How do you assess the distraction of in-vehicle information systems? A comparison of occlusion, lane change task and medium-fidelity driving simulator methods

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Abstract

There are several simplistic, low-cost methods for evaluating the distraction of in-vehicle information systems (IVIS), intended primarily for use in the formative design process. This study compared two standardised low-cost evaluation methods, Occlusion and Lane Change Task (LCT), with a medium-fidelity driving simulation. Participants carried out tasks using an in-vehicle information system under three conditions: Using the occlusion protocol; LCT; and while driving on a motorway in the simulator. Findings provided strong evidence that the occlusion technique is a stronger candidate than the LCT for evaluating driving distraction due to IVIS. Measures from the occlusion technique (Total Shutter Open Time –TSOT; and Task Time with full vision) were found to correlate highly with the majority of the driving simulator measures (total glance time, mean glance time, driving task time, standard deviation of headway and standard deviation of lane position). Importantly, TSOT was found to successfully predict the number of long off-road glances (greater than two seconds), a critical safety-related measure. In contrast, the key LCT measure of mean deviation provided little predictive ability in considering varying tasks and systems.

Introduction

In-vehicle information systems (IVIS) provide an increasing array of functionality for drivers and passengers (e.g. navigation, entertainment, travel and traffic). As the systems proliferate within modern automobiles and develop in complexity, so the concerns regarding the distraction of their user-interfaces mount (NHTSA 2013, Regan Lee and Young 2009). It is noted that current systems are predominately visual in nature, largely adopting interface designs borrowed from desktop computing paradigms (menus, icons, lists, etc.), subsequently creating fundamental conflict with primary driving tasks (Burnett 2009).

Many human factors and usability-oriented methods assist in the evaluation of user-interfaces from the human experience perspective (e.g. questionnaires, focus groups, interviews, observations), yet there is a general awareness that the driving situation creates the need for more specific approaches (Green 2007). In particular, it is recognised that methods for assessing the distraction of IVIS need to consider the divided attention nature of system use, together with performance-related variables that can be linked to safety outcomes. In this respect, there is a wide range of available methods that vary according to the environment in which they are applied (laboratory, simulator or on-road), the extent to which dual-task behaviour is directly or indirectly established and the measures utilised (quantitative or qualitative). Moreover, methods differ in terms of the extent to which they can assist the formative versus summative design stages. In formative evaluation, the goal is for methods to provide rapid and early feedback to assist a team in improving an interface. Measures adopted in formative design are often simple and predictive. In contrast, summative evaluation methods aim to benchmark a final design according to recognised criteria, often utilizing a wide range of context-rich measures.

Two methods intended primarily for formative evaluation are the occlusion technique and the lane change task (LCT). It is clear from literature over the last five years that they are commonly employed in both research and design-focused studies. Their popularity may be partly due to their low cost, but also because they are now enshrined as international standards (ISO 2007, ISO 2010).

The study reported in this paper aimed to assess the criterion validity of the key measures associated with occlusion and LCT by making comparisons with results obtained from a medium-fidelity driving simulator. The focus was on measures relevant to the assessment of IVIS distraction.

Occlusion

The occlusion technique focuses on the visual demand of secondary tasks and requires participants to interact with an IVIS while stationary within a vehicle cab under conditions of restricted vision. Typically, occlusion glasses are worn programmed to limit vision to 1.5 seconds “chunks”. Measures are taken of the Total Open Shutter Time (TSOT), that is, the amount of time the glasses were open in the execution of an IVIS task. In addition, IVIS tasks are also carried out with full vision to provide a measure of time needed to carry out tasks when uninterrupted. The ratio of TSOT divided by full vision time provides the Resumability Ratio (R). According to the most recent NHTSA guidelines (NHTSA 2013), a task should not be available on-the-move if TSOT exceeds 12 seconds. Secondly, there is a general view that R should not be greater than 1.0, as this may indicate either difficulties in resuming a task following a period without vision and/or limited opportunities to progress a task in shutter-closed periods (Pettitt, Burnett and Stevens 2007).

