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Does cognitive distraction improve or degrade lane keeping performance? Analysis of time-to-line crossing safety margins

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ABSTRACT

Studies on the effect of cognitive load (CL) on driving performance suggest that lane keeping performance is improved by cognitive distraction, due to a reduction in measures of the standard deviation of lateral position (SDLP). However, the effect of CL on drivers' lateral control is still not fully understood, and previous studies have shown mixed conclusions regarding the effect of CL on time-to-line crossing (TLC) safety margins. Hence, a driving simulator experiment was performed, requiring performance an auditory-response working memory task (CL task), during driving, presented at of three difficulty levels. Similar to previous studies, CL led to increased micro-steering activity, as well as a diminished SDLP, implying a better lane keeping performance. However, a systematic comparison of TLC calculations showed that the TLC values consistently decreased with the CL task, suggesting a degraded safety margin of lane keeping. While these decreased TLCs did not bring the vehicle close to actual lane departure, they do put into question the general finding that lane keeping is improved by cognitive distraction. We discuss how the increased micro-steering activity could lead to the somewhat counterintuitive simultaneous decrease in both SDLP and TLC. In addition, we suggest the use of a new method for TLC calculations, assuming constant lateral acceleration. We argue that by involving short time windows (3–5 s) of chunking, this method may be useful for assessing drivers' safety behavior, and correct detection of unsafe cognitive distraction.

1. Introduction

Driver distraction and inattention is a common occurrence in everyday driving, and has become a main cause of many vehicle crash accidents. For instance, results from the 100-Car Naturalistic Driving Study showed that approximately 78% of crashes, and 65% of near-crashes, involved driver inattention (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Driver inattention is mainly caused by distraction associated with secondary tasks, driving-related inattention to the forward roadway, non-specific eye glances, and fatigue (Liang & Lee, 2010). Driver distraction is described as "*a diversion of attention away from activities critical for safe driving toward a competing activity*" (Young, Lee, & Regan, 2008, pp. 34). In the US, distraction-related crashes contributed to ten percent of fatal crashes, eighteen percent of injury crashes, and sixteen percent of all police-reported motor vehicle traffic crashes in 2014 (National Centre for Statistics and Analysis, 2016). Recently, both

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cognitive and visual distraction have been widely studied, in terms of their impact on drivers' awareness and understanding of the surrounding traffic (Haque & Washington, 2014; Reyes & Lee, 2008; Ross et al., 2014; Sodhi, Reimer, & Llamazares, 2002; Strayer, Watson, & Drews, 2011), vehicle control (Blanco, Biever, Gallagher, & Dingus, 2006; Harbluk, Noy, & Eizenman, 2002; Jamson & Merat, 2005; Muhrer & Vollrath, 2011), and ability to respond to hazards (D Addario, Donmez, & Ising, 2014; Haque & Washington, 2015; Lamble, Kauranen, Laakso, & Summala, 1999).

The effect of visual distraction is clear, in that, increased visual distraction leads to degraded vehicle control (Angell et al., 2006; Kountouriotis & Merat, 2016; Liang & Lee, 2010), such as increased lane departures, and higher speed variance. However, the effect of cognitive (non-visual) distraction on driving performance is currently unclear. This term normally refers to an overall withdrawal of attention away from the driving task (i.e. "mind off road", see Engstrom, Markkula, Victor, & Merat, 2017; Victor, 2005). Studies show mixed findings regarding the effect of cognitive distraction on driving performance. On the one hand, cognitive distraction is shown to diminish drivers' perceptual ability to detect targets (Haque & Washington, 2014; Reyes & Lee, 2008) and also increase drivers' response time to hazards (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Lamble et al., 1999; Strayer & Drews, 2004). These findings seem to implicate that cognitive distraction impairs driving performance.

