Chapter 15

Driving Whilst Using In-Vehicle Information Systems (IVIS): Benchmarking the Impairment to Alcohol

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Abstract

Using the lane change task (LCT) a comparison of driving performance was made between normal (baseline) driving, driving whilst using an in-vehicle information system (IVIS) and driving while intoxicated at the UK blood alcohol level (80 mg per 100 ml). The results provided clear evidence for impaired performance of the LCT when performing an IVIS task in comparison to both baseline (LCT alone) and alcohol conditions. However, the LCT was found to be insensitive to the effects of alcohol in the absence of a secondary task. It is concluded that LCT performance can be impaired more when undertaking certain IVIS tasks than by having a blood alcohol level at the UK legal limit but the LCT requires further development before it can be used as a convincing proxy for the driving task.

Introduction

Driving is a complex, multi-task activity undertaken by a large proportion of the adult population in many developed countries. High levels of attention and vigilance are required to prevent incidents that may have fatal consequences. A realistic estimate of global road fatalities is between 750,000 and 888,000 for the year 1999 (Aeron-thomas et al., 2000) with driver error widely accepted as a major contributory factor (Treat et al. 1979). Many safety interventions have been successfully implemented to reduce the crash rate and the injury consequences of crashes, with the majority involving engineering, regulation and driver education.

The ICT revolution first impacted on road transport with the introduction of in-vehicle information systems (IVIS), systems intended to support drivers by providing information relevant to the task of driving. More recently, advanced driver assistance systems (ADAS) have been implemented that are capable of providing continuing or critical incident support to the driver. In both cases, concerns about increased task demand have been raised by human factors engineers. The risk with respect to IVIS systems is perceived as being particularly acute as the introduction of an additional information display or secondary task in a vehicle may result in driver distraction and thus increase the risk of an incident. The development of methods capable of assessing driver performance under dual task conditions (driving and interacting with an IVIS system) has been recognised as critical to the development of IVIS systems that can be used successfully and safely by drivers. This chapter presents an attempt to provide a performance baseline for an assessment measure that would enable experimental results to be considered in a "real world" context.

The need to find a criterion for acceptable driving performance when drivers are using IVIS is an important one. The lane change task (LCT; Mattes and Hallén 2009) is one of the growing number of methods developed to quantify driving performance degradation brought about by the use of in-vehicle devices (Young et al. 2011; see also Chapter 13 in this volume). The LCT is a laboratory-based, combined control and event detection measure based on the dual task paradigm. It is a PC-hosted driving simulation that requires participants to maintain control of a virtual vehicle and respond to on-screen instructions. The dual task paradigm proposes that primary task performance will degrade with the introduction of a secondary task. In this case LCT performance can be viewed as the primary task and it is designed to be analogous to the driving task.

The LCT has been used widely 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 ADAS that directly support the primary driving task (Burns et al. 2005, Engström and Markkula 2007, Harbluk et al. 2007, Bruyas et al. 2008, Wilschut et al. 2008, Wynn and Richardson 2008, Mattes and Hallén 2009, Harbluk et al. 2009, Wynn et al. 2009, Young et al. 2011).

As the number of studies using the lane change task increases, it is important to know what the results mean in the wider context of the driving environment, as poor performance on the LCT does not necessarily equate to unsafe performance when driving on the highway. A comparison to a widely accepted safety criterion such as blood alcohol concentration (BAC) would provide a context in which to place these results. However, as Lansdown et al. (2004) note, "it has been conspicuously difficult to bridge between theoretical and empirical findings to develop safety criterion regarding acceptable in-transit human interface interactions".

An acceptable risk threshold can be assessed in relative terms by comparing the effects on driving performance of IVIS use to the effects of other common risk factors (e.g., alcohol intoxication), as the risk imposed by these legislated limits can be considered a baseline of "sanctioned risk"; that is, that which has been defined as morally acceptable by wider society (Rakauskas and Ward 2005). Driving with a blood alcohol concentration at the legal limit is an established indicator of increased risk of accident involvement. It is widely accepted that driving performance whilst under the influence of alcohol is impaired and, as such, legislation commonly exists that prohibits driving when above a given blood alcohol concentration (BAC). The same is not true with regard to in-vehicle information systems, which are widely regarded as a potential cause of driver distraction. With the rapid uptake and use of new devices this is of increasing concern to policy developers and regulators and as such is becoming a focus of current research efforts.

Alcohol and driving

The effects of alcohol on driving performance have been well established in the research literature. The seminal "Grand Rapids" study (Borkenstein et al. 1964) established a risk function relating alcohol consumption and accident risk that has resulted in a range of international legislative responses; in the USA, Canada and the UK the legal limit is a BAC of 0.08 per cent; Australia, France, Germany and Italy 0.05 per cent; and Norway and Sweden 0.02 per cent. Impairments of simulated driving performance have been demonstrated even at modest blood alcohol concentrations. Arnedt et al. (2001) have identified the acute impairments of alcohol in a simulated environment. Noting a dose-dependent relationship between alcohol and performance degradation of psychomotor performance, impairment of both tracking variability and an increased number of off-road incidents were observed. Other effects of alcohol on driving performance in a driving simulator have also been observed: decreased steering ability (Dott and McKelvey 1977); increased speed variability (Gawron and Ranney 1988); increased standard deviation of lateral position (Lenné et al. 2003); reaction time increases (Zwahlen 1976, Laurell 1977); and greater brake reaction time and body sway (Liguori and Robinson 2001).

