G Model
AAP-4445; No. of Pages 8

ARTICLE IN PRESS

Accident Analysis and Prevention xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Evaluation of methods for the assessment of attention while driving

Katja Kircher[a,b,*], Christer Ahlstrom[a]

[a] The Swedish National Road and Transport Research Institute (VTI), S-58195 Linköping, Sweden
[b] Department of Behavioural Sciences and Learning, Linköping University, Linköping, Sweden

ARTICLE INFO

Article history:
Received 19 August 2016
Received in revised form 9 February 2017
Accepted 14 March 2017
Available online xxx

Keywords:
Minimum required attention
Spare capacity
Driver distraction
Eye tracking
Visual occlusion
Think aloud

ABSTRACT

The ability to assess the current attentional state of the driver is important for many aspects of driving, not least in the field of partial automation for transfer of control between vehicle and driver. Knowledge about the driver's attentional state is also necessary for the assessment of the effects of additional tasks on attention. The objective of this paper is to evaluate different methods that can be used to assess attention, first theoretically, and then empirically in a controlled field study and in the laboratory.

Six driving instructors participated in all experimental conditions of the study, delivering within-subjects data for all tested methods. Additional participants were recruited for some of the conditions. The test route consisted of 14 km of motorway with low to moderate traffic, which was driven three times per participant per condition. The on-road conditions were: baseline, driving with eye tracking and self-paced visual occlusion, and driving while thinking aloud. The laboratory conditions were: Describing how attention should be distributed on a motorway, and thinking aloud while watching a video from the baseline drive.

The results show that visual occlusion, especially in combination with eye tracking, was appropriate for assessing spare capacity. The think aloud protocol was appropriate to gain insight about the driver's actual mental representation of the situation at hand. Expert judgement in the laboratory was not reliable for the assessment of drivers' attentional distribution in traffic. Across all assessment techniques, it is evident that meaningful assessment of attention in a dynamic traffic situation can only be achieved when the infrastructure layout, surrounding road users, and intended manoeuvres are taken into account. This requires advanced instrumentation of the vehicle, and subsequent data reduction, analysis and interpretation are demanding. In conclusion, driver attention assessment in real traffic is a complex task, but a combination of visual occlusion, eye tracking and thinking aloud is a promising combination of methods to come further on the way.

1. Introduction

In many areas of driver behaviour research, it is important to be able to measure driver attention. It is critical to know how well drivers can execute additional tasks, and if certain tasks or interfaces are more distracting than others. In partially automated driving it is essential to be able to assess whether a driver can take over the control of the vehicle or not, as it no longer can be presupposed that the driver is monitoring the traffic.

Assessing the current level of a driver's attentional state requires both a definition of what is meant with "attentive", and the tools to measure the driver's state. Both are still a matter of debate. While numerous definitions of "driver distraction" and "driver inattention" have been published over the years, no consensus has been reached, and many of the published definitions contain contradictions, inconsistencies and construct validity issues (Kircher and Ahlstrom, 2016; Young, 2012a,b). Also, most of those definitions do not lend themselves to operationalisation, partly because many of them are not hindsight-free. This may be the reason why real-time driver distraction detection algorithms (for reviews see Ahlstrom and Kircher, 2010; Lee et al., 2013) are not based on the definitions found in the literature. Instead, those algorithms are all based on glance behaviour, and distraction is assumed to occur, when the driver has glanced away from the forward roadway for a certain period of time, either continuously or with consecutive glances.

While eye movements and attention are linked to each other (Itti and Koch, 2000; Theeuwes et al., 1998), there is more to attention than where a person directs his or her gaze at a particular moment.

* Corresponding author at: The Swedish National Road and Transport Research Institute (VTI), S-58195 Linköping, Sweden.
E-mail addresses: katja.kircher@vti.se (K. Kircher), christer.ahlstrom@vti.se (C. Ahlstrom).

http://dx.doi.org/10.1016/j.aap.2017.03.013
0001-4575/

Being attentive means to have a workable mental representation of the situation, including a plan for where to acquire new information next and what to do (Boer et al., 1998; Endsley, 1995; Gibson and Crooks, 1938; Johnson-Laird, 1986). Therefore, we propose to strive for a theory-based definition of driver attention, which can be operationalised with an empirical assessment, instead of working with various definitions of driver distraction, which are typically not operationalisable, and distraction detection algorithms, which are not linked to the definitions.

The theory of Minimum Required Attention (MiRA; Kircher and Ahlstrom, 2016) postulates that a driver is attentive, when he or she fulfils the minimum attentional requirements in any given traffic situation. These requirements depend on the infrastructure, the surrounding traffic, and other situational variables, including the level of automation of the vehicle. Depending on the situation, the requirements on the driver can range from very simple to highly complex. In a highly automated vehicle, it may be enough that the driver is able to perceive a signal from the vehicle that it will hand over control. When navigating a multi-lane intersection in a manual vehicle, the driver is required to keep track of who has right of way, monitor road users whose trajectories may intersect the own, understand where and when to turn, operate the turn indicators, and keep an adequate speed. In order to assess, whether the driver fulfils the current attentional requirements, it is necessary to keep track of both the requirements in the situation and the driver's state in relation to them. As illustrated in the example with the highly automated vehicle, it may not be enough to monitor visual attention alone, as the signal emitted by the vehicle may be auditory or tactile.

