Applied Ergonomics 42 (2011) 611–618

Contents lists available at ScienceDirect

Applied Ergonomics

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

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

Kristie L. Young*, Michael G. Lenné, Amy R. Williamson

Monash University Accident Research Centre, Building 70, Monash University, Clayton, Victoria 3800, Australia

ARTICLE INFO

Article history:
Received 29 October 2009
Accepted 18 June 2010

Keywords:
Driver distraction
Lane change test
In-vehicle information systems
Evaluation methods

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.,

* Corresponding author. Tel.: +613 9905 1258; fax: +613 9905 4363.
E-mail address: kristie.young@muarc.monash.edu.au (K.L. Young).

0003-6870/$ – see front matter
doi:10.1016/j.apergo.2010.06.020

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.

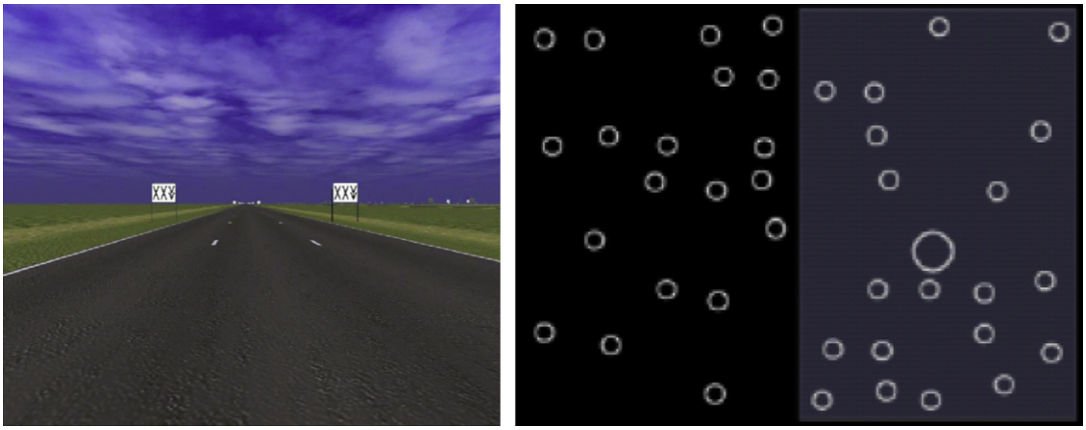

Fig. 1. Primary and secondary tasks used. Panel A (left) shows the LCT driving scene with lane change sign (arrow). Panel B (right) shows the SuRT task visual display (easy condition).

The LCT was run on a desktop PC. The set-up of the test followed that set out in the Draft ISO standard (ISO, 2009). The visual scene was presented on a single 19″ LCD monitor. Control of the simulation was achieved through a Logitech MOMO force-feedback gaming steering wheel with accelerator and brake foot pedals. Participants sat in a height adjustable chair, with the chair and pedals positioned to approximate that of a real vehicle.

2.3.2. Secondary task

Two surrogates visual-manual and cognitive IVIS tasks were used as the secondary tasks, each with two levels of difficulty. Artificial or surrogate in-vehicle information system (IVIS) tasks were used so that the level of task demand could be systematically manipulated.

2.3.3. Visual-manual task

The Surrogate Reference Task (SuRT v.2.1) was employed as the visual-manual task. The task requires participants to search for a larger target circle among visually similar, smaller distracter circles (visual demand), and to select, using the keyboard arrow keys, the portion of screen containing the target (manual demand). Task difficulty (easy, hard) was manipulated by varying the size of the distracter circles compared to the target circle, and by increasing the number of screen segments in which the target could appear (easy = 2 regions, hard = 6 regions). For the easy condition, the target circle was twice the size of the distracter circles, while for the hard condition the target circle was 15% larger than the distracters. An example of the SuRT display is contained in Fig. 1b. The visual task was semi self-paced, whereby the participants could take as much time as needed to make their selection, but the software controlled when the next stimuli was presented. The SuRT has been used widely in IVIS research (e.g., Bruyas et al., 2008; Rognin et al., 2007) and has been found to be a valid measure of IVIS task demand (Wynn and Richardson, 2008).

The visual secondary task was presented on a laptop with 14″ screen which was located on a table to the left of the driver, within 30° (horizontal and vertical) of their normal field of view and within easy reach.

