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The effects of driving environment complexity and dual tasking on drivers' mental workload and eye blink behavior

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ABSTRACT

The goal of the present study was to assess the effectiveness of eye blink behavior in measuring drivers' mental workload. Previous research has shown that when mental workload increases with the primary task difficulty, blink frequency drops. On the opposite, the number of blinks increases when a cognitive secondary task has to be performed concurrently. However, the combined effects of the primary task difficulty and dual-tasking on blink rate have not been investigated. The present study was thus designed to vary systematically both the primary driving task and the cognitive secondary task demand to examine their combined effects on blink rate. The driving task was manipulated by varying the complexity of a simulated driving environment. The cognitive load was manipulated using a concurrent simple reaction time task or a complex calculation task. The results confirmed that eye blink frequency was a sensitive measure to elicit increased mental workload level coming from the driving environment. They also confirmed that blink rate increased with the introduction of a cognitive secondary task while blink duration was not affected. However, eye blink behavior did not provide a clear mental workload signature when driving task demands and dual-task conditions were varied simultaneously. The overall picture goes against the suitability of eye blink behavior to monitor drivers' states at least when external and internal demands interact.

1. Introduction

Driving a vehicle imposes perceiving, identifying and anticipating road elements and other road users' behavior while maintaining an appropriate control of steering and speed. Drivers have then to pay and shift attention to multiple task-relevant objects and to process a large amount of visual and spatial information in a highly dynamic situation. However, allocation of attention and information processing may be impaired by mental workload level (Brookhuis & de Waard, 2010), which could lead to errors or degraded control of the vehicle. For example, data from the naturalistic 100-car study showed that lapses of attention were the first contributing factor to crashes (Dingus et al., 2006; Klauer, Dingus, Neale, Sudweeks, &

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Ramsey, 2006). This study noted that 78% of accidents and 65% of near crashes were associated with driver inattention, with the majority due to secondary task.

Mental workload refers to "the portion of operator information processing capacity or resources that is actually required to meet system demands" (Eggemeier, Wilson, Kramer, & Damos, 1991, p. 207). Mental workload can thus be seen as the result of the interaction between task demands and the attentional resources capacity of the operator (Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2014; O'Donnell & Eggemeier, 1986; Recarte, Pérez, Conchillo, & Nunes, 2008; Teh, Jamson, Carsten, & Jamson, 2014). Operator's capability depends on intrinsic factors such as age and experience and temporary states due to drowsiness or drug consumption (e.g., Cantin, Lavallière, Simoneau, & Teasdale, 2009; Cuenen et al., 2015; Patten, Kircher, Östlund, Nilsson, & Svenson, 2006). Task demand is also multifaceted. It can be categorized between external demands (i.e., coming from the road environment) and demands coming from inside the vehicle (i.e., phoning or interacting with driving assistance or in-vehicle information systems).

Following Patten, Kircher, Östlund, and Nilsson (2004), Patten et al. (2006), external demand of the driving task depends on the level of requirements placed upon information processing and/or vehicle handling. Traffic density (e.g., Brookhuis, de Vries, & de Waard, 1991; Hao et al., 2007; Teh et al., 2014) and type of maneuver (e.g., Cantin et al., 2009; Hancock, Wulf, Thom, & Fassnacht, 1990) are factors that act upon both information processing and vehicle handling and have been highlighted as affecting the level of drivers' mental workload. Complexity of the driving environment, on which the present study is focused, also affects drivers' mental workload.

Some studies dealing with the effects of driving environment complexity on task demands have used a peripheral detection task (PDT) as a secondary subsidiary task requiring simple manual responses to visual stimuli, to measure drivers' mental workload level. Törnros and Bolling (2006) examined the effects of rural and urban environments of varying speeds and complexities on drivers' workload. Results showed that urban driving tapped more on attentional resources than rural driving as reaction times to the secondary subsidiary task were longer in the former environment. Similar results were found by Patten et al. (2006) who examined in a field study the effects of route complexity. Depending on the demands placed upon information processing and/or vehicle handling, route was classified as being of high (e.g., driving in city centre environments), medium (e.g., negotiating regulated intersections) or low complexity (e.g., driving freely in urban, rural or motorway environments). Results revealed an upward trend in the reaction times to the subsidiary task with increasing route complexity (for similar effects of the complexity of the driving environment on drivers' mental workload, see Ariën et al., 2013; Jahn, Oehme, Krems, & Gelau, 2005, or Verwey, 2000).

Young et al. (2009) examined the effects of road type (i.e., urban, rural and motorway environments) on driving performance, subjective workload measure and visual behavior. Road type was shown to affect the number of lane excursions and the time spent out of the lane but not self-rated scores of mental workload. Compared to the urban condition which was used as an arbitrary reference, lateral control was more stable in the motorway condition but it was degraded in the rural environment. In addition, fewer fixations were directed outside the road in the rural driving environment when compared to the motorway and urban driving environments, suggesting increased task demands in the former environment. Similar visual behavior was found by Victor, Harbluk, and Engström (2005), as driving rural curved roads exhibited higher proportion of fixations on the road centre than rural straight roads or motorway. In a car following situation, Jamson and Merat (2005) examined the effects of varying the driving task demands on longitudinal and lateral control of the vehicle by comparing straight and curved sections of road. When driving on a winding road section, mean speed was slower, lane position was more variable and the number of steering wheel corrections increased, which suggest a higher level of drivers' workload. On the opposite, de Waard, Jessurun, Steyvers, Raggatt, and Brookhuis (1995) compared two different roadside environments (curved road in woodland area vs. straight road in moorland area) but no significant effects on driving performance or physiological mental load measures were found.

Previous research dealing with the effects of driving environment on mental workload and driving behavior has shown contrasting results regarding the effects of rural and urban driving environment. This could come from the large variety in the complexity of driving environments. It could otherwise come from the large range of mental workload measures that have been used.

Although convergence between different mental workload measures has been shown on some occasions (e.g., Benedetto et al., 2014; Recarte et al., 2008), performance and subjective measures are not always reliable indexes of workload (e.g., Yeh & Wickens, 1988; see also Hao et al., 2007; Young et al., 2009). Measuring drivers' workload objectively and reliably is an important issue for the monitoring of drivers' attentional states (e.g., Tsai et al., 2007) or the evaluation of in-vehicle users interfaces (e.g., Solovey, Zec, Garcia Perez, Reimer, & Mehler, 2014). Among the physiological measures available, several indices have been shown to be sensitive to mental workload variations. O'Donnell and Eggemeier (1986) reported that the most frequently used variables are heart rate (e.g., Di Domenico & Nussbaum, 2011), EEG signals (e.g., Baldwin & Coyne, 2003; Borghini et al., 2014; Savage, Potter, & Tatler, 2013) and eye activity measures (e.g., Konstantopoulos, Chapman, & Crundall, 2010; Lehtonen, Lappi, & Summala, 2012). Of all the eye-related measures, eye blinking has the potential to provide a useful and reliable signature of drivers' mental workload variations (Savage et al., 2013). Such potential is based on the unobtrusive nature of this measure as eye blinks are not guided by top-down or bottom-up scene exploration processes, as is the case with fixations (e.g., Tatler, Hayhoe, Land, & Ballard, 2011), nor are they affected by light conditions, as is the case when measuring pupil diameter (e.g., Pedrotti et al., 2014). In addition, they do not interfere with the primary driving task. However, previous research showed that mental workload increase has contrasting effects on blink frequency depending on whether it comes from the primary task difficulty or from the presence of a concurrent secondary task.