The effects of low doses of alcohol on cognitive performance which have been found include significant impairments of divided attention, and immediate and delayed free recall; however, no impairment of word recognition was observed despite delays in reaction time to the words (Parks et al. 2002). Other cognitive effects of alcohol include impaired response inhibition (Fillmore and Vogel-Sprott 1999, 2000), restricted focus of attention (Steele and Josephs 1990) and risk perception (Frick et al. 2000). Lenné et al. (1997) suggest a note of caution regarding the use of driving simulators to assess the impairment of driving performance by alcohol in that degradation of psychomotor performance occurs more rapidly in a simulated environment in comparison with real task performance. Although the degree of impairment is dose-related, it is not identical or linear for all behaviours. Behavioural skills requiring cognitive functioning suffer the greatest impairment.

Driving and mobile phone use

In the UK, legislation regarding the use of hand-held mobile phones while driving prohibits drivers from using any "device, other than a two way radio, which performs an interactive communication function by transmitting and receiving data" (The Road Vehicles (Construction and Use) (Amendment) (No. 4) Regulations 2003, paragraph 2), including hand-held mobile phones. This amendment was passed on the strength of research evidence (Burns et al. 2002) that suggests that driving while using a mobile phone is detrimental to performance of the driving task, so much so that performance is degraded to unsafe levels.

There is growing evidence for the influence of mobile phone usage on crash statistics, and a number of epidemiological studies have attempted to quantify this risk. Up to nine-fold increases in risk of fatality have been reported for drivers who use mobile phones while driving (Dragutinovic and Twisk 2005, Violanti and Marshall 1996, Violanti 1998, Redelmeier and Tibshirani 1997a, McEvoy et al. 2005).

Violanti and Marshall (1996) report that participants who spent more than 50 minutes per month talking on their mobile phones while driving were 5.59 times more likely to be involved in a road traffic accident than those who used their mobile phones less frequently. In addition, Violanti (1998) analysed 223,137 reported road crashes in the state of Oklahoma between 1992 and 1995 and found that the likelihood of fatality was approximately doubled (OR=2.11) by the presence of a mobile phone in the vehicle, in comparison with the risk for drivers with no mobile phone in their car. Drivers who reported using a mobile phone stood an approximate nine-fold risk of a fatality compared with drivers who did not use a phone (OR=9.29). Similarly, McEvoy et al. (2005) found a four-fold increased likelihood of crashing (OR = 4.1), irrespective of whether or not a hands-free device was used (hands-free: OR=3.8; hand-held: OR=4.9).

Laberge-Nadau et al. (2003) examined the relationship between mobile phone use and road crashes by analysing 36,078 responses to a postal questionnaire about driving behaviour,[1] in comparison with mobile phone activity (provided by mobile service provider companies) and police reports for the previous four years. Results suggest that the relative risk for all collisions is 38 per cent higher for mobile phone users. When taking into account potentially confounding variables (kilometres driven, driving habits, educational level, listening to and adjusting the radio, CD player etc.), the adjusted relative risk for all collisions was 1.11 for male phone users and 1.21 for female phone users compared with non-users. Furthermore, there was a dose–response relationship between the frequency of mobile phone use and crash risks. The adjusted relative risks for heavy users were at least double (OR = 2.21 for those making 193–258 calls per month, 2.73 for those making 259–384 calls and 2.42 for those making more than 385 calls per month) compared with those making minimal use of mobile phones. Light mobile phone users were found to have similar collision rates as non-users.

Talking on a mobile phone is distinctly more risky than listening to the radio, talking to passengers and other activities commonly occurring in vehicles (Redelmeier and Tibshirani 2001). Conversational phone use seriously impairs a driver's ability to perform basic driving manoeuvres such as changing lanes and adapting speed (McKnight and McKnight 1993, Hancock et al. 2003). Performance of the driving task while simultaneously using a mobile phone becomes increasingly difficult as speed increases (Shinar et al. 2005). Calls close to the time of the collision were particularly hazardous: the relative risk was 4.8 for calls within five minutes before the collision, compared with 1.3 for calls more than 15 minutes before collision (Redelmeier and Tibshirani 1997a).

Redelmeier and Tibshirani (1997b) studied 699 drivers who had cellular telephones and who were involved in motor vehicle collisions resulting in substantial property damage but no personal injury, who reported to the North York Collision Reporting Centre between 1 July 1994 and 31 August 1995. The mobile phone records of each participant were analysed for activity on both the day of their accident and the preceding seven days, with particular attention to the time, duration and direction (incoming or outgoing) of each call. It was found that the "relative risk" of having a car accident is increased four-fold when a mobile phone is present. The relative risk of accident involvement is similar to the level of risk associated with driving with a BAC at the legal alcohol limit (BAC 0.08 per cent); however, the relative risk of a collision is considerably higher when driving with a BAC above the legal limit. (Simpson, 1985, suggests a ten-fold increase in relative risk with a BAC 50 per cent above the legal limit.) Furthermore, it is often noted that the effects of phone-related distraction are episodic whereas alcohol intoxication can be extended.

Rakauskas and Ward (2005) aimed to assess the relative risk of impairment resulting from mobile phone usage compared with the impairment caused by driving with a BAC of 0.08 per cent. Using a motion-base advanced driving simulator and a car-following task they found that driving performance while talking on a mobile phone was consistently worse than baseline performance (driving with no secondary task). Notably, sober drivers interacting with IVIS tasks were often more impaired than intoxicated drivers driving without performing a secondary task. They reported significantly higher headway variability and speed coherence in both in-vehicle task (prompted HVAC and radio adjustment) and cell phone task conditions compared with a baseline condition.

