COMPARISON OF TWO EYE-GAZE BASED REAL-TIME DRIVER DISTRACTION DETECTION ALGORITHMS IN A SMALL-SCALE FIELD OPERATIONAL TEST

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Summary: Driver distraction is a field which has received increasing attention in the last years, especially after it became evident that distraction is a major factor contributing to road casualties. Monitoring, detecting and limiting driver distraction could contribute significantly to improve road traffic safety. With the introduction of novel unobtrusive gaze-tracking systems real-time algorithms based on the driver's gaze direction can be developed for driver distraction warning systems. The study describes and compares two different algorithms for gaze-based driver distraction detection based on the eye tracking data obtained in a field study. One algorithm relies on the metric "percent road centre" of gaze direction, the other on gaze zones in the vehicle. Results show that both algorithms have potential for detecting driver distraction, but that no effect of the distraction warnings on attention as defined by the algorithms could be observed.

INTRODUCTION

Driver distraction is a field which has received increasing attention in the last years, especially after it became evident that distraction is a major factor contributing to road casualties (Dingus et al., 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). In recent years new technology has emerged both for driver support and infotainment. Many of those functions require the driver's visual attention. This fact, together with technical advances in the area of remote and unobtrusive eye trackers has led to the development of a number of glance based algorithms that are meant to detect driver distraction and issue a distraction warning in real time (e. g. Almén, 2003; Donmez, Boyle & Lee, 2007; Holmström & Johansson, 2003; Karlsson, 2005; Victor, 2005).

As machine based real-time gaze tracking is a relatively new asset, not many well established gaze direction based performance indicators exist. Percent Road Centre (PRC) is one such indicator that has been used in several studies (Rydström, 2007; Victor, 2005; Victor, Harbluk, & Engström, 2005). It was introduced by Victor (Victor, 2005; Victor, Harbluk, & Engström, 2005), and is defined as the percentage of gaze data points labelled as fixations that fall within the road centre area. The road centre area is a circle with a radius of 8°, centred around the driver's most frequent gaze angle, although in some cases for the distraction detection algorithm a circle with a radius of 10° was used. It is computed based on fixations, but it has been stated that a computation based on raw gaze data should yield similar results (ibid.).

Several studies have shown that PRC and other gaze distribution based performance indicators were sensitive to both visual secondary tasks, which led to a decreased gaze focus on the road centre, and auditory secondary tasks, which led to an increased gaze focus on the road centre

(Engström, Johansson & Östlund, 2005; Recarte & Nunes, 2000; Rydström, 2007; Victor, 2005; Victor, Harbluk, & Engström, 2005). In an on-road study reported by Victor, Harbluk and Engström (2005) the average PRC per minute was about 70 to 80 % for baseline driving, while Rydström (2007) obtained PRC values of over 90 % for baseline driving in a simulator study.

In Victor's research a distraction detection algorithm was developed, which was based on a combination of PRC value computed with a 10°-radius and single glance duration. A PRC of more than 92 % was considered to be indicative of gaze concentration resulting from cognitive distraction. When the PRC decreased below 58 %, computed over one minute, a visual distraction warning was issued. Fixations were used for the computation of PRC.

A further distraction detection algorithm called AttenD was evaluated in the study presented here. It is based on a 3D world model dividing the car into different zones like the windshield, the speedometer, the mirrors, the dashboard, etc., and on the time the driver spends glancing at those zones. A time based "attention buffer" with a maximum value of two seconds is decremented over time when the driver looks away from the "field relevant for driving" (FRD), which consists of the intersection between a circle of a visual angle of 90° and the vehicle windows, excluding the area of the mirrors. When the driver's glance is inside the FRD, the buffer is incremented until the maximum value is reached. One-second latencies for decrementing are built in for the mirrors and the speedometer. There is also a delay of 0.1 seconds before increasing the buffer again after it has been decreased, in order to compensate for focal adaptation and an "adaptation of the mind" to the road scene and away from the secondary task that has been attended. When no eye tracking but only head tracking is available, a simplified algorithm based on "nose direction" only is employed: If the driver's nose is directed at a point within a circle of 90° forward but excluding the area below 22.5° downward, the driver is assumed to be attentive. The algorithm is described in detail in Kircher, Kircher and Claezon (in press).

