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Deep in thought while driving: An EEG study on drivers' cognitive distraction

Hossam Almahasneh [a,1], Weng-Tink Chooi [b,*], Nidal Kamel [a,2], Aamir Saeed Malik [a,3]

[a] Centre of Intelligent Signal and Imaging Research (CISIR), Department of Electrical & Electronic Engineering, Universiti Teknologi Petronas, 31750 Seri Iskandar, Perak, Malaysia

[b] Universiti Sains Malaysia, Advanced Medical and Dental Institute, Bandar Putra Bertam, 13200 Kepala Batas, Pulau Pinang, Malaysia

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A B S T R A C T

Our research employed the EEG to examine the effects of different cognitive tasks (math and decision making problems) on drivers' cognitive state. Forty-two subjects participated in this study. Two simulated driving sessions, driving with distraction task and driving only, were designed to investigate the impact of a secondary task on EEG responses as well as the driving performance. We found that engaging the driver's cognitively with a secondary task significantly affected his/her driving performance as well as the judgment capability. Moreover, we found that different features of the secondary task had different effects on EEG responses and different localizations in the frontal cortex. Our hemispheric analysis results showed that the most affected area during distracted driving was in the right frontal cortex region; thus, it is suggested that the activation in the right frontal cortex region may be considered the spatial index that indicated a driver who is in a state of cognitive distraction.

1. Introduction

Driving is a complex task that depends on a set of cognitive skills in association with the contributions of planning, memory and motor control and visual capabilities. These capabilities vary from one individual to another depending on the cognitive skills and level of attention (Shinar, 1993).

In past decades, driving distraction is increasingly identified as one of significant causes of traffic accidents and has the same effect on driving performance as drugs and alcohol. In fact, NHTSA estimated that various drivers' distraction sources caused about 20–80% of crashes and near-crashes (Stutts & Association, 2001). More recently, a wide naturalistic driving study of 100 cars found that inattention was a cause in 78% of all crashes and near crashes, thus considering it the largest crash causation factor in their analysis (Dingus et al., 2006).

Driving distraction, generally, is defined as the deviation of driver's attention away from operating safe driving toward a competing activity (Young, Lee, & Regan, 2008). Therefore, the cause of driving distraction could be due to any cognitive

* Corresponding author. Tel.: +60 4 562 2304.
E-mail addresses: hossam.almahasneh@gmail.com (H. Almahasneh), wengtink@amdi.usm.edu.my (W.-T. Chooi), nidalkamel@petronas.com.my (N. Kamel), aamir_saeed@petronas.com.my (A.S. Malik).
[1] Tel.: +60 135174443.
[2] Tel.: +60 5 368 7871.
[3] Tel.: +60 5 368 7693.

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process such as daydreaming, mind wondering, mathematical problem solving or decision making issues in addition to using in-vehicle information systems (IVI's) such as Audio systems, navigation systems and cell phones that may affect driver's attention on driving. When drivers are cognitively distracted, visual information processing becomes lower which markedly impairs driving performance in detecting targets across the entire visual scene (Lee, Lee, & Boyle, 2009; Recarte & Nunes, 2000, 2003). Many studies have investigated the impact of a secondary task on driving performance. These studies have used mobile phone related task (general usage of the mobile phone), conversation with passengers, and other tasks as a secondary task (Brookhuis, de Vries, & de Waard, 1991; Chaparro, Wood, & Carberry, 2004; Crundall, Bains, Chapman, & Underwood, 2005; Lamble, Kauranen, Laakso, & Summala, 1999; Levy, Pashler, & Boer, 2006). The two major types of distraction are visual distraction and cognitive distraction. Visual distraction can be defined as "eyes-off-road", and cognitive distraction as "mind-off-road" (Victor, 2005). Both types of distraction can affect driving performance such as lane variation, steering control, response to hazards, and visual perception efficiency. Moreover, visual and cognitive distraction interacts with each other and can occur in combination. The current study will focus on driver's cognitive distraction.

Cognitive distraction and inattention will be used interchangeably in our context of study. From the general definition both are considered as the decrement of mental concentration to a specific task (Anderson, 2009).