1 Items included on the questionnaire related to driving habits, exposure to risk, opinions about activities likely to be detrimental to safe driving, socio-demographic information, information about potential crash involvement within the last 24 months and additional questions about mobile phone use.

Burns et al. (2002) attempted to benchmark the impairment of both hands-free and hand-held phone conversation to alcohol intoxication at the UK legal limit (alcohol was individually determined for participants using the Widmark factor (Widmark 1932, Watson et al. 1981). Twenty participants drove a 15 km route in the TRL advanced driving simulator. There were four conditions – control (no talking, just driving), alcohol (no talking, driving with alcohol), hand-held (HH) conversation and hands-free (HF) conversation. The phone conversation task consisted of questions from the Rosenbaum Verbal Cognitive Test Battery (Waugh at al. 2000) that measures judgement, flexible thinking and response times. The test consists of 30 sentence memory tasks and 30 verbal puzzle tasks. Results showed that performance when driving while intoxicated at around the legal limit was significantly worse than baseline driving performance.

Poorest performance, however, was on measures of driving behaviour (speed, control and response time) when participants were engaged in the mobile phone conversation tasks (talking and listening but not dialling); HH conversation was significantly worse than HF. For example, the root mean square (RMS) error at 60 mph on curves, a measure of lateral position consistency, was significantly higher in the HH condition than in the control and HF conditions. Mean speed was significantly slower in the HH condition than in the alcohol condition. The standard deviation of speed was not significantly different for driving on the straight; however, when navigating curves, the HH group showed significantly greater variation than the control or HF condition.

Lane-keeping performance was not significantly different between groups, except for the part of the route that was dual carriageway, where the alcohol group performed significantly poorer than the control, HH and HF groups. Reaction times to the presence of road signs were significantly longer than in the control condition (12.4 per cent longer for alcohol, 26.5 per cent for HF and 45.9 per cent for HH). Within these data, reaction times were found to be significantly slower in the HH and HF conditions than in the control and alcohol conditions. Furthermore, misses and false alarms were also significantly more frequent in the HH and HF conditions than in the alcohol condition. Drivers also reported that it was easier to drive in the alcohol condition than to drive while using a phone. Overall, it was concluded that driving behaviour was more impaired during a phone conversation than by having a blood alcohol concentration at the UK legal limit (BAC 0.08 per cent).

Further comparisons of performance between intoxicated drivers and those using mobile phones were undertaken by Strayer et al. (2003). They used a driving simulator to compare drivers' performance in a car following task in a number of conditions (baseline, mobile phone and alcohol intoxication). It was found that drivers in each of these conditions exhibited different driving profiles. Drivers in the cell phone condition exhibited 8.4 per cent slower reactions than the baseline group and compensated for this by driving 3.1 per cent slower, increasing their following distance by 4.4 per cent. Drivers in the alcohol condition demonstrated a more aggressive driving style; in comparison with the baseline condition their headways were 3.0 per cent shorter and their brake force was 23.4 per cent greater in response to an unexpected collision event. Controlling for time on task and driving difficulty, drivers talking on a mobile phone were more impaired, with respect to brake onset time and following distance, than drivers under the influence of alcohol.

Using a driving simulator, Reed and Robbins (2008) assessed the relative impairment of text messaging while driving on the performance of participants from the 17–25 years age group. They subsequently compared their results with those found in earlier TRL studies; Sexton et al. (2002), looking at the impact of cannabis and alcohol on driving; and Burns et al. (2002), looking at alcohol and mobile phone use while driving. They found that reaction times to a visual stimulus, presented as a red bar above the carriageway, were 34.7 per cent greater when text messaging while driving. These reaction times were longer than those for alcohol (Burns et al. 2002; 12.4 per cent higher), cannabis (Sexton et al. 2000; 21.0 per cent higher) and hands-free conversation (Burns et al. 2002; 26.5 per cent higher), but less detrimental than using a mobile phone for hand-held conversations (Burns et al. 2002; 45.9 per cent higher). Reed and Robbins' (2008) participants drove more slowly in the text messaging condition; compared to a control condition mean speeds in unconstrained motorway driving were on average 6.3 per cent lower while text messaging. In comparison, in a study of mobile phone use (for voice) participants drove around 2.2 per cent slower when driving with their phone hands-free and 4.8 per cent slower when using their phone hand-held than a baseline condition (Burns et al. 2002). However, greater speed reductions were observed when drivers were intoxicated with cannabis compared with a placebo condition (7.7 per cent; Sexton et al. 2000, 9.1 per cent, Sexton et al. 2002). It would seem likely that the reduction in speed observed in these studies reflects a desire to increase safety margins because of the self-perceived impairment and does not indicate a real safety improvement.

Quantifying distraction potential

A number of safety-critical principles regarding the time an IVIS task should take to complete have been proposed. The main guiding principle is the "15-second rule" proposed by the Society of Automotive Engineers (SAE J2364 1998). This proposal suggests that a task can be considered safe to undertake whilst driving when it takes 15 seconds or less to complete when executed without driving (static task time), given that there is a high correlation between task time, while driving, and total eyes-off-the-road time. If the task requires 15 seconds of continuous visual attention, it is likely to impede performance of the driving task and therefore pose a significant threat to safety (Tijerina et al. 1998). Alternatively, Zwahlen et al. (1988) recommend that, for safety reasons, drivers should not be distracted from the driving task for more than two seconds. This is reflected in the European statement of principles (European Commission 2006), which recommends that a task should take no more than four glances, with maximum eye glance durations of two seconds (giving a total glance time of eight seconds). Similarly, the Society of Automotive Engineers (SAE J2364 1998) recommends that the duration of a single glance away from the road scene while the vehicle is in motion should not exceed two seconds. In addition, the task completion should not require more than a total of 20 seconds of total eye glance time to the system display or controls.