2.3.4. Cognitive task

The cognitive task comprised a math problem solving task, involving basic addition, again with two levels of difficulty – easy and hard. Random numbers were read aloud to the participant (through a headset) using DirectRT software. For the easy level, the participant was asked to add 5 to the number and say their response out loud. For the difficult level, participants were required to add 7. The task was semi self-paced, whereby participants were given as much time as needed to respond to each problem (self-paced), but the system presented the next problem immediately after the previous response was given (system-paced). This task was piloted extensively prior the experiment to ensure that there was an adequate degree of difficultly and differentiation amongst the easy and hard levels.

2.4. Procedure

On arrival at the session, participants completed a demographic questionnaire. They were then given a verbal explanation of the LCT and secondary tasks, followed by static (no LCT) practice and baseline trials of the visual and cognitive secondary tasks. Participants completed 1–2 practice drives on the LCT and then the six trial runs: baseline, visual easy, visual hard, cognitive easy, cognitive hard and a final baseline trial. Before each dual-task drive, participants were instructed to "concentrate your attention on driving safely, but do not ignore the secondary tasks".

The order in which the visual and cognitive secondary tasks were presented was counter-balanced across participants to accommodate any practice effects.

2.5. Data analysis

The LCT driving performance examined can be broadly categorised into lateral vehicle control measures and event detection measures:

2.5.1. Lateral control measures

2.5.1.1. Mean deviation. Drivers' mean lateral deviation score was compared to the LCT normative model that is automatically calculated by the LCT analysis software. The normative model represents an ideal lane change path. Deviation scores were calculated for each run over the entire length of the drive (standard mean deviation score), as well as for the straight sections between lane changes (10 m after change to 10 m before next change), which provides an additional measure of lateral control with the effect of the lane changes removed. Instances where the participants had made an incorrect lane change were excluded from the straight section analysis as they over-inflated the deviation score.

2.5.1.2. Mean steering angle. The mean steering angle in grads (equivalent to $^1/_{400}$ of a full circle) was calculated for each entire LCT run. This measure was calculated automatically using the standard LCT analysis software.

2.5.1.3. Lane excursions. The number of lane excursions made during each run was calculated by examining the lateral position trace schematics produced by the LCT. A lane excursion was defined as any instance where the LCT actual deviation trace moved outside of the correct lane of travel. Lane excursions were examined for the entire drive, including during lane change manoeuvres and straight sections.

2.5.2. Event detection measures

2.5.2.1. Lane change initiation (LCI). LCI represents the difference (in metres) between the distance at which the lane change information appears on a sign and the distance at which the driver actually initiated the lane change. Thus, LCI represents an event detection measure.

2.5.2.2. Percent correct lane changes. The percentage of lane changes that were correctly executed in each run was calculated as a measure of the participants' ability to correctly respond to the lane change commands. In addition, the types of lane change errors made by drivers were qualitatively examined. Two types of errors were examined: missed lane changes (where the driver continued straight ahead without changing lanes) and erroneous lane changes (where the driver executed the lane change, but into the wrong lane).

2.5.3. Secondary task performance

Mean task completion time (in milliseconds) was calculated for the visual and cognitive secondary tasks in order to examine any potential trade-offs in performance across the secondary and LCT tasks.

Analyses were carried out using SPSS version 15.0. One-way repeated measures analyses of variance (ANOVAs) were used to compare mean scores for all LCT performance measures (except percent correct lane changes). The results were corrected for sphericity violations where necessary using the Greenhouse-Geisser modification. Greenhouse-modifications were made for the straight section mean deviation and LCI analyses. Pairwise comparisons were calculated using least significant difference (LSD). The percent correct lane change data were not normally distributed and, hence, were analysed using the non-parametric Friedman test. Descriptive analysis of lane change errors (missed versus incorrect LC) was also undertaken. No significant differences were found between the two baseline runs for any measure, thus these data were combined into a single baseline condition ($p > .05$). Due to a corrupted data file, mean deviation and LCI data were not able to be calculated for one driver.

