Applied Ergonomics 68 (2018) 1–11

Contents lists available at ScienceDirect

Applied Ergonomics

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

An analysis of the suitability of a low-cost eye tracker for assessing the cognitive load of drivers

Tomaž Čegovnik*, Kristina Stojmenova, Grega Jakus, Jaka Sodnik

Faculty of Electrical Engineering, University of Ljubljana, Trzaska 25, Ljubljana, Slovenia

ARTICLE INFO

Keywords:
Eye tracking
Pupillometry
Eye Tribe
Driver
Driving simulator
Cognitive load

ABSTRACT

This paper presents a driving simulator study in which we investigated whether the Eye Tribe eye tracker (ET) is capable of assessing changes in the cognitive load of drivers through oculography and pupillometry. In the study, participants were asked to drive a simulated vehicle and simultaneously perform a set of secondary tasks with different cognitive complexity levels. We measured changes in eye properties, such as the pupil size, blink rate and fixation time. We also performed a measurement with a Detection Response Task (DRT) to validate the results and to prove a steady increase of cognitive load with increasing secondary task difficulty. The results showed that the ET precisely recognizes an increasing pupil diameter with increasing secondary task difficulty. In addition, the ET shows increasing blink rates, decreasing fixation time and narrowing of the attention field with increasing secondary task difficulty. The results were validated with the DRT method and the secondary task performance. We conclude that the Eye Tribe ET is a suitable device for assessing a driver's cognitive load.

1. Introduction

Operating a vehicle is a cognitively demanding and responsible task, where the driver's primary task is to focus on the road, the surrounding traffic, to obey traffic rules, and to safely operate a vehicle. Today's vehicles provide an increasing amount of other features such as advanced communication and infotainment systems, and other luxury facilities, which can divert the driver's focus and attention. There are also other non-driving related sources of distraction, such as simple mobile phone conversations or interactions with other passengers. Driver distraction has been shown to be one of the major causes of vehicle accidents (Klauer et al., 2014; Kahn et al., 2015). It is therefore reasonable to research a driver's cognitive load and the available methods for assessing it, in order to find solutions to decrease driver's distraction and, consequently, increase on-road safety.

Cognitive load has been assessed in various ways, mainly with the use of self-evaluating questionnaires, monitoring of psychophysiological activities, and the evaluation of driving and in-vehicle related task performance. Although the self-evaluation questionnaires and self-ratings may appear questionable, studies have demonstrated that people are capable of giving a numerical indication of their perceived load (Paas et al., 2003). Most subjective measures are multidimensional in that they assess groups of associated variables, such as mental effort, fatigue, and frustration, which are all highly correlated (Paas et al., 2003). A commonly used test isthe Rating Scale Mental Effort questionnaire (Zijlstra and Van Doorn, 1985) which is a scale for measuring perceived effort. Nasa Task Load questionnaire (NASA-TLX) (Hart and Staveland, 1988) on the other hand, focuses on perceived mental, physical and temporal demands, user's performance, effort and frustration. An adapted version of NASA TLX adjusted for driving for accessing specifically drivers' efforts – Driving Activity Load Index (DALI) (Pauzié, 2008). For perceived effort the Subjectively experienced effort scale (Eilers et al., 1986) has been used, and other one-dimensional scales (Likert 7 and 9 point scales), which mostly concentrate on cognitive load demands (Paas et al., 2003).

Cognitive load can be assessed indirectly also by measuring the performance of various secondary tasks (performed in addition to driving). The most typical example is the use of a Detection Response Task (DRT), which can be performed simultaneously with any kind of visual-manual or pure cognitive secondary task (ISO, 2016). The DRT is specified by ISO Standard 17488 as a standard for assessing the attentional effects of a driver's cognitive load. In this method, the driver's task is to respond to a stimulus by pressing a button attached to the driver's index finger. The stimuli can be visual or tactile. Visual stimulus can be presented remotely (remote DRT) or can be head-mounted to the driver's head, so it is always in the driver's visual field (head-mounted DRT). For visually demanding secondary tasks, tactile stimulus can be used, in the form of a vibration presented through a small tactor placed on the driver's collarbone. Changes in cognitive load can be assessed from the driver's response time – the longer the response time, the

* Corresponding author. Faculty of Electrical Engineering, University of Ljubljana, Trzaska 25, 1000 Ljubljana, Slovenia.
E-mail addresses: tomaz.cegovnik@fe.uni-lj.si (T. Čegovnik), kristina.stojmenova@fe.uni-lj.si (K. Stojmenova), grega.jakus@fe.uni-lj.si (G. Jakus), jaka.sodnik@fe.uni-lj.si (J. Sodnik).

http://dx.doi.org/10.1016/j.apergo.2017.10.011
Received 29 March 2017; Received in revised form 7 September 2017; Accepted 17 October 2017
0003-6870/

higher the cognitive load – and miss rate (non-detected stimuli for longer than 2500 ms).

On the other hand, changes in cognitive load can also be detected through different psychophysiological measures of drivers. The greatest advantage of these types of measurements is that they allow the continuous collection of data and do not require any kind of response from the driver (self-report or performing an additional task), leaving the driver's attentional and cognitive resources focused only on the observed tasks. Research studies report on monitoring ocular activities (Fakuda et al., 2005; Palinko et al., 2010a,b; Korbach et al., 2017), cardiac functions (Humphrey and Kramer, 1994; Mehler et al., 2011a; Ferreira et al., 2014; Mackersie and Calderon-Moultrie, 2016), electrodermal activity (Shi et al., 2007; Haapalainen et al., 2010; Ferreira et al., 2014) and electrical brain activity (Borghini et al., 2014), among others.

