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Sensitivity of the lane change test as a measure of in-vehicle system demand

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ABSTRACT

The Lane Change Test (LCT) is one of the growing number of methods developed to quantify driving performance degradation brought about by the use of in-vehicle devices. Beyond its validity and reliability, for such a test to be of practical use, it must also be sensitive to the varied demands of individual tasks. The current study evaluated the ability of several recent LCT lateral control and event detection parameters to discriminate between visual-manual and cognitive surrogate In-Vehicle Information System tasks with different levels of demand. Twenty-seven participants (mean age 24.4 years) completed a PC version of the LCT while performing visual search and math problem solving tasks. A number of the lateral control metrics were found to be sensitive to task differences, but the event detection metrics were less able to discriminate between tasks. The mean deviation and lane excursion measures were able to distinguish between the visual and cognitive tasks, but were less sensitive to the different levels of task demand. The other LCT metrics examined were less sensitive to task differences. A major factor influencing the sensitivity of at least some of the LCT metrics could be the type of lane change instructions given to participants. The provision of clear and explicit lane change instructions and further refinement of its metrics will be essential for increasing the utility of the LCT as an evaluation tool.

1. Introduction

Driver distraction is acknowledged internationally as an important road safety issue (Regan et al., 2008). In particular, the potential for in-vehicle and portable technologies, including, information, communication, entertainment and advanced driver assistance systems, to distract drivers from the driving task and degrade performance has been the subject of intense research and policy initiatives worldwide (Collet et al., 2009; Wittmann et al., 2006). An important goal in the design of these systems is to ensure that their use while driving does not interfere with the driving task and unduly compromise safety. This is a challenge in an area where the introduction of technology is largely commercial, rather than safety driven. The realisation of this goal is dependant upon the provision of widely accepted and scientifically robust methods for informing the design and assessing the safety implications of in-vehicle systems. Several such methods have been developed, including the visual occlusion technique (Chiang et al., 2004; Gelau et al., 2009; Noy et al., 2004; Senders et al., 1967) and the peripheral detection task (Harms and Patten, 2003; Olsson and Burns, 2000,p. 8; van Winsum et al., 1999).

As evidenced by its current development into an ISO standard (ISO, 2009), another candidate methodology that shows promise in this area, is the Lane Change Test (LCT; Mattes, 2003; Mattes and Hallén, 2008). To be useful as an evaluation tool, however, the LCT must be valid (i.e., it measures what it claims to measure) and reliable (i.e., the results obtained are consistent across administrations), as well as having high sensitivity. The focus of this paper is on the LCT method's sensitivity. That is, its ability to distinguish the differential effects of various types of distraction on driving behaviour.

1.1. Driver distraction

Driver distraction is commonly described as comprising a range of different, but not mutually exclusive, elements; for example, visual, cognitive, auditory and biomechanical (physical) (Ranney et al., 2000). These distraction types, particularly visual and cognitive distraction, have been shown to impair different aspects of driving performance, with lateral control and event detection metrics being particularly sensitive to different forms of distraction. For instance, visual load has been shown to increase lane keeping variation (e.g., Greenberg et al., 2003; Zwahlen et al., 1988). Moderate levels of cognitive load, in contrast, have been shown to have little effect on lane keeping performance and can even lead to more precise lateral control (Brookhuis et al., 1991; Engstrom et al.,

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2005; Jamson and Merat, 2005). Further, both cognitive and visual tasks can impair event detection (Klauer et al., 2006), but cognitive distraction can also impair drivers' ability to respond to events quickly and adequately (Consiglio et al., 2003; Recarte and Nunes, 2003; Strayer et al., 2003).

Given its current development into an ISO standard and its increasing use in distraction research, it is important that the LCT is capable of measuring and distinguishing these diverse distraction effects. This study therefore aimed to evaluate the sensitivity of a range of LCT metrics in being able to distinguish between visual-manual and cognitive tasks with different levels of demand.

1.2. The lane change test

The LCT is a PC-based driving simulation that is designed to quantitatively measure the level of degradation in driving performance induced by the simultaneous performance of a secondary task. It has been widely used to assess driving performance with concurrent use of a range of in-vehicle information systems (IVIS) which provide information that supports primary driving tasks (e.g., navigation), as well as Advanced Driver Assistance Systems (ADAS) that directly support the primary driving task (Burns et al., 2005, pp. 1980–1983; Mäntylä et al., 2009).