3. Results

3.1. Lateral control measures

3.1.1. Mean deviation

The mean deviation scores for the entire drive and the straight line segments are presented in Fig. 2. The mean deviation across the entire drive differed significantly across the task conditions (F (4,100) = 6.53, $p < .001$). Mean deviation was lower in the baseline condition than in all dual-task conditions ($p < .05$). Across the secondary tasks, mean deviation scores were significantly higher in the visual easy and hard conditions compared to the cognitive easy condition ($p < .05$).

Significant differences in straight line (between signs) mean deviation were found across tasks (F (3,73) = 3.07, $p < .05$). Although there was a trend for mean deviation scores to be higher when performing visual tasks compared to the cognitive tasks or baseline condition, the only significant difference observed was that mean deviation scores were higher in the visual easy compared to the cognitive easy condition ($p < .05$).

3.1.2. Steering angle

While mean steering angle appeared higher for the visual hard condition ($M = 0.024$) compared to baseline ($M = 0.016$), cognitive easy ($M = 0.016$), cognitive hard ($M = 0.014$) and visual easy conditions ($M = 0.016$), there was no significant difference across conditions (F (4,104) = 1.88, $p > .05$).

3.1.3. Lane excursions

The mean number of lane excursions for each driving condition is displayed in Fig. 3. Significant differences in the number of lane excursions made was found across conditions (F (4,104) = 8.86, $p < .001$), whereby all dual-task conditions contained a greater number of lane excursions than the baseline condition ($p < .01$). The visual hard condition also contained a significantly higher number of lane excursions than any of the other conditions ($p < .01$). The number of lane excursions did not differ significantly across the other three dual-task conditions.

3.2. Event detection and response measures

3.2.1. Lane change initiation

The distance at which participants initiated a lane change from the appearance of the information on each sign was recorded and the means displayed in Fig. 4. A significant effect of driving condition was found (F (3,77) = 4.04, $p < .01$), whereby the mean distance from the lane change sign presentation to the initiation of the lane change was shorter in the Cognitive Hard condition than the Visual Easy and Visual Hard conditions ($p < .01$).

3.2.2. Percent correct lane changes

The mean percentage of correct lane changes made in each experimental condition was high, ranging from 95.5% in the cognitive hard condition to 97.9% in the baseline condition (Table 1). There was no significant difference in the percentage of correct lane changes made across the driving conditions (χ^2 (4) = 2.97, $p > .05$).

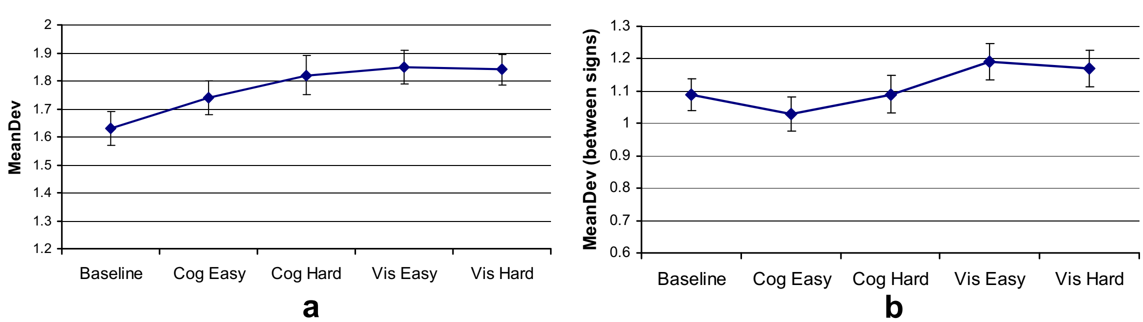

Fig. 2. Mean deviation in lane change path for each experimental condition. Panel A (left) shows the overall mean deviation. Panel B (right) shows the straight line mean deviation (between signs).

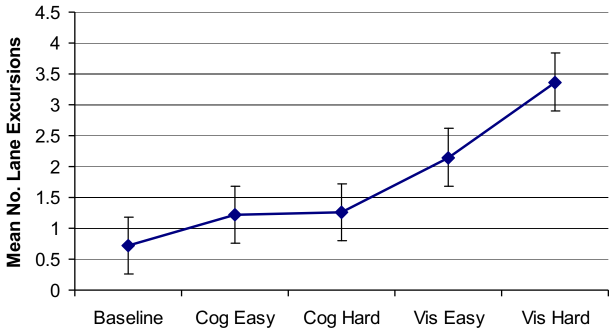

Fig. 3. Number of lane excursions made in each experimental condition.