When the buffer reaches zero the driver is considered to be distracted, and when further conditions are met (direction indicator not activated, speed above 50 km/h, no brake activation, no extreme steering manoeuvres), which are described in detail in Kircher, Kircher and Claezon (in press), a warning is issued. When the buffer lies between 1.8 s and 2.0 s, the driver is considered to be fully attentive. For the AttenD algorithm single gaze cases instead of fixations were used, because the algorithms were less computational intensive without considering fixations.

Here PRC and the AttenD algorithm were analysed and compared in relation to the warnings given by AttenD. Neither PRC nor the algorithm presented here are established enough to be given a "ground truth" status for distraction, therefore only their relationship was investigated.

The following hypotheses were investigated:

1. Drivers that are classified as fully attentive by AttenD have higher PRC values than drivers that are considered to be distracted.
2. The PRC value is lowest at the moment the AttenD attention buffer reaches zero.

3. After an inattention event both the PRC value and the attention buffer increase, and they increase faster after a warning than in the baseline condition when no warning is given.
4. PRC and the AttenD attention buffer are influenced by driving speed.

METHOD

A field study was conducted to evaluate a distraction warning system. The main requirement for participation was high mileage, therefore the goal was to recruit drivers who covered at least 200 km per day. The participants should not be professional drivers, however. Further requirements were that the drivers should be at least 25 years of age, and they should have held their driver's licence for at least seven years. In order to ensure good eye tracking results the participants should not wear eye glasses, they should not apply heavy mascara and should not be bearded.

Seven drivers participated in the study, four men and three women. Their mean age was 42 years (sd = 10.9 years), and on average they had held their driver's licence for 25 years (sd = 10.9 years). One participant did not report his age. During the field study they drove on average 4350 ± 2181 km, and they received on average 564 ± 544 warnings.

The test car was a Saab 9-3 SportCombi Aero from 2007 with a 2.8 litre engine and automatic transmission with six gears. It was provided by SAAB Automobile AB. The car was instrumented with an autonomous data acquisition system which logged CAN data, position and video films of the forward scene and the vehicle cabin. Furthermore, the vehicle was equipped with the non-obtrusive eye tracker SmartEye Pro 4.0 (SmartEye AB, Gothenburg, Sweden). Two cameras observing the driver's face were installed in the vehicle. With a frequency of 42 Hz the system logged eye movements and head movements, which were used by the algorithms determining driver distraction.

The system could provide a warning to the driver via four vibration actuators that were integrated into the driver's seat. When the driver was classified as distracted by the AttenD algorithm, all four actuators started vibrating at the same time. The vibration stopped when the driver looked at the FRD again, or at the latest after two seconds.

Each participant drove a baseline phase during approximately ten days. During this time data were logged, but the distraction warning system operated in silent mode, that is, they were not discernible for the driver, even though they are called "warnings" throughout this paper. After the baseline phase the driver was informed that the vehicle was equipped with a distraction warning system, which was then demonstrated. During the following three weeks the participant drove with the distraction warnings activated. Several questionnaires were filled in during the course of the study.

Data analysis

Initial filtering of the eye movement data was performed in SmartEye Pro 4.0 (SmartEye AB, Gothenburg, Sweden). This filter computed a running average over a 300 ms time window with new time window calculation in case the angle between two gaze vectors was over 10 degrees. Further signal processing steps were conducted with in-house analysis tools developed in

MATLAB 7.2 (The Mathworks Inc, Natick, Mass). Driving sessions with less than three minutes of active driving (i.e. speed > 0 km/h and gaze quality > 0.25) and sessions with a maximum speed of less than 50 km/h were excluded from the analysis.

The PRC performance indicator, based on gaze cases, was used to analyse data from the eye tracking system. The road centre area was defined as a circular area with a radius of 8° centred around the road centre point, determined as the most frequent gaze angle in each driving session. A histogram with 100 x 100 bins, covering 180 degrees of the data in the forward view, was used to calculate the most frequent gaze angle. For each driving session, the road centre point and the corresponding road centre area were redefined to account for changes in the driver's seating position. PRC was calculated in a four seconds wide sliding rectangular window which was incremented in one-second intervals. This resulted in a time trace which allowed monitoring of PRC over time. All four-second segments where less than 80 % of the gaze cases had a quality of more than 0.25 were excluded from the analysis. Further, all gaze cases that were directed towards the centre rear mirror were considered to be outside the road centre area.