On the other hand, many studies indicate that cognitive distraction leads to a reduction in the vehicle's standard deviation of lateral position (SDLP), but there is currently a divergence in views regarding whether such reductions should be interpreted as impaired (Mehler, Reimer, Coughlin, & Dusek, 2009; Reimer, 2009) or improved (Engström, Johansson, & Östlund, 2005; He & McCarley, 2011; He, McCarley, & Kramer, 2014; Jamson & Merat, 2005; Kaber, Liang, Zhang, Rogers, & Gangakhedkar, 2012; Kountouriotis & Merat, 2016; Liang & Lee, 2010; Son, Lee, & Kim, 2011) driving performance. In addition, studies have found this reduction in SDLP to be accompanied by a higher gaze concentration towards the road center (Cooper, Medeiros-Ward, & Strayer, 2013; Victor, Harbluk, & Engstrom, 2005; Wang, Reimer, Dobres, & Mehler, 2014), which is thought to be a possible reason for this reduction in SDLP (Boer, Spyridakos, Markkula, & Merat, 2016; Kountouriotis & Merat, 2016; Liang & Lee, 2010; Victor et al., 2005), though, again, the relationship between these two particular metrics is not currently understood.

Investigations on drivers' steering control show that cognitive distraction increases micro-steering activity (Engström et al., 2005; Son et al., 2011), results in higher steering entropy (Boer, Rakauskas, Ward, & Goodrich, 2005; Kountouriotis, Spyridakos, Carsten, & Merat, 2016), increased micro-steering reversal rate and higher steering wheel acceleration (Kountouriotis et al., 2016). This finding has also been regarded as the direct reason for the diminished SDLP (Engstrom et al., 2017; He et al., 2014). However, it is not currently clear whether the increased steering activity during cognitive distraction is synonymous with good or bad lane keeping performance, although Kountouriotis et al. (2016) state that the increased steering activity is likely to be associated with more careful 'micro-corrections'.

Although it can be argued that measures outlined above provide a good indication of drivers' control behavior during cognitive distraction, there is still a need to identify the correct parameters and methods to understand the effect of cognitive distractions on drivers' lateral safety margin, and, therefore, whether this activity is likely to impair driving performance. Moreover, both SDLP and steering reversal rate are usually measured using a long time window (normally 30 s or more) (Engström et al., 2005; Kountouriotis & Merat, 2016; Liang & Lee, 2010), which makes these discrete measures unsuitable for the immediate and real-time detection of cognitive distraction. There is, therefore, a need to consider the value of a more continuous parameter, for identifying real-time cognitive distraction.

In terms of drivers' lateral safety control, Time-to-Line Crossing (TLC) is a commonly used parameter (Mammar, Glaser, Netto, & Blosseville, 2004; Society of Automotive Engineers., 2015; Van Winsum, de Waard, & Brookhuis, 1999; Östlund et al., 2005). TLC represents the time available for a driver "*until the moment at which any part of the vehicle reaches one of the lane boundaries*" (Godthelp, Milgram, & Blaauw, 1984), served as an indication of the safety margin during steering control (Van Winsum et al., 1999). TLC is often used to evaluate driving performance (de Nijs, Mulder, & Abbink, 2014; Green, 2007; Van Winsum et al., 1999), investigate steering control (Godthelp, 1986; Godthelp & Konings, 1981), and predict lane departures (Lee, Kwon, & Lee, 1999; Mammar, Glaser, & Netto, 2006; Mammar et al., 2004). Therefore, we argue that TLC may be a good measure for investigating drivers' safety control during cognitive distraction, and that its continuity makes it more suitable for real-time cognitive distraction detection. Previous studies have provided mixed conclusions regarding the effect of cognitive load on TLC. For instance, a series of linked studies from the European HASTE project (Östlund et al., 2004) found a significant change in TLC during cognitively loading task for elderly drivers (over 60 years old), while no significant effect was observed for average drivers (25–50 years old). This may be because TLC is not considered an easy metric to measure correctly (Mammar et al., 2004; Society of Automotive Engineers, 2015; Van Winsum et al., 1999). Therefore, in the present study, we methodically considered different approaches for computing this metric, and are able to show that cognitive load does indeed affect TLC, in a somewhat unexpected way.

2. Method

2.1. Participants

35 participants were recruited for the experiment. All of them held a valid driving license, for a minimum of 2 years, and had normal or corrected-to-normal vision. A within-subjects design was used for the experiment, but due to simulator