Descriptive analysis was performed to examine the type of lane change errors made (missed or incorrect changes). The percentage of incorrect lane changes made in each condition that are attributable to each error type is contained in Table 1. This analysis showed that of the small percentage of lane change errors made, most consisted of missed lane changes, suggesting a failure to detect the sign rather than misread it. This error type was most common in the hard task conditions and was slightly more common when performing cognitive tasks.

3.3. Secondary task performance

Two separate analyses were conducted to investigate task completion times on the two secondary tasks statically (no driving) and when completing the LCT. Two, 2 (baseline, LCT) × 2 (easy, hard) repeated-measures analysis of variance (ANOVA) were conducted for the visual task and the cognitive task separately. Due to technical problems, visual task data was not recorded for one participant.

3.3.1. Visual task

Mean completion times for each visual display for the baseline and LCT conditions are displayed in Fig. 5a. No significant interaction between task difficulty and condition was found (F (1,25) = 2.19, $p > .05$); however, significant main effects were found for condition (F (1,25) = 15.12, $p < .01$) and difficulty level (F (1,25) = 79.37, $p < .001$). Drivers took longer to complete the cognitive stimuli when completing the LCT compared to when performing the cognitive task alone (baseline). Completion times were also significantly longer for the hard visual stimuli than the easy stimuli.

3.3.2. Cognitive task

Mean completion times for the cognitive math task stimuli for each task condition was calculated and compared, as displayed in Fig. 5b. A significant main effect was found for difficulty level (F (1,26) = 36.17, $p < .001$), whereby completion times were significantly longer for the hard cognitive stimuli than the easy stimuli across both baseline and LCT conditions. The interaction between condition and difficulty level was not significant, (F (1,26) = 0.01, $p > .05$), nor was there a significant main effect of condition (F (1,26) = 0.09, $p > .05$). This latter result is interesting, as it suggests that drivers did not trade-off performance on the cognitive task in favour of the driving task.

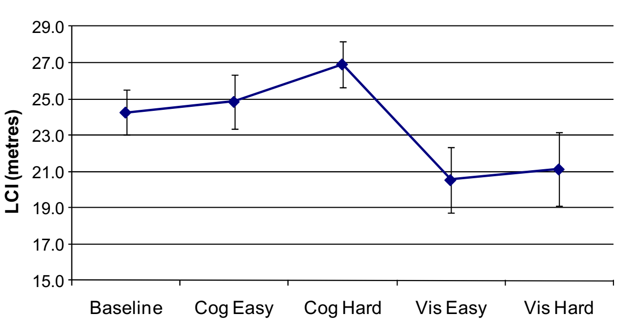

Fig. 4. Mean Lane Change Initiation for each experimental condition.

Table 1
Percentage of incorrect lane changes (LC) attributable to each error type for task condition.

Condition	% Correct LC	% Missed LC	% Incorrect LC
Baseline	97.94	0.82	1.24
Cognitive Easy	97.72	2.06	0.22
Cognitive Hard	95.46	3.50	1.04
Visual Easy	97.52	2.06	0.42
Visual Hard	95.87	2.47	1.66

4. Discussion

The current study evaluated the ability of several recently proposed LCT lateral control and event detection parameters to discriminate between visual-manual and cognitive surrogate IVIS tasks with different levels of demand. 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. These results have important implications for the battery of metrics that might be included in the ISO standard.

Lateral control is a commonly used driving performance measure that has been shown to be sensitive to several forms of driver impairment (e.g., drug driving and distraction; Lenné et al., 2010; Young et al., 2008). In terms of the LCT lateral control metrics, the results for the overall mean lane deviation measure confirm that this measure is sensitive to the differential effects of visual and cognitive distraction. As expected, overall mean deviation scores were highest when drivers were performing the visual secondary tasks, and were significantly higher than the cognitive easy and baseline conditions. Mean deviation scores for the two cognitive tasks were significantly higher than the baseline condition, although the impact of these tasks on lateral control was less than that of the visual tasks.