Several validation studies have now been conducted concerning the occlusion technique demonstrating the potential of the TSOT measure to differentiate between system designs. For instance, Uno et al. (2010) compared the results of a road study with the data from occlusion, lane-change task and peripheral-detection approaches and concluded that TSOT provided the most sensitive measure with the greatest link to the safety-related impacts of secondary tasks. In contrast, difficulties have been expressed in the interpretation of R, due to the multiple influencing factors (Monk and Kidd 2007).

Lane Change Task (LCT)

The Lane Change Task method purports to assess not only visual demand but also the cognitive demand of IVIS tasks (Young, Lenné and Williamson 2011). The method utilizes software which is widely available and can be run on different simulator platforms. In LCT studies, participants drive along a straight three-lane road at a constant speed of 60 km/h and change lanes in response to the signs that appear on both sides of the road. Throughout the drive, participants must continuously undertake the relevant IVIS task. Various measures can be taken generally focused on the extent to which a driver deviates from an optimum lane-change performance.

Validation studies for LCT have provided mixed results. There is a view that the method is sensitive to the demands of visual-manual user-interfaces (Harbluk et al. 2007), whereas others have found that the approach can only identify particularly demanding user-interfaces (Mattes and Hallén 2009). As Mattes and Hallén state, the LCT method is intended to “distinguish black from white instead of detecting all shades of grey” (p.109).

Reliability and consistency concerns have also been raised regarding LCT, relating to the equipment used, training provided, and in particular the prioritisation that participants should place on the primary (lane changing) versus secondary (IVIS) task (Young, Lenné and Williamson 2011).

Simulator studies

For summative evaluation, the most widely recognized technique is driving simulation. Simulators vary in fidelity (the faithfulness with which reality is represented), and provide flexibility in use, enabling presentation of different driving scenarios and collection of different driving metrics. They also minimize extraneous variables, providing more experimental control than real road driving. Finally, simulators provide a safe environment for participants and researchers, an important feature for studies testing unproven systems. Such a range of advantages means that they are commonly employed as an approximation of real-road driving (Reed and Green 1999).

Nevertheless, a key issue discussed in the literature with respect to the use of simulators in driving research is behavioural validity, that is, the extent to which participants drive the simulator as they would in the real-world. Despite the large number of simulators used in academia and industry, validity studies are rarely conducted, partly due to cost, but also due to the inevitable specificity in findings (i.e. only able to consider validity for a particular simulator configuration and focused scenarios/variables). In the few studies conducted there is a general consensus that driving simulators often demonstrate good relative validity, that is, an experimental effect (e.g. higher speed) observed in a simulator is typically also seen in road trials. In contrast, absolute validity is more difficult to prove, so a driver’s behaviour/performance (e.g. speed) may not be at the same level in the two environments (e.g. Wang et al. 2010). As noted by Reed and Green (1999), such a situation rarely creates a problem in simulator usage as researchers and practitioners are usually looking to identify a relative effect (e.g. is interface A more distracting than interface B?), rather than an absolute one (e.g. is the level of distraction for interface A or B comparable to what would be found on road?).

What constitutes a ‘good’ method for the assessment of IVIS distraction?

There are many criteria for success upon which a human factors method can be judged, some practical (e.g. cost-effectiveness, usability, expertise requirements) and others scientific (e.g. validity, reliability, sensitivity) (Wilson 2005). Although some comments are made in this paper concerning the economy of methods, the emphasis is placed on validity, that is, the extent to which the method measures what it purports to measure (Walker 2010). Validity is a complex concept with many different facets in experimental research. Of significance in Human Factors applications is the extent to which measures provided by a method have real-world significance, and, in this respect criterion validity is a fundamental concept – defined as, “the effectiveness [of a method] in predicting criterion, or indicators of a construct” (Walker 2010). In this case such criteria would be variables rooted in real-world performance with clear safety-related relevance, for example eyes-off-road time or vehicle control.

Method

Participants

Fourteen experienced drivers (8 males; 6 females; mean age 29, SD = 7.4, range 22 – 49). were recruited for the study. Participants had held a driving licence for an average of 10 years (SD = 6.47, range: 4 – 25) and drove frequently (average miles driven/year = 7800, SD = 5325). Participants were paid £50 for their time in High Street Vouchers.