Measures based on static task time can be criticised, as many of the proposed limits are somewhat arbitrary. Much of the evidence available supports maximum times well under the 15-second limit (Dingus 1988, Campbell et al. 1997, Tijerina et al. 1998, Green 1998, Tijerina et al. 2000). In particular, the 15-second rule cannot be used to reliably predict the acceptability of a device, although it has been found to be effective at identifying the most distracting tasks. However, much of the evidence evaluating the diagnostic sensitivity of J2364 has concluded that, in general, the probability of accurately classifying unsafe performance is around chance level and, in this regard, the discrimination accuracy is comparable to far greater time limits (e.g., 30 or 45 seconds; Parkes and Hooijmeijer 2000). It is important to note that lower task time limits (< ten seconds) further reduce the distraction potential of IVIS, but may be too restrictive in terms of the tasks that would be allowed. It is for this reason that new metrics such as the occlusion technique and the LCT have been considered as replacement measures. A practical result of the 15-second rule is that most destination entry tasks will not be allowed in moving vehicles.

Currently, the major alternative approach to assessing the distraction potential of IVIS is the occlusion technique. The occlusion technique is designed to reproduce visual time-sharing between the road and IVIS devices (Goujon 2001). The main apparatus used to run the occlusion method are PLATO goggles (portable liquid-crystal apparatus for tachioscopic occlusion; Milgram and van der Horst 1984), the lenses of which can switch between transparent and opaque states on the passing of an electronic trigger signal, thus obstructing the view of participants within a matter of milliseconds. The key premise of the occlusion technique, when using it to evaluate IVIS tasks, is that the periods when participants' vision is occluded are representative of their glances to the road scene. ISO 16673 (2007), the occlusion technical standard, specifies an evaluation procedure for the laboratory based assessment of in-vehicle systems involving a 1.5 s viewing procedure and 1.5 s occlusion period.

Using a task designed to meet the static criterion of a total task time of 15 seconds, Baumann et al. (2004) argued that the occlusion tool is an appropriate method for evaluating the safety of IVIS. The task involved the presentation of short text messages on a hand-held computer suitable for in-car use (containing the names of German highways). The texts were presented at a rate of three words per screen and each screen was presented for an occlusion period lasting 0.7 seconds. The participants were required to recall the names of the highways included in the text and answer questions regarding the content of the text message. Degradation in performance was observed in the occlusion condition where the task was interrupted at two-second intervals. Around one third of answers in the occlusion condition were correct. Information presented during the interruption phase of the trial was lost and could not be recovered, making it difficult to complete the task.

This illustrates that a task can meet Green's (1998) 15-second criteria but at the same time participants fail to complete the task within Zwahlen et al.'s (1988) requirement that each interaction with the system should take no more than two seconds. Recommendations regarding acceptable values for un-occluded vision (total shutter open time, TSOT) have been made; however, research suggests that many driver support systems seriously exceed these (Baumann et al. 2004).

There is limited research that has successfully established the validity of the visual occlusion technique as a measure of driver distraction. The research that does exist lacks consensus regarding the best means of achieving occlusion: on the length of the interval periods (Gelau et al. 2009); whether the occlusion and inspection intervals should be computer- or self-paced (Rolle 2006) and if they should be fixed or variable (Altmann and Trafton 2002); the level of training given to participants (Stevens et al. 2004) and whether a distracter task is necessary during the occlusion interval to prevent participants from rehearsing their next move or operation during this period (Monk and Kidd 2007).

It is important to recognise that key aspects of time-sharing are ignored by the occlusion technique (Lansdown et al. 2004). Participants are able to maintain their task goal state during the occluded periods without interference from another task. This is contrary to naturalistic driving where drivers perform several tasks while looking at the road, such as monitoring the road and traffic and looking for navigational cues. The technique therefore produces an estimate of performance that fails to account for any attentional cost when switching back and forth between two tasks. Therefore, it is difficult to know if participants are able to resume the IVIS task without any attention switching latency.

Furthermore, the occlusion technique does not take into account the interruptability of the task (Noy et al. 2004, Chiang et al. 2004, Pettitt et al. 2006). The problem with assessments based on total glance time is that a high value implies that the task would be unsafe; however, a task that can be completed with multiple short glances will not affect performance in the same way as a task that can be completed quicker but requires much longer individual glances. For example, a task with a total glance time value of ten seconds comprising ten individual one second glances is more desirable than a task that takes five seconds to complete but comprises a single five second glance. Chiang et al. (2004) found that participants took longer than 15 seconds to complete a number of destination entry tasks; however, 92 per cent of all glances lasted less than two seconds, indicating that drivers can accommodate tasks that are user-paced and interruptible even if they exceed the prescribed 15-second limit.