In terms of task difficulty, there was a trend for mean deviation scores to be higher in the hard task conditions compared to the easy conditions; however, this difference was not significant. It is not completely clear why the mean deviation measure was not sensitive to differences in task demand. It is unlikely to be due to the levels of task difficulty used, which were shown in extensive piloting prior to conducting the experiment to have sufficiently different perceived levels of demand. For the visual task at least, the insensitivity may stem from the nature of the SuRT task used. The different levels of complexity for this task largely derive from differences in task duration, rather than greater or lesser amounts of cognitive resources. As the participants were continually engaged in the SuRT task (i.e., the next stimulus was presented immediately after completion of another), it is not unexpected that the differences in individual task duration across the easy and hard conditions are not reflected in the driving scores.

The mean deviation results are generally consistent with past research in this area, which have shown that increased visual-manual load increases lane keeping variation, while cognitive secondary tasks have less of an effect, or no effect, on lane keeping performance (Engstrom et al., 2005; Greenberg et al., 2003; Wilschut et al., 2008). Reduced lane keeping performance during periods of visual-manual demand is believed to result from the

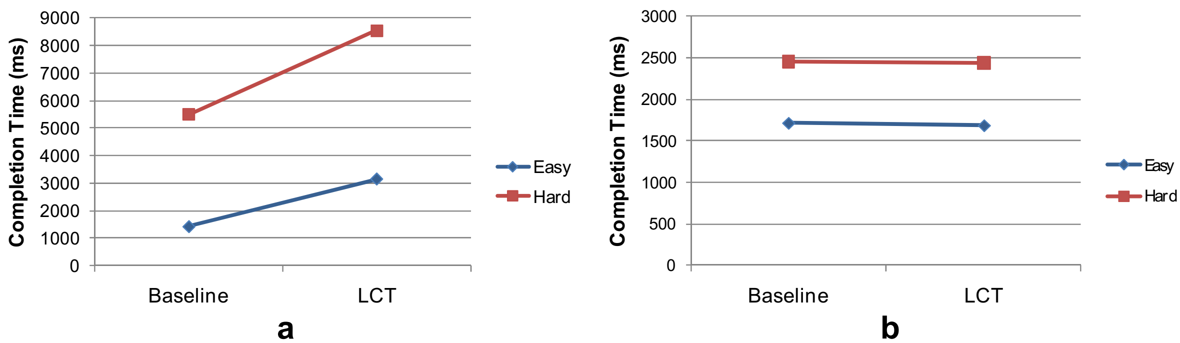

Fig. 5. Mean completion time (in milliseconds) for the a) visual and b) cognitive secondary tasks.

build up of steering errors. When visual attention is diverted from the road, drivers tend to maintain a fixed steering angle and make less micro steering corrections, which can in turn lead to lane weaving and excursions. The manual demand associated with the SuRT task may have also contributed to the increase in lane keeping variation. Cognitive demand, however, is believed to have less of an impact on lane keeping due to the effects of visual tunnelling. Engstrom et al. (2005) found that when performing a cognitive task drivers' visual scanning patterns changed such that they increased their gaze concentration towards the centre of the road. This led to an improved tracking response and a decrease in lateral deviation.

A similar pattern of results were found for the mean number of lane excursions. The highest number of lane excursions (where any part of the vehicle was outside the correct lane) was found in the visual hard condition, and this was significantly higher than for all other dual-task conditions and the baseline condition. The number of lane excursions was also higher in the cognitive and visual easy tasks compared to baseline. These results suggest that the lane excursion measure is at least somewhat sensitive to differences in task type and level of demand.

The other two lateral control metrics appeared to have limited sensitivity to distinguish visual-manual and cognitive tasks and different levels of demand. No significant differences were found across tasks for mean steering angle. Few differences were also found across tasks for the straight line mean deviation measure, with only the visual and cognitive easy tasks differing from each other (although the pattern of trends was in the expected direction).

Both event detection metrics examined also appeared to have limited sensitivity to the different IVIS tasks. No significant differences were found across tasks for percentage of correct lane change measures. The results for the lane change initiation measure were highly unexpected. Not only were few differences found across tasks, LCI scores were longer in the baseline condition than in the dual-task conditions. This indicates that participants were taking less time to initiate their lane change when performing another task than when not distracted, a finding that contradicts other LCT studies (Bruyas et al., 2008; Harbluk et al., 2007). Lane Change Initiation (LCI) represents an event detection measure and previous research has found that drivers' ability to detect and respond to events in a timely manner is degraded when performing secondary tasks (Greenberg et al., 2003; Strayer and Drews, 2004; Strayer et al., 2003).