Equipment and Materials

All experimental trials were undertaken within the driving simulator environment located in the Human Factors Research Group at The University of Nottingham. The simulator environment consists of the half front of a right-hand drive Honda Civic (2001 model) with original pedals and steering wheel. For the simulation condition only, STISIM Drive (version 2) software was used to present a three-lane motorway driving scenario on a curved wall, providing a 270° field of view for the driver, together with a rear-projection and side mirror representations. In addition, digital/analogue speed information was presented inside the vehicle and road and engine noise was provided via a surround sound system. For the occlusion condition, occlusion LCD goggles and accompanying software were used. For the LCT, the lane change software developed by DaimlerChrysler AG (Mattes and Hallén 2009) was used and scenarios projected onto the front portion (90°) of the curved wall in front of the driver.

The IVIS system was prototyped on an HP Elite Book Tablet PC with touchscreen and was linked to three supplemental devices (a steering wheel controller, a touchpad and a rotary controller). The touchscreen was located in the central console, the steering wheel controller was situated on the left hand side of the steering wheel and the touchpad and rotary controller were positioned on the transmission tunnel.

A picture of the simulator environment with a participant using the touchscreen under conditions of occlusion is shown in Figure 1.

Secondary IVIS tasks

Three different secondary (IVIS) tasks were chosen for the study representing activities that a driver might (or would like to) perform frequently in a vehicle:

- Menu navigation – selecting an item from menus varying in depth and breadth
- List selection – moving to a music track on a long list (approximately 5 pages away) and then selecting that track.
- Alphanumeric entry – dialling an 8 digit phone number and then pressing call.

The visual interface for all three tasks was presented on the touch screen. Moreover, the tasks could be completed by using the touch screen alone or by using one of three other supplementary devices: A Rotary Controller, which allowed the user to progress through the menus and options by rotating the device; a Steering Wheel Controller, which allowed the user to navigate through menus and options without taking the hands away from the steering wheel; and a Touchpad, which allowed the user to write letters and numbers and also to scroll though lists and menus. These four devices were chosen as they are already used, or might be feasible for use, within a car environment. Comparison of the different devices and tasks is beyond the remit of this paper.

Figure 1 Simulator environment with participant wearing occlusion goggles

Experimental Design

In a within-subjects design, all 14 participants were asked to carry out the secondary IVIS tasks under three different conditions: Driving Simulation; Occlusion; and LCT. The driving simulation condition was conducted first in a single session. Approximately three weeks later, participants were invited back to the simulation laboratory for a second session to carry out the same secondary tasks utilising the occlusion and LCT methods. The order in which participants experienced the occlusion and LCT conditions was counterbalanced.

Dependent variables

The three key measures taken from the occlusion method were: Total Shutter Open Time (TSOT), Task Time with full vision (TT-OCC) and Resumability Ratio (R). The two key measures captured from the LCT method were the mean deviation from the ideal path (MDEV) as well as the mean secondary task time while driving (TT-LCT). The Mean Deviation is a measure of lateral control that is obtained by comparing the actual driving trajectory of the participant to a reference trajectory, referred to as the basic model (ISO, 2010). Both measures are commonly employed and reported in LCT studies (see for example Harbluk, et al. 2007, Bruyas, et al. 2008).

Seven measures were collected for the simulator condition, based on videos and driving performance data. All are commonly employed in simulator studies (Burnett 2009, Green 2007) and are listed below:

- The time needed to complete secondary tasks while driving in the simulator (TT-SIM)
- Total glance time (TGT) – the total amount of time spent with eyes off road viewing the devices
- Mean glance duration to devices (MGD)
- The number of times the glances to devices were greater than two seconds (G>2secs)
- The standard deviation of Headway to lead vehicle (SDHW)
- The standard deviation of Lane Position (SDLP)
- The number of times the participant exceeded the lane (LANEX)

Procedure

Participants were initially provided with an information sheet briefly describing the aims of the study as well as the activities involved. They were asked to sign a consent form and to complete a personal details questionnaire.

During the first session, participants received training on the secondary tasks using the different devices to ensure that all participants were confident and competent in the execution of the tasks. Participants then drove a short (approximately 10 minute) route in the simulator to familiarise themselves with the simulator controls. Participants were then asked to drive four identical routes along a 3-lane motorway (each approximately ten minutes in duration), in which they were required to follow a lead vehicle at a perceived safe distance. During each of the four drives, participants used a different device to carry out all three secondary tasks. The experimenter instructed the participant when they should start each task. The importance of the primary driving task was emphasised.