The region of interest in this paper was the time interval surrounding the inattention warnings. More specifically, the region of interest started ten seconds before a warning and lasted till ten seconds after the warning. PRC values were calculated for this 20-second time frame and averaged across all available warnings. The data were separated into baseline and treatment data. Furthermore, periods of "full attention" were extracted from both the baseline and the treatment phase. They were based on data segments where the inattention buffer was larger than 1.8 s for at least twenty seconds.

RESULTS

Average PRC time traces and average AttenD attention buffer values were computed around the AttenD warnings across participants for four speed intervals that are representative of different road environments (see Figure 1). For the lower three speed intervals the mean values were based on 160-500 warnings for both the baseline and the treatment phase, while the PRC values for attentive driving were based on more than 400 cases. For the highest speed interval, which was clearly above the speed limit of 110 km/h in Sweden at the time the study was conducted, only between 50 and 120 cases could be found. Many of those stem from one single driver. No inferential statistics were employed, because the number of participants was very small.

In Figure 1 it is shown that the PRC value is higher for drivers with a full attention buffer than for drivers who were classified as distracted according to the AttenD algorithm, as was postulated under Hypothesis 1. The PRC values for attentive drivers are slightly below those reported by Victor (2005) for attentive driving and lie at around 70 %. About 10 seconds before an inattention event was detected by the AttenD algorithm the average PRC value lay with ca. 40 % already clearly below the value obtained in the fully attentive condition. On average, the PRC value had not reached the level of a fully attentive driver 10 seconds after the warning either. Also the average attention buffer curve in Figure 1 indicates that the attention buffer decreased already several seconds before an attention warning was given. In general, both PRC and the AttenD algorithm behaved similarly around the distraction warnings given by the AttenD algorithm.

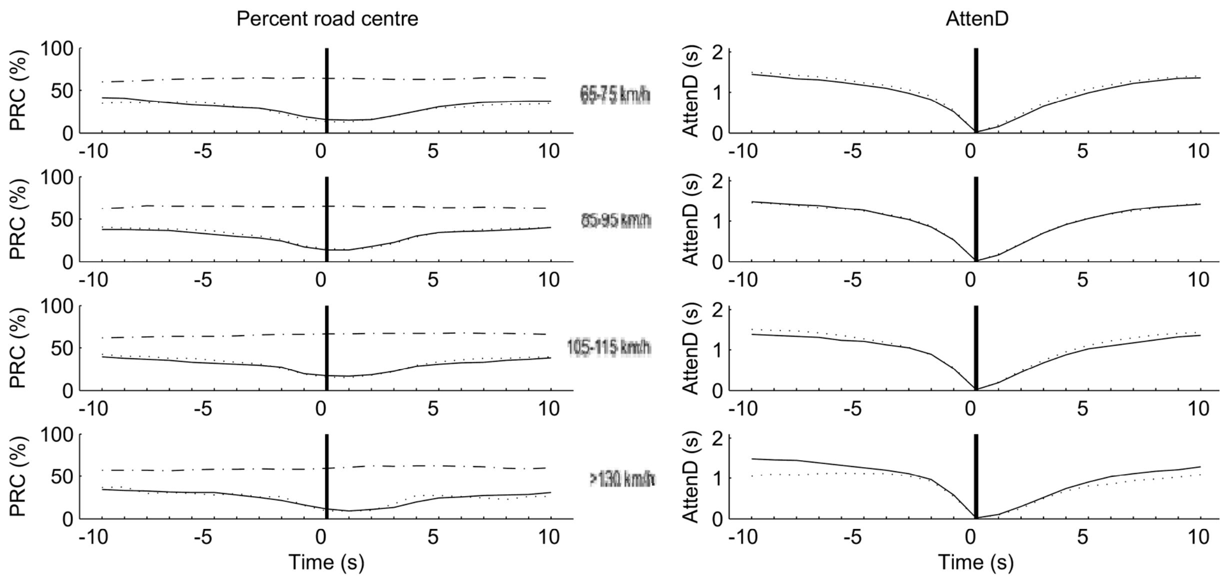

Figure 1. PRC value (left) for cases of full attention (dash-dot line), and around warnings during baseline (solid line) and treatment (dashed line) for four speed intervals; average attention buffer (right) around warnings for baseline (solid line) and treatment (dashed line).

The AttenD algorithm classified a driver as distracted when the attention buffer reached zero. At approximately this time the average PRC value reached its lowest level, where it remained for around one to two seconds, before it increased again, corroborating Hypothesis 2. Both values increased more quickly in the interval up to five seconds after the warning, then the increasing slope became less steep.