To better understand driver psychological behavior and the sources of driver cognitive distraction, researchers have attempted to develop models that captured brain electrical activity (EEG) (e.g., Dong, Hu, Uchimura, & Murayama, 2011 and Lin, Ko, & Shen, 2009). Such models provide a better understanding of the effects of distraction on driver behavior through capturing changes in EEG activity. Measures of brain electrical activity (EEG) are the most valid measures used for distraction measurement (Lin et al., 2009). EEG has the advantage of high temporal resolution which allows for the ability to perform cognitive studies and instantaneously evaluate the corresponding brain activity. EEG recording is completely non-invasive and can be applied repeatedly to patients, normal adults, and children with no risk or limitation (Teplan, 2002). Galán and Beal (2012) in their study in evaluating whether the EEG could estimate the attention and the cognitive workload in predicting success or failure of math problem solving, suggested that EEG might be a valuable tool for assessing cognitive workload.

Due to the rapid increase of in-vehicle technologies, the psychological changes in drivers are more complex and hard to detect. Therefore, a study by Schier (2000) has described the need of using more advanced technologies to study the rapid changes of the driver cognitive state during driving. The study has investigated the suitability in using EEG-based technologies simultaneously with a driving simulator through the activities in the alpha frequency band (8–13 Hz) between driving and driving-replay sessions. It has been agreed that the alpha band is the most dominant band for studying attention (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Schier, 2000 and Wolfgang, 1999). Dynamic changes in alpha activity corresponding to the changes in driving events have been documented (Schier, 2000). Furthermore, this study concluded a high effectiveness of the exploratory experimental work in demonstrating the practicality of such EEG recordings during simulated driving.

Many studies have investigated the human factor in road crashes. Lee et al. (2009) have investigated the effect of drivers' cognitive load on the relation between internal and external attention control; as reviewed, the cognitive load has a high influence on withdrawing driver attention and decrease the driver's ability in detecting road hazards through a cue-based pedestrian paradigm. He has found that the cognitive load delayed the driver response and reduced his fixation to pedestrians and external cues.

A good index of cognitive distraction that is widely accepted in EEG measurements consists of theta activity (4–8 Hz), alpha activity (8–14 Hz) and Beta activity (14–35 Hz) (Lin, Chen, Ko, & Wang, 2011). Theta and beta activity in brain frontal lobes are associated with cognitive processes such as judgment, problem solving, working memory, decision making and mathematical problem solving (Lin et al., 2011). The increasing amplitudes of these particular bands are often a result of brain engagement in such activities.

The role of attention on EEG activity has been extensively studied. Klimesch et al. (1998) studied induced alpha band power changes in EEG signals and attention through an oddball task. After separating alpha into 3 sub-bands – lower, medium and upper – they found that only the lower alpha reflected the attentional demands. Also from his study on the reflection of cognitive and memory performance on alpha and theta EEG bands (Wolfgang, 1999), he suggested that alpha in different sub bands was highly influenced by attentional and semantic memory processes. One of the most important findings was the increasing in the upper alpha bands desynchronization during the semantic judgment task but there was no response from theta activity. The highest activities of alpha corresponded to the judgment task seen in the prefrontal left hemisphere, and this was supported by findings from a PET study (Endel, Shitu, Craik, Morris, & Sylvain, 1994). An important conclusion was that the increase in theta power and decrease in alpha power indicated poor cognitive and memory performance. On the other hand, the decrease in alpha power indicated high attention to a specific task while increase in theta power indicated distraction (low attention) to a specific task.

As a matter of fact, drivers' cognitive distraction is the most difficult to assess and evaluate among the three types of driver distraction due to the inability of directly observing what is going on in the driver's brain. One possible solution to the problem is to capture changes in driving behavior using objective measures that will also serve as a qualitative assessment associated with cognitive distraction and visual distraction (Angell et al., 2006; Engström, Johansson, & Östlund, 2005). Such objective measures in tracking driving behavior and performance have been widely used to confirm the effects of different types of driving distraction. For example, (Horberry, Anderson, Regan, Triggs, & Brown, 2006) focused on two speed-related variables (mean speed and deviation from the posted speed limit) in measuring driving behavior changes. They reported that