During the second session, participants only required a brief reminder of the tasks and use of the devices. All participants were familiarised with the equipment, the occlusion technique and LCT task. The relevant ISO documents (ISO 2007, ISO 2010) were followed as far as possible in both cases. For the Lane Change Task, participants undertook a baseline drive (a complete three minutes' drive with no IVIS tasks), on at least one occasion until the MDEV value was less than 1.2 (representing an acceptable level of performance in the primary driving task). Twelve experimental drives (one for each device/task combination) were then conducted. For each drive, participants were instructed to continually execute a secondary IVIS task with a device while changing lanes according to the signs.

For the occlusion protocol, participants were asked to adopt a normal driving position in the car simulator wearing the occlusion goggles. The goggles were adjusted to ensure that the participant could not see the touch screen when the shutter was closed. Afterwards, they were instructed to carry out the three IVIS tasks with each of the four devices. The experimenter prompted the participant when they should start the task, and participants were told to start the task as soon as the shutter was opened after the prompt. In a counter-balanced fashion, in one condition the goggles remained open for the duration of the task (to enable TT-OCC to be measured), whereas in another the goggles opened and closed in 1.5 second periods (to enable TSOT to be measured).

The simulator study session took approximately two hours. The second session with Occlusion and Lane Change Task took approximately one and a half hours to complete.

Results

To study criterion validity, the measures from the occlusion and LCT methods were correlated with measures from the driving simulation. Pearson's Product-Moment Correlation (R) was calculated throughout and significance testing conducted.

Table 1 Correlation values between occlusion and LCT measures and driving simulation measures (* p<0.05; ** p<0.01)

		Driving simulator measures						
		TT-SIM	TGT	MGD	SDHW	SDLP	LANEX	G>2secs
Occlusion	TSOT	0.943**	0.952**	-0.203	0.896**	0.891**	0.840**	0.615*
	TT-OCC	0.800**	0.877**	-0.106	0.840**	0.861**	0.739*	0.571
	R	0.093	0.062	-0.657*	0.025	-0.098	-0.015	-0.303
LCT	MDEV	0.119	0.255	0.032	0.014	0.233	-0.031	0.261
	TT-LCT	0.963**	0.927**	-0.272	0.947**	0.847**	0.779**	0.534

Figures 2 to 5 below highlight some particularly important correlations for the TSOT variable when compared with driving simulator measures (TGT, G>2secs, SDLP and LANEX). Best-fit equations are provided to indicate the nature of the relationship between variables.

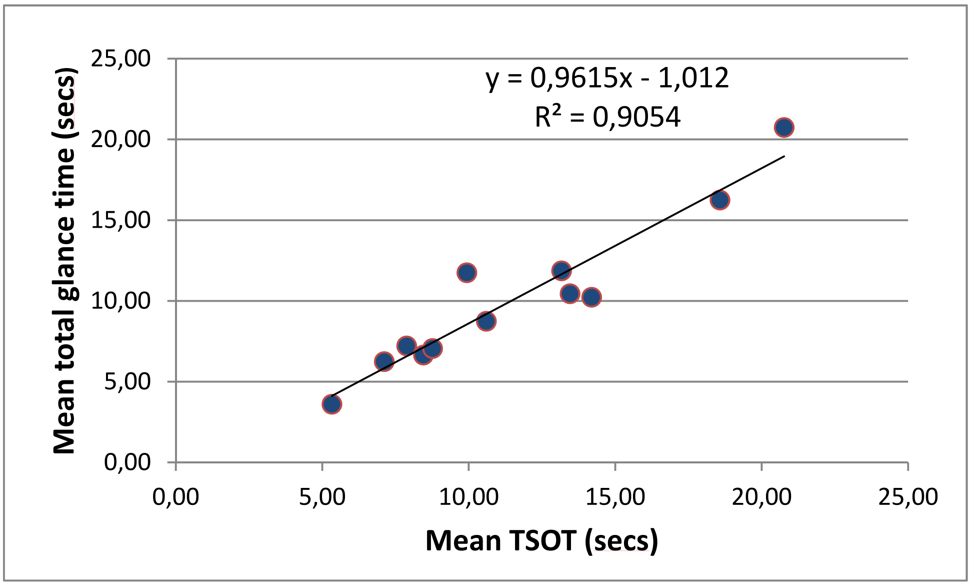

Figure 2 **Scatterplot of mean TSOT (secs) (from occlusion) against mean Total Glance Time (secs) (from simulation)**