One explanation for the current LCI results may rest with the nature of the lane change events, which are expected and highly predictable because they occur at regular and approximately equal intervals. Drivers may, therefore, be able to anticipate the lane change events and regulate their behaviour with the secondary task accordingly so that their response to these events is not degraded, and may even be improved if they are assigning higher priority to the driving task. Indeed, when observing the participants complete the LCT, the experimenters noted that many participants were regulating their secondary task engagement so that they were only performing the task immediately after the lane changes. Although other research has found that drivers have difficulty responding to events when distracted, these events have typically been unexpected or unanticipated (Klauer et al., 2006; Strayer et al., 2003). It may be that drivers' ability to detect and respond to events is less impaired by engagement in secondary tasks if these events are expected. This explanation may also account for why the percentage of correct lane changes was very high in the dual-task conditions.

The study data also have implications for the LCT instructions as stated in the ISO draft standard. An important factor that may have influenced both the lateral control and event detection results is the lane change instructions given to participants. In line with the LCT ISO draft standard (ISO, 2007), participants in the current experiment were instructed to change lanes as soon and as quickly as possible after the lane change information appears on the sign. Unlike the instructions adopted in other LCT experiments (e.g., Harbluk et al., 2007; 2009), the current participants were not instructed to have completed their lane change by the time they reach the lane change sign. While the instructions used in the current study led to more gradual and, arguably, more naturalistic lane changes, it did have the effect of inducing much higher mean deviation values than have been found in other studies and, possibly, the inconsistent LCI scores (e.g., Bruyas et al., 2008; Harbluk et al., 2007, 2009, 24–30 p.). These more gradual lane change manoeuvres may have reduced the level of attentional demand required by the LCT, making it less sensitive to the differential effects of the secondary tasks. The use of different lane change instructions to increase the level of LCT task demand may increase the sensitivity of the measures examined in this study.

It is important to acknowledge that the 1.2 m mean deviation criterion specified in the ISO standard was not met in this study before embarking on the experimental trials. Indeed, this criterion was not reached for any of the trials, including the final baseline drive (mean deviation = 1.6 m). The relatively higher mean deviation scores found during the study are believed to be the result of the instructions given and not a lack of practice with the task. Our results highlight the potential implications of inconsistent interpretation of the LCT instructions and the need for the LCT instructions to be made more explicit in the ISO draft standard, including whether lane changes are required to be completed before drivers reach the sign. Consideration should also be given to whether the 1.2 m criterion specified in the draft standard is too strict, in that it represents a lane change manoeuvre that is not a realistic representation of what occurs in real driving.

Another methodological issue concerns the use of the artificial surrogate IVIS tasks. While these tasks allow the level of demand imposed by the secondary tasks to be easily and systematically manipulated, it can be argued that their forced-paced nature is discordant with real IVIS tasks, which are typically self-paced. An attempt was made to overcome this limitation by making the surrogate IVIS tasks semi-self paced, whereby drivers could take as long as necessary to make their response, but the presentation of new tasks was controlled by the system. It is important, however, that the sensitivity of the LCT metrics are also examined using real IVIS tasks in order to see what effect self-paced interaction has on drivers' task allocation strategies and driving performance. Finally, this study used a relatively small and homogenous sample of participants and the extent to which their LCT performance reflects that of the wider driving population is limited. Thus, further research examining the validity and sensitivity of the LCT must employ a wider sample of participants from a range of driving and demographic backgrounds that may differ in their ability to cope with secondary task demands while driving.

5. Conclusions

Given its development as an ISO standard, the LCT is increasingly being used by researchers and policy makers to draw conclusions about the design of in-vehicle systems and the acceptability of using them when driving. While this is a positive step, it is important to establish that the metrics used to draw such conclusions are sensitive to a range of driving and secondary task demands. This study has sought to establish the sensitivity of several recent LCT lateral control and event detection metrics to the differential effects of visual-manual and cognitive tasks with varying levels of demand. A number of the LCT metrics examined, particularly the event detection metrics, demonstrated poor sensitivity in this study. This may be due to the expected nature of the LCT task, or could also be an artefact of the instructions used. Beyond evaluating LCT sensitivity, a contribution of this paper has been to demonstrate the importance of the LCT instructions and the manner in which they can alter the level of demand required by the task and, hence, the results obtained. Currently, the LCT instructions are unclear and open to interpretation. Indeed, different researchers have used different lane change instructions, with noticeable effects on LCT results. Along with the refinements being made to the LCT metrics (e.g., using an adaptive path trajectory model rather than the normative model in calculating mean deviation; ISO (2009)), the provision of clear and explicit lane change instructions will be essential for increasing the utility of the LCT as an IVIS design and safety evaluation tool.

