is that in general older citizens have a higher need for security, and thus have a risk-reduced driving style with less deliberate violations. Furthermore due to the distinct routine and experience of the elderly car drivers in traffic the ability to appropriately plan action steps increases which has the effect that elderly car drivers commit slightly fewer decision errors (3,6% of the drivers) than the non-elderly drivers (4,7% of the drivers) such as an inappropriate maneuver.

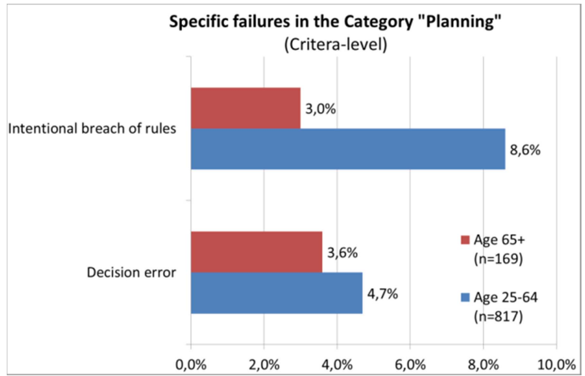


Figure 11: Frequencies of specific failures (criteria) in the human failure category 4 (Planning) comparing the two groups of elderly and non-elderly car drivers

When it comes to executing the planned action again a higher percentage of elderly car drivers had failures in both of the criteria of the “operation”- category than the younger car drivers (Figure 12). On the one hand the decision time during the planning phase for older traffic participants is extended, which leads to the fact that with increased time pressure a false reaction or no reaction at all is conducted (Reaction error: 4,7% of the elderly; 3,7% of the non-elderly).

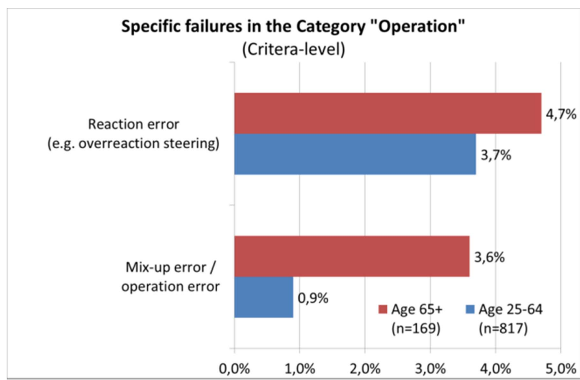


Figure 12: Frequencies of specific failures (criteria) in the human failure category 5 (operation/action) comparing the two groups of elderly and non-elderly car drivers.

On the other hand difficulties with the execution of an operation due to restricted mobility can also be seen as a result of age related diseases. Particular diseases (dementia, degenerative diseases) [9] likewise have a disruptive impact on human action programs, which could be the explanation why “mix-up” and operation errors such as confusing the brake pedal with the accelerator pedal are more frequently found among the elderly car drivers (3,6%) than among the non-elderly (0,9%).

To benefit from the analysis of the causation information especially in the sense of accident prevention the knowledge of the accident severity as a function of the human causation category is of significant importance.

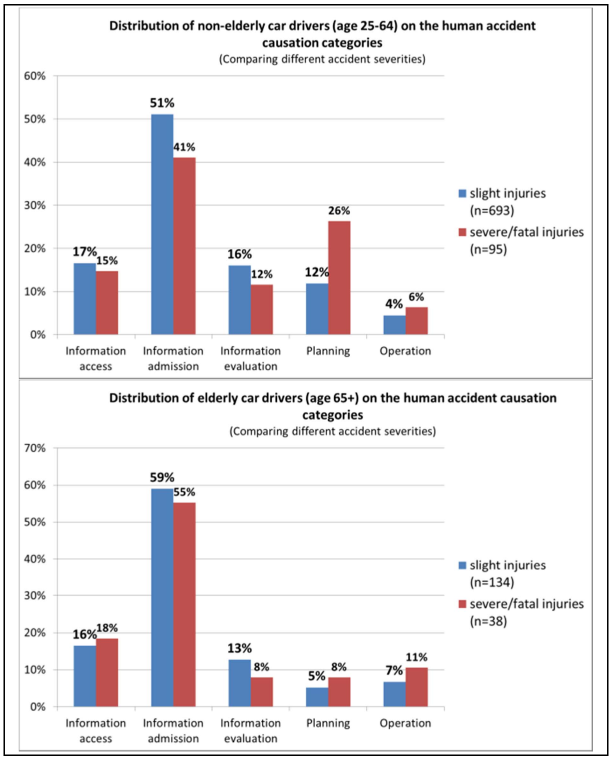
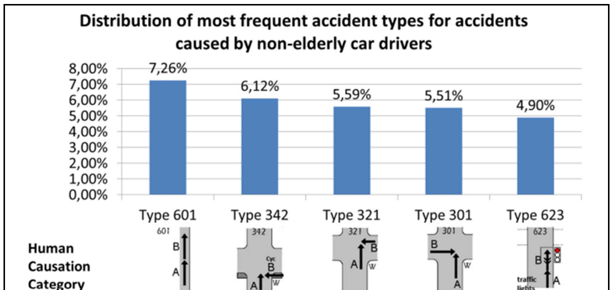