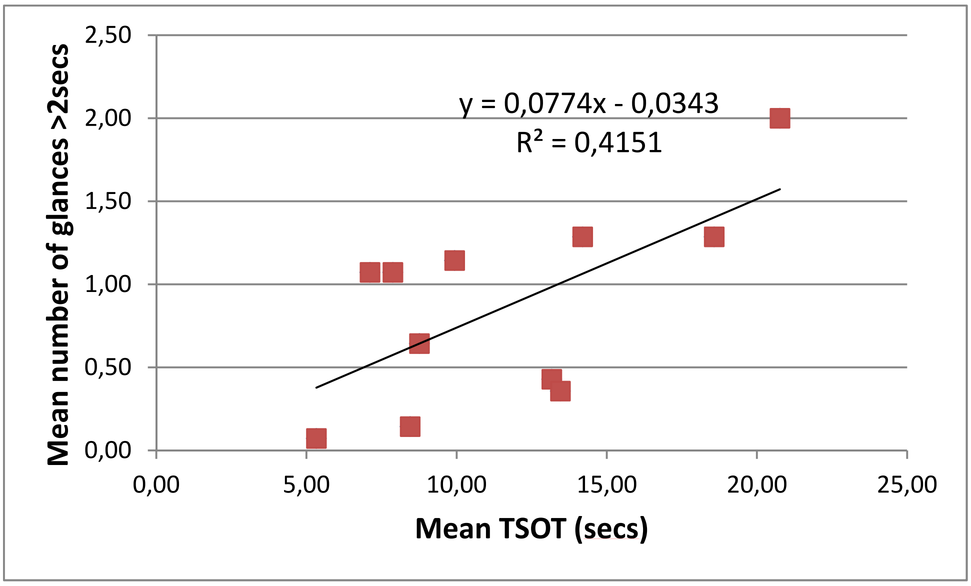

Figure 3 **Scatterplot of mean TSOT (secs) (from occlusion) against Mean Number of Glances > 2secs (from simulation)**

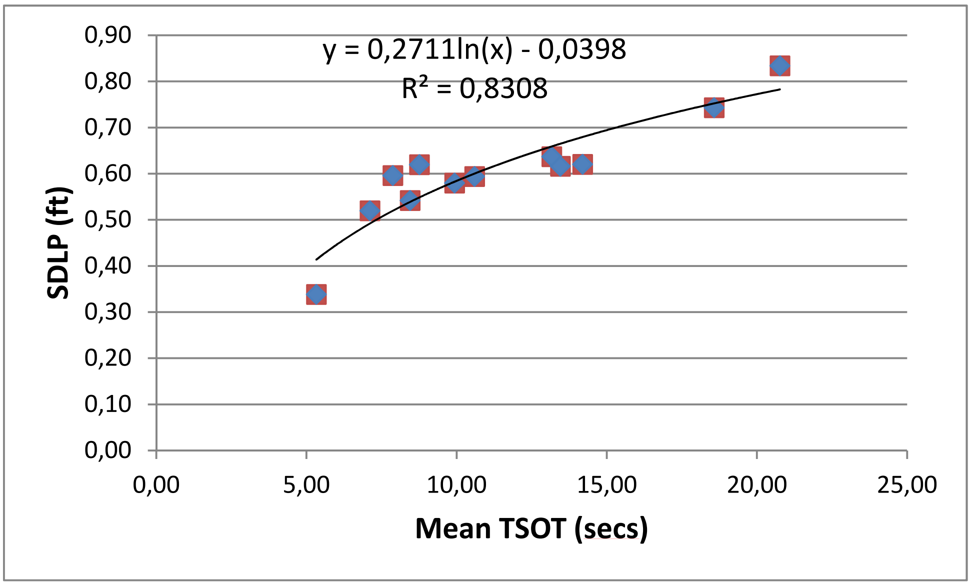

Figure 4 **Scatterplot of mean TSOT (secs) (from occlusion) against Mean Standard Deviation of Lane Position (ft) (from simulation)**