Different aspects of driver attention and distraction have been estimated by employing techniques such as visual occlusion, eye tracking, expert knowledge, and verbal protocols. So far, however, there has been no systematic overview and evaluation of those methods in how well they are able to access attention, and how they could be fused for a better overall picture.

The purpose of the current paper is to investigate several methods for their possible contribution in monitoring driver state with the goal to assess driver attention, assessing their strengths and weaknesses with respect to different aspects of the construct "driver attention". The study has a pilot-like character, investigating how methods can be combined, how robust they are, and how feasible they are for the assessment of the minimum required attention in a particular situation.

1.1. Driver attention assessment techniques

Visual occlusion while driving can be used to assess the driver's visual spare capacity. In visual occlusion, the participant wears eye glasses that can be rendered transparent or opaque, for example using liquid crystal shutters or mechanical shutters. Either the experimenter or the participant can control the opening/closing of the shutter, and the duration of the opened/closed sequences can be fixed or variable. The occlusion technique has been used in real traffic to assess the visual demands and visual spare capacity in different traffic environments (Senders et al., 1967), to simulate glances to traffic in a parked car to evaluate in-car technology (Baumann et al., 2004; Gelau and Krems, 2004), to simulate distraction while driving on a closed course (Brown, 2005), and to assess the influence of a secondary task in driving situations of varying complexity in a simulator (Tsimhoni, 2003).

Within attention and distraction research, *eye tracking* is used to measure foveal vision direction. As mentioned previously, this gives a good estimate of where the driver's attention is directed (Itti and Koch, 2000; Theeuwes et al., 1998). Applications include the investigation of the extent to which a driver glances at a secondary task (Donmez et al., 2006, 2007), differences in visual scanning between experienced and inexperienced drivers (Crundall et al., 2012; Underwood et al., 2002), and to estimate the driver's present attentional level (see Lee et al., 2013 for an evaluation of several algorithms).

Expert knowledge can be used to set up general rules about what a driver should attend to. Examples of such rules include: "having a wide picture", "keep the eyes moving", "scan the entire traffic scene", "look at mirrors and instruments", "centre on a target 12 s ahead" and "employ an orderly visual search pattern" (Zwahlen, 1991). Expert judgements are problematic in the sense that they are affected by the process used to gather the information. They are conditioned on various factors, such as question phrasing, information considered and assumptions (Kirkeboen, 2009). It is therefore up to the analyst to extract tacit knowledge from the thoughts and beliefs of the experts.

A think-aloud *verbal protocol* gives access to information present in the participants' working memory (Ericsson and Fox, 2011; Ericsson and Simon, 1980, 1993). Think-aloud protocols involve participants' verbalising their thoughts as they are performing a set of specified tasks. The drivers are asked to explain whatever they are looking at, thinking, doing, and feeling while driving. It is claimed that verbal reports of working memory tend to be complete, unless the subject is under high cognitive load. Using this method, Hughes and Cole (1986) divided drivers' reports into eight categories, four traffic relevant (road related, traffic control devices, vehicles, people) and four not immediately relevant to traffic (immediate road surroundings, general surroundings, vegetation, advertising).

Other methods, like situation awareness probes (Endsley and Garland, 2000) and dual task performance, have also been used to assess aspects of attention. While the large body of research available has generated much knowledge about the topic at hand, there is still a lack of understanding how much attention is really needed in a given traffic situation, such that a definite judgement can be made about whether a driver is sufficiently attentive or not.

2. Method

Six driving instructors (two female, four male), who are labelled the 'core participants', participated in all conditions of the study. Their mean age was 35 years (std = 7.2 years), with an age range between 27 and 46 years. All participants had several years of experience as driving instructors. They were all very familiar with the route driven. Each of the core participants received 2000 SEK for participation in all conditions. Another six experienced drivers, who were all familiar with the route, participated in the 'car occlusion glasses' condition, see Table 1. Their mean age was 45 years (std = 12.6 years, range 30–64 years). For the expert judgement condition an additional 85 driving instructors and 85 experienced drivers delivered a written description. Twenty-five of the driving instructors also filled in a form showing a schematic forward view, in which they specified how attention should be distributed across different targets in percent, and how much spare attentional capacity they assumed was available. The study was approved by the regional ethics committee in Linköping (Dnr 2014/0177-8.2). The participants signed an informed consent before each driving session.

The test route consisted of a dual-lane motorway section of 14 km in length. Within each condition each participant drove this section three times. The speed limit was 110 km/h on the whole section.

The test vehicle was a Volvo V70 with manual transmission and six gears. It was equipped with a five-camera eye tracker (SmartEye Pro 6.1, Smart Eye AB, Gothenburg, Sweden), a front radar (UMRR Type 29, smart microwave sensors GmbH, Braunschweig,