The third hypothesis was confirmed only partly. Both the PRC value and the attention buffer increased after an inattention event, with the average PRC value increasing somewhat later than the average attention buffer value. Based on visual inspection, no effect of a warning as compared to baseline could be found for either PRC or AttenD.

Hypothesis 4 postulated that the PRC and AttenD curves would look different for different speed intervals. No strong indication supporting this hypothesis could be found, however. Even though the speed intervals presented here represent very different road environments, the curves look quite similar across speeds. PRC values appear to be somewhat lower at the moment of a warning and afterwards for the highest speed interval.

DISCUSSION

The data from the present study support Victor's (2005) findings that fully attentive drivers have a PRC of about 70 to 80 %. However, Victor used different road centre sizes in different studies, but always based PRC on fixations, while a computation with raw gazes and with a radius of 8° was done here. As shown by Ahlström, Kircher and Kircher (submitted), fixation based PRC values typically lie about 8 % below gaze based PRC values. The time windows for PRC computation was not equal in the different studies, either, which makes comparisons difficult.

The time traces for PRC and AttenD resemble each other around the warnings issued by the AttenD algorithm. The somewhat smoother progression of the PRC trace can be ascribed to the PRC being computed over a time window, which tends to cancel out peaks in traces, whereas the average attention buffer level could be computed for each point in time. This result together with the comparable values for fully attentive drivers indicates that the PRC value and the AttenD algorithm classify glance distribution in a similar way, even though they work differently.

Victor (2005) proposed to classify a driver as distracted when the PRC fell below 58 % computed over 60 seconds. Using such a wide time window does not allow a comparison of the AttenD distraction criterion, which is why in the present study a much shorter time window of only four seconds was used.

Drivers did not concentrate their gaze on the road centre more, or more quickly, after having received a distraction warning. This may have several reasons. The type of warning might not have been appropriate. A vibrating seat might not prompt drivers to look back at the road, and another type of warning might have had a greater effect. Then again, only one aspect of the distraction warning system was evaluated here, which is the drivers' glance variation given the distraction criterion was reached. The warning can very well have effects on other aspects of glance behaviour, and on driving behaviour in general. Other glance behaviour related results from this study are presented in Kircher, Kircher and Ahlström (in press).

The present data indicate that PRC and AttenD based driver distraction algorithms perform in a very similar manner in the different speed groups chosen in the study. Whether the somewhat lower PRC values for the highest speed interval indicate a more active traffic related scanning behaviour or rather reckless behaviour, resulting in a combination of illegal speeds and driver distraction cannot be determined without video analysis, which was not possible to do here due to budget restrictions.

One major problem when studying driver distraction is that no generally accepted ground truth for the concept exists. Hancock, Mouloua and Senders (2008) discuss the inherent difficulties comprehensively. For algorithms like those discussed here it is in principle enough to detect when a driver looks away from the relevant traffic scene long enough to pose a danger. However, even perfect glance detection alone, without any information about the driving scene, would not always allow an unambiguous classification of whether a glance was directed at a traffic relevant or traffic irrelevant target. In order to compare the algorithms for their capability to detect driver distraction, a comparison to manually classified distraction based on gaze direction and information about the surrounding traffic would be the next step. Even with this method it is not necessarily possible to detect cognitive distraction reliably.

Here it was analysed how PRC follows the AttenD algorithm in the vicinity of AttenD generated inattention warnings. It remains to be investigated whether AttenD detects warnings based on PRC, too, and how the two algorithms perform in comparison with further algorithms. With respect to the effect of the distraction warnings it is necessary to investigate whether effects on glance duration, driving behaviour, frequency of inattention events etc. can be found, and how those effects relate to traffic safety. Here, only mean values were analysed, but especially in scenarios where undesirable behaviour like driver distraction occurs, it is recommended to investigate extreme values like the outer percentiles, too. A reduction of extreme glance behaviour might not show in mean values, but still be positive for traffic safety.

To conclude, it can be stated that PRC decreased when AttenD detected that the driver looked away from the FRD for too long. Neither of the algorithms detected an effect of the distraction warning on glance distribution. Speed does not appear to affect the glance distribution to a large extent. Even though speed could be neglected in the presented driver distraction detection algorithms, there seems to be a general trend against "stand-alone" warning systems, and towards system integration and sensor fusion, where a distraction warning system may be part of a range of driver assistance system present in a vehicle.

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