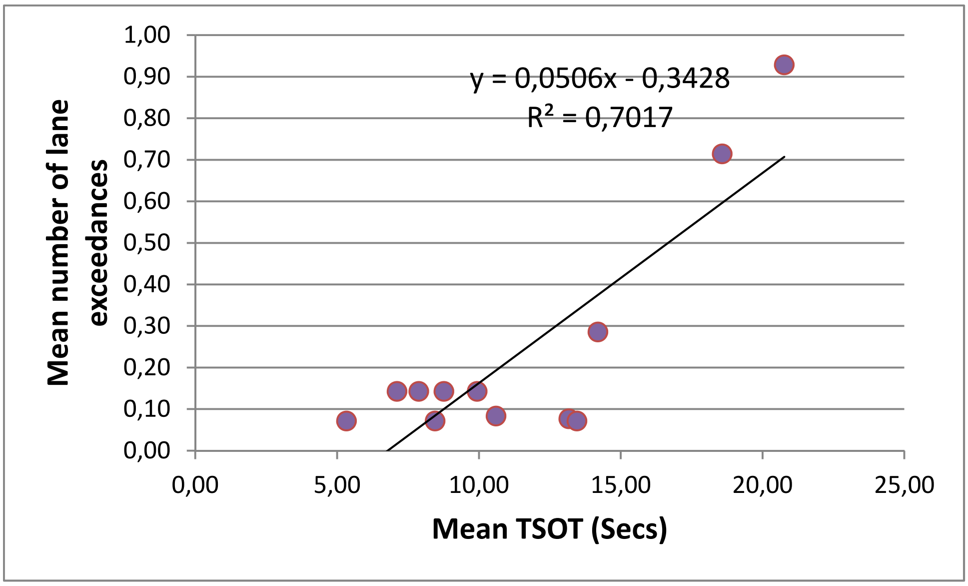

Figure 5 **Scatterplot of mean TSOT (secs) (from occlusion) against Mean Number of Lane Exceedances (from simulation)**

Discussion

A study was carried out with the aim of investigating the criterion validity of the measures associated with two low cost/low fidelity surrogate methods, occlusion and LCT. Comparisons were made with measures collected from a medium cost/mid-fidelity driving simulator study, providing a higher level of fidelity in method and closer approximation to real driving situations.

In order to study the criterion validity of occlusion/LCT, values were correlated with the six driving simulator measures (see Table 1 and Figures 2-5). This analysis investigated if the results obtained from the two different methods had similar magnitude and direction of change to measures grounded in the construct of interest (in this case distraction and driving safety) (Harms 1992).

With respect to occlusion, the TSOT metric was found to have high criterion validity, as it significantly correlated to all of the simulator measures, apart from the mean glance duration. These findings agree broadly with other studies. For example, Angell et al. (2006) and Uno, et al. (2010) investigated how the TSOT correlated to the standard deviation of lane position and standard deviation of headway, resulting in very highly significant correlations. In addition to these metrics, TSOT has been shown to be predictive of total glance time in a large number of studies (e.g. Niiya 2000, Pettitt et al. 2006). Such a consensus in findings are very encouraging for the use of the occlusion technique instead of driving simulation or on-road studies, as the TSOT measure is considerably less labour-intensive to analyse when compared to eyes-off-road time (where frame-by-frame video analysis is commonly employed).

A significant finding in this study not established in previous research was the positive correlation found between the TSOT measure and the number of times that glances to in-vehicle devices was greater than two seconds. This is very relevant given the emphasis placed in the literature on ‘long’ off-road glances as a key safety measure, including the recent NHTSA (2013) guidelines. Consensus in this field is that a long glance is greater than two seconds in duration, based on considerable research in the 1980s and 1990s linking the results of empirical studies on visual demand to accident statistics (Zwahlen, Adams and Debald 1988, Wierwille and Tijerina 1998). The focus here is on the likelihood of extreme visual distraction, as noted in Horrey and Wickens (2007):

> “In general, the unsafe conditions that are likely to produce a motor vehicle crash reside not at the mean of a given distribution (in other words, under typical conditions), but rather in the tails of the distribution”

The time taken to undertake tasks without occlusion (TT-OCC) correlated very highly with several of the driving simulator measures. This implies that time as a resource required to complete a secondary task can act as a basic and simple predictor of various safety-related measures. Indeed, Paul Green at UMTRI made this argument several years ago in the development of a SAE standard (Green 1999). Unfortunately, this position neglects the potential visual intensity of a task interaction, provided by measures such as the number of ‘long’ glances. Intensity measures have clear safety relevance, and cannot be predicted by task time alone.