Acknowledgements

This research was funded by the Commonwealth of Australia, through the Cooperative Research Centre for Advanced Automotive Technology. The cognitive task used was adapted from a task developed by Eve Mitsopoulous-Rubens as part of her PhD research.

References

Brookhuis, K.A., de Vries, G., de Waard, D., 1991. The effects of mobile telephoning on driving performance. Accident Analysis and Prevention 23, 309–316.

Bruyas, M.P., Brusque, C., Tattegrain, H., Auriault, A., Aillerie, I., Duraz, M., 2008. Consistency and sensitivity of lane change test according to driving simulator characteristics. IET Intelligent Transport Systems 2, 306–314.

Burns, P.C., Trbovich, P.L., McCurdie, T., Harbluk, J.L., 2005. Measuring distraction: task duration and the lane-change test (LCT). In: Human Factors and Ergonomics Society 49th Annual Meeting.

Chiang, D.P., Brooks, A.M., Weir, D.H.D.H., 2004. On the highway measures of driver glance behavior with an example automobile navigation system. Applied Ergonomics 35, 215–223.

Collet, C., Clarion, A., Morel, M., Chapon, A., Petit, C., 2009. Physiological and behavioural changes associated to the management of secondary tasks while driving. Applied Ergonomics 40, 1041–1046.

Consiglio, W., Driscoll, P., Witte, M., Berg, W.P., 2003. Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. Accident Analysis & Prevention 35, 495–500.

Engstrom, J., Johansson, E., Ostlund, J., 2005. Effects of visual and cognitive load in real and simulated motorway driving. Transportation Research Part F: Traffic Psychology and Behaviour 8, 97–120.

Engström, J., Markkula, G., 2007. Effects of visual and cognitive distraction on lane change test performance. In: Driving Assessment 2007. Stevenson, Washington.

Gelau, C., Henning, M.J., Krems, J.F., 2009. On the reliability of the occlusion technique as a tool for the assessment of the HMI of in-vehicle information and communication systems. Applied Ergonomics 40, 181–184.

Greenberg, J., Tijerina, L., Curry, R., Artz, B., Cathey, L., Grant, P., Kochlar, D., Kozak, K., Blommer, M., 2003. Evaluation of driver distraction using an event detection paradigm. Journal of the Transportation Research Board 1843.

Harbluk, J.L., Burns, P.C., Lochner, M., Trbovich, P.L., 2007. Using the lane-change test (LCT) to assess distraction: tests of visual-manual and speech-based operation of navigation System interfaces. In: Driving Assessment 2007. Stevenson, Washington.

Harbluk, J.L., Mitroi, J.S., Burns, P.C., 2009. Three navigation systems with three tasks: using the lane change test (LCT) to assess distraction demand. In: Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Big Sky, Montana.

Harms, L., Patten, C., 2003. Peripheral detection as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. Transportation Research Part F: Traffic Psychology and Behaviour 6, 23–36.

ISO, 2007. Road vehicles – ergonomic aspects of transport information and control systems - Simulated lane change test to assess driver distraction. In: ISO/DIS 26022. Draft International Standard. International Organization for Standardization.

ISO, 2009. Road vehicles – ergonomic aspects of transport information and control systems – Simulated lane change test to assess in-vehicle secondary task demand. In: ISO/DIS 26022, Draft International Standard. International Organization for Standardization.

Jamson, H.A., Merat, N., 2005. Surrogate in-vehicle information systems and driver behaviour: effects of visual and cognitive load in simulated rural driving. Transportation Research Part F: Traffic Psychology and Behaviour 8, 79–96.

Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., Ramsey, D.J., 2006. The Impact of Driver Inattention on Near-crash/crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data. Virginia Tech Transportation Institute, Blacksburg, Virginia.