The present study

Rather than relying on design principles such as the 15-second rule, an alternative approach is to make comparisons between IVIS impairment and the level of impairment that equates to an accepted safety-critical criterion, in this case alcohol. There is a long-standing legal precedent regarding the consumption of alcohol and driving. The same is not true with regard to in-vehicle information systems. The current study, using a comparable methodology to the study of Burns et al. (2002), was intended to be a first step towards establishing a similar benchmark for IVIS devices. The purpose of this study was two-fold: firstly, it established the potential for distraction that may arise from the use of IVIS devices; and, secondly, it established a safety-critical value for the lane change task (LCT), above which performance can be considered unsafe and would be considered unacceptable. Without this process there is a difficulty in quantifying performance of the LCT. Currently the only LCT comparison undertaken is between dual- and single-task performance. This does not inform us as to whether the difference in performance is important and nor does it reveal whether IVIS will become a significant problem for drivers. Worse-than-normal driving when using IVIS devices does not necessarily mean that driving is dangerous.

It is reasonable to suggest, for reasons identified below, that the LCT method, a laboratory-based combined control and event detection metric, would be sensitive to the effects of both alcohol intoxication and IVIS use. We would expect mean deviation from the normative model (see Figure 15.5) to increase in the alcohol condition, as participants' reaction times are likely to increase (Zwahlen 1976, Laurell 1977, Sexton et al. 2000, Sexton et al. 2002, Burns et al. 2002), resulting in later lane changes. Also, evidence regarding SDLP suggests that lateral control and course following become impaired when intoxicated by alcohol (Dott and McKelvey 1977, Arnedt et al. 2001, Lennéet al. 2003, Sexton et al. 2000, Sexton et al. 2002, Burns et al. 2002), which would be likely to impede a driver's ability to follow the normative model and increase the level of deviation from this course.

Method

Participants

Fifteen participants (seven females; eight males) were selected at random from a volunteer database owned and managed by TRL; a pool of 1,300 drivers that represent a cross-section of the UK driving population. Participants were required to have a full UK driving licence and normal or corrected vision. Participants with possible alcohol problems (identified by self-report) were excluded; however, participants were required to be regular consumers of alcohol. Alcohol-abstaining drivers have little or no tolerance to the effects of alcohol. In contrast, excessive drinkers are able to tolerate increased levels of alcohol in the body without demonstrating the outer symptoms associated with alcohol consumption such as loss of concentration, impaired vision, loss of balance etc. (Chesher and Greeley 1992). Drivers drawn from either of these sub-groups would produce behaviour that was not representative of the majority of the driving population.

Participants were paid £30 for their involvement in this study. Due to the nature of this study they were also provided with transport to and from the experimental facility.

Design

A within-subjects "repeated measures" design was used with each subject completing each of the three conditions. This was a partly counterbalanced trial design, so that learning effects could be controlled for in the statistical analysis. The only condition that was not counterbalanced was the alcohol condition as it was impractical to wait for participants' BAC to return to zero before completing further sessions. The alcohol condition was, therefore, always the last part of the experiment.

Alcohol

Participants were required to drink an alcoholic beverage. The beverage comprised vodka (40 per cent) plus a disguising mixture (e.g., creamsoda) mixed using the adjusted Widmark formula (Watson et al. 1981) – so that participants become intoxicated at the legal limit (BAC 0.08 per cent) with the volume of the mixer adjusted to maintain a 20 per cent total volume. A breathalyser (Lion laboratories alcometer SD-400) was used to measure breath alcohol content (BrAC), from which BAC can be estimated using Henry's law. Care must be taken to ensure that deep lung air rather than air from the upper respiratory tract is sampled, because this is the air that has been in contact with the blood. If the measurement is taken too soon after the participant has consumed their last drink, the reading would be artificially high due to residual alcohol in the mouth. It is recommended that at least 15–20 minutes elapses between the subject's last drink and the breath test (Emerson et al. 1980).

In-vehicle information systems (IVIS)

The IVIS used in this experiment was a Hewlett Packard iPAQ (PDA) and an eight-inch TFT LCD monitor running a popular satellite navigation system application and a bespoke data display application. These were situated on the desktop in a location that reflects their typical location in the vehicle cockpit (see Figure 15.1).

Figure 15.1 Lane change task experimental paradigm

In the IVIS conditions participants were required to complete four LCT trials. Each of these trials was dedicated to one of four IVIS tasks; entering a destination by selecting a "point of interest" (POI) using the PDA; entering a destination via use of the "address" function using the PDA; and a *scrolling share task* (two levels), which comprised a three-letter stock code presented verbally which had to be located within a single-column scrolling display located on the vehicle dashboard. When participants had located the target stock code they were required to report the price located to the right of the code (Pettitt et al. 2005). To increase the demands placed on the driver in terms of workload there was a second version of this task in which participants were required to locate a share price embedded within three columns of ten stock codes (see Figure 15.2). This task is primarily a visual task. As such, it competes for resources with the visual elements of the driving task (e.g., event and obstacle detection, sign reading etc.). In terms of the LCT, the scrolling shares tasks compete for resources that would otherwise be dedicated to visual aspects of the LCT, including event detection.