The correlations between TSOT and dependent variables followed the expected linear relationships. However, for the SDLP measure, the relationship was logarithmic (see Fig. 4). This is most likely due to the nature of SDLP as a limited variable, in which drivers are unlikely to exhibit significant variation in their lane keeping performance.

In this study the Resumability Ratio (R) generally did not correlate to driving simulator measures and appeared to offer little value as a metric. A significant negative correlation was found between R and the man glance duration from the driving simulator metrics. As this was contrary to expectations, it requires some potential explanation. Further analysis revealed that the correlation was associated with one task (list selection) and one device (touchscreen). Two potential reasons for the result can be proposed; firstly, the moving/unstable nature of the list scroll task on the touchscreen promoted long glances when driving, but there was also good opportunity for proceeding the task during the shutter closed period in occlusion, thus reducing R. Secondly, results could have been influenced by participants' strategy on completion of the task. The list scroll selection task had two ways of achieving it (flick scroll or page by page). It may have been that participants generally adopted the technique requiring longer glances when driving (flick scroll) but a more resumable technique (page by page) during occlusion. In general terms, the difficulties in interpreting R results within an occlusion study highlights the overall problem of understanding what this ratio metric actually measures, as noted by Pettitt, Burnett and Stevens (2007).

With respect to the LCT method, the mean deviation measure did not relate significantly to any of the driving simulator measures. This finding is consistent with that from Uno et al. (2010), where the correlations between the mean deviation (from LCT) and the standard deviation of lane position and headway (from a road study) were not significant. It is difficult to postulate reasons why this measure showed poor predictive power. Previous studies have raised concerns over the LCT approach, in particular concerning the learning required to reach a stable level of performance (e.g. Petzoldt et al., 2011) and the effects of framing on instructions relating to what constitutes the primary/secondary tasks (Young et al., 2011). In our work, it was clear that participants often found it difficult to satisfy the ISO requirement to reach a baseline mean deviation value of 1.2. It is feasible that participants developed strategies for timesharing the primary and secondary tasks with LCT that are fundamentally different to those employed in actual driving. Future research could consider this possibility.

In contrast, the mean secondary task times found using the LCT method was found to highly correlate with several of the driving simulator measures investigated. Once again, this indicates the importance of time as a resource with clear safety-relevance in driving distraction studies. Given such results concerning the LCT technique, it may be tempting to solely rely on mean secondary task completion time as the performance measure, due to the lack of criterion validity associated with the mean deviation metric. However, taking into account the time and resources needed to implement the LCT technique, and contrasting it to the limited results it provides, it is questionable if it is appropriate to choose this method over a driving simulator study, or even the occlusion technique.

Conclusions

This paper describes a study in which two low-cost formative design and evaluation methods (Lane Change Test and Occlusion) were compared with a medium-fidelity driving simulation in order to test their criterion validity (or real-world prediction of results).

The occlusion method, in particular the TSOT measure, appears to offer considerable benefits as a low-cost means of evaluating the distraction of IVIS tasks. The most exciting result here was the established link between TSOT and the number of glances greater than two seconds. Further work should aim to verify such a finding utilising a wider range of tasks and systems. Occlusion is of considerable value as an approach to IVIS evaluation, not only as a user trial method, but also because it lends itself to precise human modelling techniques (see Burnett et al. 2011). With such modelling, it is possible to accurately predict human safety-related performance in a matter of minutes, rather than days with no need for participants or the development of working IVIS prototypes.

In contrast, LCT appears to offer little value for human factors researchers and practitioners aiming to evaluate IVIS distraction, at least for the types of visual-manual tasks under consideration in this study. The fundamental metric mean deviation did not predict driver behaviour and performance in the simulator.

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