A number of studies have focused on validating the LCT. Many of these early validation tests were carried out as part of the Advanced Driver Attention Metrics (ADAM) project, in which the LCT was developed, and suggest that the LCT is a valid, reliable and sensitive measure (see Mattes and Hallén, 2008). Subsequent research demonstrated that the LCT could discriminate between secondary tasks with different workload levels (Burns et al., 2005, pp. 1980–1983), with drivers demonstrating a greater deviation in lane change path when performing a complex versus simple navigation task while driving.

More recently, work has continued on the LCT to expand its diagnostic power by proposing new performance metrics (Mattes and Hallén, 2008). Given the complexity and multifaceted nature of distraction, it is important for any evaluation method to measure multiple aspects of the driving task in order to draw conclusions about the safety effects of in-vehicle devices.

A number of studies have examined the sensitivity of several of the LCT metrics in being able to distinguish between different types of distraction (Bruyas et al., 2008; Engström and Markkula, 2007; Harbluk et al., 2009, 24–30 p.). Engström and Markkula (2007) have examined the sensitivity of two new LCT metrics – path control (high-pass filtered SDLP) and sign detection/recognition (Percent correct lane; PCL) – to distinguish visual and cognitive tasks. Results revealed that the two types of distraction each impaired LCT performance differently. The visual, but not cognitive, tasks led to reduced path control, while the cognitive, but not visual, tasks affected detection and sign recognition and responses. Bruyas et al. (2008) found that the adapted mean deviation score, ratio of correct lane changes and Lane Change Initiation (LCI) metrics were capable of differentiating some visual-manual and auditory tasks, but not others. Finally, in order to take into account task duration, Harbluk et al. (2009, 24–30 p.) examined the LCT mean deviation per average task by dividing the mean deviation score by the number of task completed per run. They found that this adapted measure was better able than the original mean deviation score to discriminate between navigation tasks with different levels of complexity.

These studies demonstrate that at least some of the proposed LCT performance metrics are sensitive to the disparate effects of different forms of distraction. However, there is still a need to determine if other LCT metrics, that are increasingly being used by researchers and policy and system developers to draw conclusions about the safety and design aspects of IVIS systems (e.g., Maciej and Vollrath, 2009), are also sensitive to task differences. This study extends the findings of the previous research discussed above by examining the sensitivity of a range of new and recently proposed LCT lateral control and event detection parameters (lane keeping variation between signs, percent correct lane changes, number of lane excursions, LCI, and mean steering angle) in being able to distinguish between visual-manual and cognitive tasks with different levels of demand. The findings of this study can be used to inform decisions regarding which LCT metrics are suitable for use and which ones may need further refinement. It will also add to the growing number of studies aimed at establishing the psychometric properties of the LCT as part of its development into an ISO standard.

2. Method

2.1. Design

This study used a repeated-measures design, with one independent variable, task condition, which had five levels: a baseline (no secondary task) condition and four secondary task conditions: visual easy, visual hard, cognitive easy and cognitive hard. Participants completed the four secondary task conditions while driving a PC version of the LCT. Further details of the secondary task conditions are contained in Section 2.3.2. This combination of secondary task conditions ensured that it was possible to examine the ability of the LCT to distinguish between different *levels* of demand as well as different *types* of distraction.

2.2. Participants

Twenty-seven drivers who held a valid drivers license participated the study. Sixteen of the participants were male and 11 were female and the mean age for the group was 24.4 years (SD = 3.0; range = 21–31 years). All participants held a valid full drivers license, apart from one who held a probationary license, which is issued for the first four years of solo driving and contains certain passenger, mobile phone and vehicle power restrictions. The mean age at which their solo (probationary) license was obtained was 19.3 years (SD = 2.6), and the average time spent driving each week was 7.3 h (SD = 6.6).

Participants were recruited through campus notice boards and newsletters, the Monash Careers Website and the local newspaper (Waverley Leader). Ethics approval for the study was granted by the Monash University Standing Committee on Ethics in Research Involving Humans (SCERH). Participants were reimbursed for their time and travel expenses.

2.3. Materials

2.3.1. Driving task

Driving performance was measured using the LCT (version 1.2; Mattes, 2003). The LCT is a simple driving simulation consisting of a 3000 m straight, three-lane road. Speed is limited to 60 km/h by the system, which the test participants were asked to maintain throughout the drive. No other traffic is present on the road. The drivers are instructed to change lanes via 18 signs that appear on each side of the road every 150 m, on average. The signs are blank until 40 m before the sign, at which point the lane change information is given (Fig. 1a). Participants were instructed to changes lanes as soon and as quickly as possible after they see the information appear on the sign. Participants were not required to have completed their lane change before they reached the sign.