QBY	£76.12	MKH	£34.76	ERR	£77.34
HBN	£23.45	SDF	£34.56	GYO	£34.64
JAC	£33.28	YHR	£15.36	QWE	£51.31
PPL	£58.92	LKJ	£44.23	MMN	£72.66
FNA	£56.34	RMT	£81.46	MWP	£34.65
RES	£67.45	HSL	£10.98	WDR	£12.36
RLQ	£45.86	RST	£18.48	EDF	£51.90

Figure 15.2 Screen shot scrolling share price task

Horberry et al. (2007) evaluated the four IVIS tasks used here using expert opinion and "keystroke level model" task analysis (KLM; Pettitt et al. 2007). The KLM technique involves breaking down the task into its basic actions, referred to as operators, which include key presses and hand movements. The total time taken by an expert performer can then be calculated, accounting for both mental and physical tasks (Table 15.1). The tasks were assessed on four criteria: input (how the driver enters information); task (what needs to be done); display (what information is presented); and output (what results are displayed by the system). The negative, neutral and positive factors

Table 15.1 Results of observed and predicted TSOT and R (adapted from Horberry et al. 2007)

Task	Predicted TSOT	Observed TSOT	Predicted R	Observed R
PDA POI	7.50	7.63	0.96	0.85
PDA address	10.50	11.77	0.77	0.81
Shares short	7.35	10.94	0.58	0.78
Shares long	5.85	11.62	0.73	0.87

of each task were identified. Table 15.2 provides a summary of the expert review in terms of these factors with an aggregate score (positive minus negative features) calculated for each task.

Total task time (TTT) was calculated for each of the IVIS tasks. This serves both as a measure of the costs associated with performing the LCT and IVIS tasks concurrently, and as a comparison between other methods of quantifying the distraction potential of the IVIS tasks used.

Table 15.2 Summary of scores from the expert review matrix

Task	Positive features	Negative features	Total score
PDA POI	14	9	+5
PDA address	8	7	+1
Shares short	3	11	-8
Shares long	3	12	-9

Lane change task

The LCT requires participants to "drive" a 3,000 m long section of three-lane highway presented on the monitor of a desktop driving simulator (see Figure 15.3). Participants are instructed by signs on the roadside (150 m apart) to perform a lane change manoeuvre (see Figure 15.4). During this task participants are required to perform a specific secondary task. To avoid speed confounding the results it is controlled by the program and is kept at a constant 60 km/h. The illumination reflects daytime driving with a constant light level. Visual information is presented using an egocentric (front) view; no rear or side view information is presented.

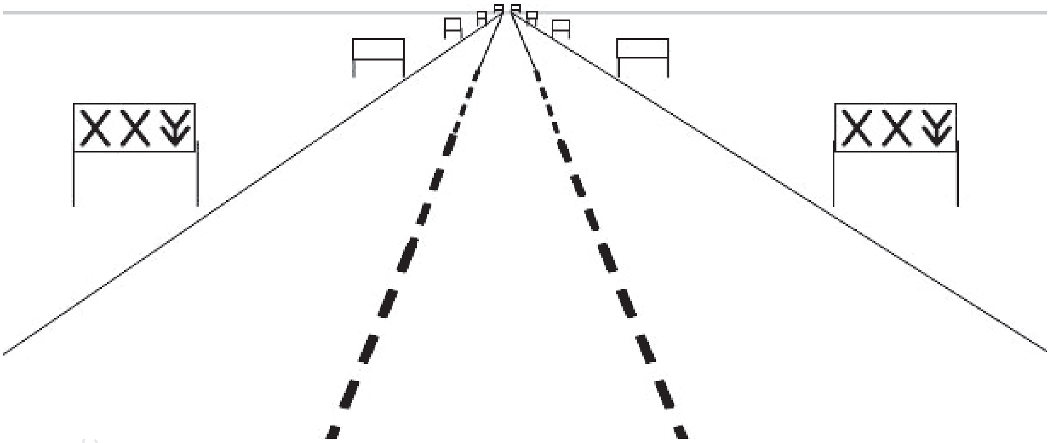

Figure 15.3 In this instance the driver has to change from the centre lane to the right lane (source: ISO 26022:2010. Reproduced from a screen shot from the LCT, with permission)

Figure 15.4 LCT signs: (a) left, (b) centre, (c) right (source: ISO 26022:2010, with permission)

Participants are required to change lanes when instructed. When not performing a lane change manoeuvre they are required to maintain a central position within the lane. Performance of the lane change task by itself is used as a measure of baseline performance for comparison with performance of the LCT when performed with a secondary task.

During a trial the LCT program automatically records data to the computer on which it is running. From this data the LCT analysis program can calculate a number of performance measures. These include mean deviation from the normative model (see Figure 15.5), standard deviation from the normative model and mean steering angle, as well as time course and distance information to allow for standardisation of experimental runs. The normative model is an "ideal" path which assumes a centre lane position and a consistent lane change manoeuvre. The only parameters that are free to vary are the distance at which the lane change sign is displayed (onset) and the angle of deflection for the lane change. Default values were used in both cases in the current study.

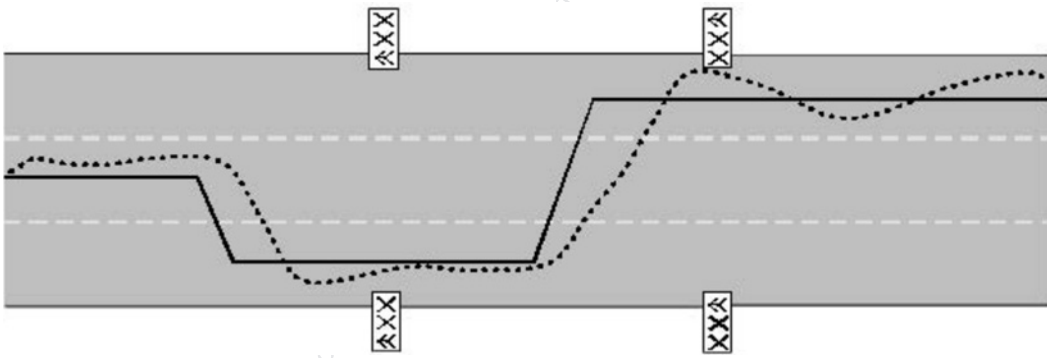

Figure 15.5 The LCT compares the normative model (solid line) to the participant's driven course (broken line) (source: ISO 26022:2010, with permission)

Procedure

Informed consent was sought from participants prior to commencement of the experiment. Upon giving consent participants were required to complete a health questionnaire to ensure that their participation was consistent with the study's ethical approval. All participants were breathalysed before the experiment started to ensure that they were not already intoxicated.