Research indicates that the pupil dilation is a very precise indicator of cognitive activity (Seeber, 2013; Chen et al., 2016, Marquart et al., 2015). Furthermore, the pupil dilation will increase when performing more difficult mental tasks compared to easier tasks. It indicates that the pupil response can be correlated to changes in cognitive load. Therefore, pupillometry has been used for assessing changes in cognitive load in various research fields, including driving and driver's cognitive load. Pupil dilation and other properties of the eye and eye movements can be measured with various eye tracking (ET) devices. The main obstacle to a broader use of ET devices used to be a relatively high cost as well as high complexity of use. However, with a significant drop in prices and availability of some low-cost and simple-to-use ET devices, pupillometry has become more accessible to everybody.

2. Related work

2.1. Observing pupillometry for driver's cognitive load assessment

In a study on assessing driver's cognitive load, Palinko et al. concluded that using a remote tracking device might be reliable for assessing driver's cognitive load, especially in simulators (Palinko et al., 2010a,b). Their results showed high correlation between pupillometric data and driving performance data. Significant differences in pupil sizes for increased cognitive load of drivers was found also in other studies, suggesting that the pupillary response could be an important indicator for estimating cognitive load of drivers (Heeman et al., 2013; Gable et al., 2013).

However, assessing driver's cognitive load by observing eye activity can be challenging, because of the driving environment's characteristics, both on the road and in simulated environments. One specific challenge lies in the changing lightning conditions and the trackers' mounting position. For example, the intensity of illumination of the experimental environment influences the results collected with remote eye-tracking devices. Furthermore, pupils are also very sensitive to light and their diameter decreases with increased luminosity (Palinko and Kun, 2011). Palinko et al., decoupled the effects of light and cognitive load and assessed their impact on the driver's pupil size. Their results showed that it is possible to dissociate those two effect on pupil diameter.

2.2. Using a low-cost eye-tracker for measuring eye activity

Measuring the exact size of the pupil can be difficult due to the varying distances between the eyes and position of the tracker. Changes of the pupil size, on the other hand, can be tracked easily and therefore they suffice to detect different levels of cognitive activity. Studies have shown that even low cost eye-tracking devices can provide reliable results. An evaluation of the low cost Eye Tribe's (THE EYE TRIBE, 2016) suitability and usability for scientific studies as a low-cost and affordable device, showed that it’s accuracy and precision seem to be very good under predefined optimal circumstances (Dalmaijer, 2014). He got this conclusions by comparing it to a professional eye-tracking device – the EyeLink 1000 – and validated its precision and accuracy, pupillometry and fixation. Another study showed that the accuracy and precision of the Eye Tribe is comparable to other similar devices (Ooms et al., 2015). As its accuracy and precision were compared with another well-established and comparable eye-tracker, the SMI RED 250. Eye Tribe's advantage against the SMI RED 250 is that it is easy to transport and set up very quickly, but it has to be used correctly because there are many factors that can affect the recordings.

2.3. Our research contribution

The aim of this study is to assess the suitability of the Eye Tribe – as a low cost ET – for detecting and measuring changes in the cognitive load of drivers. While the majority of the referenced studies focused primarily or solely on the pupillometry as the main indicator of changes in cognitive load, we decided to observe also other ocular activities that could also indicate these changes (i.e. blink rate, fixation time and eye movements). We systematically induced different levels of cognitive load by a delayed digit recall task and performed a reference measurement of changes in cognitive load with the standardized method – Detection Response Task.

The two unique contributions of this study are therefore:

1. The use of the low-cost ET for the holistic assessment of eye activities in order to detect changes in cognitive load
2. Direct comparison of the ET-based method for detecting changes in cognitive load and the standardized DRT method

3. Experiment design

Our study was designed as a within-subject (repeated measures) experiment carried out in a driving simulator. The participants were asked to follow the leading vehicle at a constant safety distance and simultaneously perform a secondary cognitively demanding task. We measured the pupil size, blink rate, eye movement and fixation rate with the ET and also performed a reference DRT measurement.

3.1. Driving simulator

The driving simulation was running on a high performance gaming computer, consisting of an i7-6700K CPU and GeForce GTX 980Ti graphics card. The visual output was a triple-screen combination of three Samsung 48″ curved TV displays using the Nvidia Surround technology, placed at an angle of 70°. The speakers of the central display were used for the audio output. The driver's seat was placed in front of the central screen at a driver's head distance of 140 cm. The steering wheel, consisting of a Fanatec wheel base V2 and a Fanatec Porsche 911 wheel, a -set of three Fanatec ClubSport pedals and an H-pattern Fanatec ClubSport shifter with locked reverse and 7th gear were mounted on the same platform as the driver's seat (see Fig. 1).

The software used was OKTAL SCANeR Driver Training Studio (provided by NERVteh) (NERVTEH, 2016), which provides a highly realistic driving environment including realistic car physics and appropriate feedback. A special scenario was created for this experiment, containing a standard two-lane two-way country road without intersections, surrounding objects and altitude changes. There was an autonomous leading car on the road periodically changing its speed, and random traffic on the opposite lane.

3.2. Tasks

3.2.1. Driving performance

The primary task was to drive safely and follow the leading car at a steady safety distance. The leading car was changing its speed every 20 s to a random velocity between 50 km/h and 90 km/h. The driving