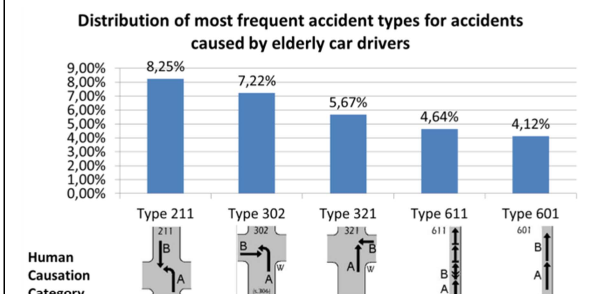
Figure 13: Distribution of human causation categories for different accident severities (maximum injury severity), comparing non-elderly car drivers with elderly car drivers.

The distribution of slight-injury-accidents on the human causation categories compared to the distribution of severe-injury-accidents (including fatal accidents) shows an evident variation for both age groups (figure 13). For the non-elderly car drivers 51% of the slight-injury accidents were caused by an "Information admission" problem while only 41% of the severe/fatal accidents came from this category. Also more slight-injury accidents than severe-injury accidents were caused by "Information evaluation" problems. This ratio however reverses for the causation categories "Planning" of an action and executing the planned action ("Operation"). Accidents caused by these categories provide considerably higher shares to the severe injury accidents than to the slight injury accidents. Thus even though accidents caused by failures from the category of "Planning" and "Operation" occur less often, than accidents caused by "information admission" failures, their injury outcome is more severe. For the group of the elderly car drivers the balance between slight-injury accidents and severe-injury-accidents are equally distributed as with the non-elderly. However the deviation between the two distributions is not as big as with the younger control group.

Analyzing the GDV-accident-type is an appropriate method to describe differences in the accident events of certain age groups. The accident type is classified by the initial conflict situation which led to the crash. There are 7 main categories of accident types (driving accidents, Turning-off accidents, Crossing accidents, Pedestrian accidents, accidents with parked vehicles, accidents in lateral traffic and "other" accidents) which are further specified by nearly 300 subtypes in those categories.



Human Causation Category	Type 601	Type 342	Type 321	Type 301	Type 623
Info. access	4%	19%	7%	22%	6%
Info. admiss.	75%	86%	48%	65%	35%
Evaluation	14%	8%	22%	22%	41%
Planning	14%	0%	26%	17%	12%
Operation	7%	0%	0%	0%	12%



Human Causation Category	Type 211	Type 302	Type 321	Type 611	Type 601
Info. access	27%	50%	17%	0%	0%
Info. admiss.	73%	60%	83%	33%	75%
Evaluation	18%	0%	0%	0%	25%
Planning	0%	0%	0%	67%	0%
Operation	0%	0%	0%	33%	25%

Figure 14: Accident types of accidents with non-elderly and elderly car drivers crossed with the categories of human causation factors.

The 5 most frequent accident types of non-elderly and elderly car drivers are displayed in figure 14.

Accidents with elderly car drivers are often based on a conflict between a vehicle turning to the left and oncoming traffic (Type 211: 8,25%) or traffic from the left (Type 302: 7.22%) Both types of accidents are mainly caused by information admission errors (73% respectively 60%) and also have a fair amount of errors from the "information admission". In contrast the causes of accidents with vehicles in front which are braking (Type 611) or driving (Type 601) also seem to have a high emphasis on the failure categories "Planning" (67% respectively 0%) and "Operation" (33% respectively 25%). The non-elderly car drivers have a slightly different distribution of accident types than the elderly: The most frequent type is the conflict with a vehicle driving in front (Type 601: 72,6%) followed by crossing accidents (Types 342, 321, 301). With the exception of the accidents with bicyclists coming from the right (Type 342) a fairly high amount of causes from the categories "Evaluation" and "Planning" can be observed here.

CONCLUSIONS

The analysis and evaluation of accident causation data is a necessary step to prevent more accidents from happening. The knowledge about the human failures is an essential part e.g. for the development of driver assistance systems. One of the European methodologies to collect accident causation data is the accident causation analysis System ACAS which is used in Germany in the framework of the GIDAS accident data collection. This study gives an example of the causation analysis with ACAS in the context of reflecting differences of causation factors comparing younger and older car drivers involved in accidents. This is done by focusing on the human factors (human failures) and analyzing these along the ACAS-classification scheme of five categories of basic human functions that were effective when coping with the driving task.