Participants completed a practice session in order to familiarise themselves with the operation of the LCT simulator. This consisted of a maximum of five practice laps, or until the participant felt comfortable with the demands of the task. Similarly, participants were able to practise the four IVIS tasks prior to starting the IVIS trials. Each practice session included five example tasks for participants to complete. During the experimental conditions participants were required to complete 14 LCT trials lasting 45 minutes in total. Five of these trials were completed without the presence of a secondary task and without the influence of alcohol. These trials served to act as a baseline measure of driving performance. In the IVIS conditions participants were required to complete four LCT trials, one for each of the four IVIS tasks. The order of IVIS trials was counterbalanced across subjects.

In the alcohol condition participants were given ten minutes' drinking time in which to consume the intoxicant, followed by a brief waiting period (40 minutes from finishing the drink). The justifications for such a waiting period are that the effects of alcohol take around 20-65 minutes to reach their peak and it may take this long for any residual alcohol on the breath to disperse. Participants were breathalysed again prior to beginning the LCT section of the experiment to ensure that they were at, or over, the legal limit. Participants were then required to perform a further five three-minute LCT trials lasting a total of 15 minutes. Instructions were provided to participants as to how to complete the LCT trials. Participants were required to remain in the facility for some time after completion of the alcohol condition LCT trials to allow the BAC to return to a normal level.

The experimental design was partially compromised in that, while the order of IVIS tasks was counterbalanced, all subjects undertook the alcohol condition last. This introduced a possible practice effect but was necessitated by the impracticality of restoring subjects to a sober state (without residual impairment) following the alcohol condition. Furthermore, the uncontrolled effect would presumably have acted to enhance performance in the alcohol condition rather than improve it in the IVIS condition, thus providing a less challenging test.

Two performance measures were calculated for each condition of the study, the participants' mean deviation from the LCT normative model and the mean total task time (TTT) for the four IVIS tasks. These two global measures indicate participant response to the demands of the two concurrent tasks.

Results

A one-way, repeated measures ANOVA was calculated for mean deviation from the normative model on the LCT across the six conditions (Baseline, PDA POI, PDA address, shares short, shares long and alcohol). There was a significant main effect by condition for mean deviation from the normative model [F (5, 15) = 14.421, $P<0.05$]. A Tukey post hoc comparison of the six treatment conditions was conducted. There was a number of significant comparisons (baseline and shares short, baseline and shares long, baseline and PDA POI, baseline and PDA address, alcohol and shares short, alcohol and shares long, and alcohol and PDA address, $P< 0.05$).

Figure 15.6 shows the mean deviation from the normative model by LCT treatment condition. It shows that there was only a marginal (non-significant) difference between baseline performance of the LCT and performance of the LCT under the influence of alcohol. This was supported by the post hoc comparison.

Comparison of the four IVIS conditions revealed no significant difference in the mean deviation from the normative model for LCT driving between any of the tasks. There was, however, an increase in mean total task time in dual task conditions (see Figure 15.7). A paired samples t-test revealed a significant difference in the mean total task time when performed alone and under dual task conditions, $t\ (3) = -4.129$, $P< 0.05$. This indicates that the mean total task time was significantly higher in the LCT condition ($M = 24.566$) than when performed alone ($M = 12.711$).

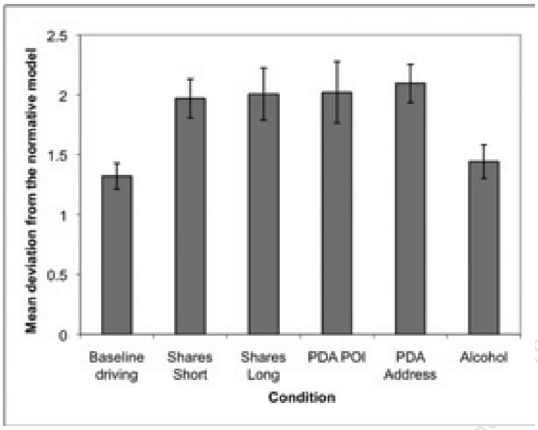

Figure 15.6 Mean deviation from the normative model by LCT condition

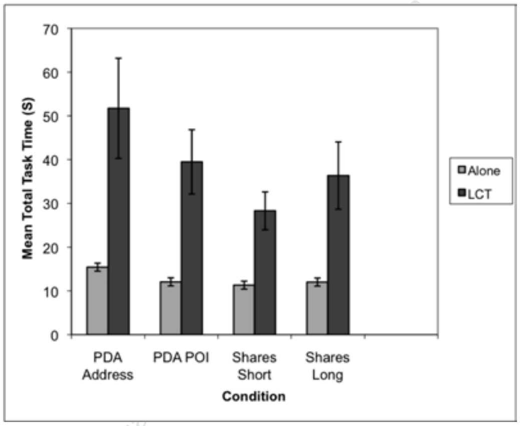

Figure 15.7 Mean total task time alone and under dual task (LCT) conditions

Table 15.3 Comparison of total task time (TTT) with Horberry et al. 2007

Task	Observed TSOT (s)	TSOT + TSCT[1] (s)	Observed LCT (s)
	Horberry et al. (2007)		
• PDA POI	• 7.6	• 15.1	19.23
PDA address	• 11.7	• 23.7	35.13
Shares short	• 10.8	• 18.0	19.3
Shares long	• 11.15	• 21.65	24.61