Lenné, M.G., Dietze, P., Triggs, T., Walmsley, S., Murphy, B., Redman, J., 2010. The effects of cannabis, alcohol, driving experience and task demand on simulated driving. Accident Analysis and Prevention 42, 859–866.

Maciej, J., Vollrath, M., 2009. Comparison of manual vs. speech-based interaction with in-vehicle information systems. Accident Analysis & Prevention 41, 924–930.

Mäntylä, T., Karlsson, M.J., Marklund, M., 2009. Executive control functions in simulated driving. Applied Neuropsychology 16, 11–18.

Mattes, S., 2003. The lane change task as a tool for driver distraction evaluation. In: IHRA-ITS Workshop on Driving Simulator Scenarios. Dearborn, Michigan.

Mattes, S., Hallén, A., 2008. Surrogate distraction measurement techniques: the lane-change test. In: Regan, M.A., Lee, J.D., Young, K.L. (Eds.), Driver Distraction: Theory, Effects and Mitigation. CRC Press, Boca Raton, FL, pp. 107–122.

Noy, Y.I., Lemoine, T.L., Klachan, C., Burns, P.C., 2004. Task interruptability and duration as measures of visual distraction. Applied Ergonomics: The Occlusion Technique 35, 207–213.

Olsson, S., Burns, P.C., 2000. Measuring Driver Visual Distraction with a Peripheral Detection Task.

Ranney, T.A., Mazzae, E., Garrott, R., Goodman, M.J., 2000. NHTSA driver distraction research: past, present, and future. In: Driver Distraction Internet Forum, 2000. NHSTA.

Recarte, M.A., Nunes, L.M., 2003. Mental workload while driving: effects on visual search, discrimination and decision making. Journal of Experimental Psychology: Applied 9, 119–137.

Regan, M., Lee, J.D., Young, K., 2008. Driver Distraction: Theory, Effects and Mitigation. CRC Press, Boca Raton, Florida.

Rognin, L., Alidra, S., Val, C., Lescoaut, A., Chalandon, X., 2007. Driver strategies when interacting with information and comfort systems. In: 20th International Technical Conference on the Enhanced Safety of Vehicles. Lyon, France.

Senders, J.W., Kristofferson, A.B., Levison, W.H., Dietrich, C.W., Ward, J.L., 1967. The attentional demand of automobile driving. Highway Research Record 195, 15–33.

Strayer, D.L., Drews, F.A., 2004. Profiles in driver distraction: effects of cell phone conversations on younger and older drivers. Human Factors 46, 640.

Strayer, D.L., Drews, F.A., Johnston, W.A., 2003. Cell phone-induced failures of visual attention during simulated driving. Journal of Applied Psychology 9, 23–32.

van Winsum, W., Martens, M., Herland, L., 1999. The Effect of Speech versus Tactile Driver Support Messages on Workload, Driver Behaviour and User Acceptance. TNO-report TM-99-C043. TNO, Soesterberg, Netherlands.

Wilschut, E.S., Rinkenauer, G., Brookhuis, K.A., Falkenstein, M., 2008. Effects of visual search task complexity on lane change task performance. In: Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems. Lyon, France.

Wittmann, M., Kiss, M., Gugg, P., Steffen, A., Fink, M., Pöppel, E., Kamiya, H., 2006. Effects of display position of a visual in-vehicle task on simulated driving. Applied Ergonomics 37, 187–199.

Wynn, T., Richardson, J.H., 2008. Comparison of subjective workload ratings and performance measures of a reference IVIS task. In: European Conference on Human Centred Design for Intelligent Transport Systems. Lyon, France.
Young, K.L., Regan, M.A., Lee, J.D., 2008. Measuring the effects of driver distraction: direct driving performance methods and measures. In: Regan, M.A., Lee, J.D., Young, K.L. (Eds.), Driver Distraction: Theory, Effects and Mitigation. CRC Press, Boca Raton, FL, pp. 85–106.
Zwahlen, H.T., Adams, C.C., de Bald, D.P., et al., 1988. Safety aspects of CRT touch panel controls in automobiles. In: Gale, A.G. (Ed.), Vision in Vehicles II. The North Holland Press, Netherlands, pp. 335–344.