An overview over the situation of elderly car drivers in accidents using the typically available accident data from the national statistics and also from the GIDAS in-depth data is well suitable to identify the responsibility for the accident and breach of rules in the judicial sense. The German national statistics data for example shows that the elderly have higher frequencies of certain violations of traffic rules than non-elderly car drivers and the analysis of the GIDAS data additionally shows that elderly car drivers are more often solely or mainly responsible for the accident occurrence than non-elderly car drivers. However distinct human failures in the phase of the accident emergence which led to the violation of rules (why did the violation occur?) cannot be identified with these data.

For the assessment of the human accident causes with ACAS some 817 non-elderly car drivers (age 25-64) and 169 elderly car drivers (age 65+) from the GIDAS database which had contributed to the emergence of an injury accident were used. The causation factors collected for these two age groups were analyzed concerning the main failure categories of human failures and for more detail concerning the subcategories (criteria) of these main categories. The non-elderly car drivers had more failures from the categories of the information evaluation (Misjudgment of a situation) and the planning of an appropriate action (e.g. intentional breach of rules). In contrast to this the elderly car drivers more frequently had problems with the admission of the necessary information (perception) in a traffic situation and with the operation of the vehicle. Relevant information often was not perceived by elderly car drivers due to the symptoms of age relate diseases and difficulties with the execution of an operation due to restricted mobility was found to be more frequent with elderly car drivers.

The results of the causation analysis display that with elderly traffic participants the human failures are mostly about perception problems and difficulties with the execution of a desired action. To cope with these constraints the conditions of perception must be simplified (e.g. at the level of transport planning) and the complexity of infrastructure and vehicle technology must be reduced. The study also revealed that the causation category of an accident has an influence on the accident severity (injury-outcome) this is an important factor which has to be kept in mind when looking for countermeasures to decrease severe injuries or fatalities.

This study has shown that ACAS is an appropriate tool to collect and to deliver relevant accident causation data. The findings from real world accidents are consistent with statements found in literature on the constraints of elderly traffic participants and the background of their typical causes of accidents. With larger case numbers in the future research questions concerning the causes of accidents can be answered in more detail and with more statistical certainty.

ACKNOWLEDGEMENT

GIDAS collects records and processes data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and their causation. The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the participants of the project.

Further information on GIDAS can be found at http://www.gidas.org

REFERENCES

[1] Otte, D. (2009): A new approach of accident causation analysis by seven steps ACASS, ESV-Conference, Paper Number 09-0245

[2] Statistisches Bundesamt: 11. Koordinierte Bevölkerungsvorausberechnung. Annahmen und Ergebnisse, Wiesbaden 2006, S. 28

[3] Kubitzki, J. & Janitzek, T. (2009). Sicherheit und Mobilität älterer Verkehrsteilnehmer. München-Ismaning: Allianz Zentrum für Technik (ATZ)

[4] Rompe, K. (2012). Unfallrisiken der Senioren am Steuer und Möglichkeiten zur Reduzierung durch intelligente Fahrzeugtechnik. Zeitschrift für Verkehrssicherheit, 58, 129 – 134.

[5] Statistisches Bundesamt: Unfälle von Senioren im Straßenverkehr, Wiesbaden 2012

[6] Seeck, A., Gail, J., Sferco, R., Otte, D., Hannawald, L., Zwipp, H., Bakker, J. (2009): Development of the accident investigation and data handling methodology in the GIDAS project, ESV-Conference, Paper Number 09-0282

[7] Jänsch, M., Otte, D., Pund, B., Chiellino, U., Hoppe, M. (2009): Implementation of ACASS – Accident Causation Analysis with Seven Steps – in In-Depth Accident Study GIDAS. In: Reports on the ESAR-Conference on 5th/6th September 2008 at Hannover Medical School, Berichte der Bundesanstalt für Straßenwesen, Heft F 72

[8] Wagner, H.J. (1994): Arzneimittel- und Drogenuntersuchungen bei auffällig gewordenen älteren Kraftfahrern. In: ADAC (Hg.)(1995): Ältere Menschen im Straßenverkehr. Bericht über das 9. Symposium Verkehrsmedizin des ADAC, München, S. 102-107

[9] Schlag, B. (Hrsg.) (2008). Leistungsfähigkeit und Mobilität im Alter. Schriftenreihe Mobilität und Alter der Eugen-Otto-Butz-Stiftung, Band 03. Köln: TÜV-Media Verlag