TSOT = total shutter open time

TSCT = total shutter closed time

1 An occlusion schedule of 1.5 seconds shutter open and 1.5 seconds shutter closed was used.

Comparison of the four IVIS conditions revealed a significant increase in mean total task time (TTT) in dual task conditions. There was, however, no significant difference in the mean deviation from the normative model for LCT driving between any of the tasks. A paired samples t-test revealed a significant difference in the mean total task time when performed alone and under dual task conditions, t (3) = –4.129, $P< 0.05$. This indicates that the mean total task time was significantly higher in the dual-task condition (M = 24.566) than when performed alone (M = 12.711). This suggests that, despite poorer performance in general, participants can maintain a consistent level of performance across the four IVIS tasks (evidenced by no significant difference in LCT performance). Table 15.3 is a comparison of the TTT obtained in this trial to those obtained by Horberry et al. (2007). As might be expected, it shows that the tasks take longer to complete while performing the LCT than predicted by the key stroke analysis (single task conditions). However, it also shows that tasks take longer to complete than observed using the occlusion technique, where there is task interruption consistent with dual task operation but no active secondary task. This would suggest that the LCT places a greater demand on the participant, reflecting a higher cost of concurrent task performance and does so more accurately than either the KLM and occlusion techniques would predict.

Discussion

Previous research has established the negative effects on driving performance of mobile phone usage and this risk has been quantified by benchmarking the effects to the impairment caused by alcohol at the UK legal driving limit (BAC 0.08 per cent). The aim of the current study was to extend the benchmarking approach to in-vehicle information systems. Such an approach, if successful, would allow comparative judgements to be made that would enable discrimination between tasks based on the level of driving impairment they cause.

Drivers' performance of the lane change task, both alone and under the influence of alcohol, was significantly better than performance of the LCT with an IVIS task. The best performance of the LCT task was observed in the baseline (LCT alone) condition. LCT performance under the influence of alcohol was slightly worse than baseline performance, but did not reach significance. The key elements of the LCT are lateral control and event detection. In the driving task there may be some leeway in terms of lateral control. Event detection, however, is a critically important task for safe driving.

The comparison of the four IVIS tasks revealed no significant differences in mean deviation from the normative model. This suggests that, despite poorer performance, participants could maintain a consistent level of performance across the four IVIS tasks (evidenced by no significant difference in LCT performance). There is, however, a significant increase in mean total task time (TTT) in dual task conditions, which would suggest that participants are prioritising LCT performance, over completion of the secondary IVIS tasks (no instructions regarding which task to prioritise were provided during the experiment). The largest differences were observed in the PDA address entry and shares long conditions. The same is true of the shares long task as it is the most visually demanding task; again, it is reasonable to suggest that this task would compete for resources with the visual elements of the LCT (event detection), as illustrated by poorer performance in dual-task conditions. There is, however, no difference in LCT performance between this and the less demanding shares short task. Expert analysis (Pettitt et al. 2005) did not identify any operational differences between the two share price tasks; however, there will be a difference in the visual search strategies required on the part of the participant as there is an increase in visual workload due to there being three scrolling lists rather than one. This is exacerbated by the fact that these tasks are not interruptible, but are system paced – and if participants miss the target they have to wait for it to scroll round. These elements would seem the most likely causes of the increases in TTT for the shares long task illustrated in Table 15.3.

One of the aims of this research was to establish a performance value for the LCT beyond which performance should be considered unacceptable. There was, however, no significant difference between baseline performance of the LCT and performance under the influence of alcohol. There are a number of possible reasons for this.

Firstly, the dosing procedure may not have produced the required blood alcohol level in all participants as the complex interaction of moderating factors makes it difficult to achieve the desired 80g per 100 ml rate in every participant. Ideally a participant's blood alcohol concentration would not be directly calculated from the adjusted Widmark factor, as this can be inaccurate (Brouwer 2004). Experimenters should initially calculate intoxication using the Widmark formula and then adjust the amount of alcohol over repeated sessions, plotting intoxication–elimination curves for each participant in order to ensure that a precise dosage is given at the time of the experiment.

Secondly, there was a limit to the accuracy of BAC measurement in this study due to the limitations placed on resources. These limitations did not allow for the repeated intoxication of participants and therefore there is an element of unreliability in the BAC measurement. Thirdly, the quasi-experimental nature of the design may have introduced a confound. As participants always completed the alcohol condition last, combined with the fact that participants were novice users of the LCT, there may have been a practice effect introduced in the alcohol condition; that is, participants were better at the LCT by the time they completed the intoxicated trials. Therefore, it must be accepted that the mean deviation from the normative model may be lower than its true value due to artefacts introduced by the procedure.

Finally, the LCT mimics only two aspects of the driving task (event detection and lateral control). Speed is held constant by the software and so the driver does not have to manage longitudinal control. It is now well established that alcohol, at low volumes, does not impair all driving related tasks equally. For example, at low levels (up to BAC 0.02 per cent) divided attention tasks are affected (Starmer 1989, Moskowitz et al. 1985). However, visual perception, reaction time and steering tasks may not be affected until BAC is above 0.05 per cent (Starmer 1989, Howat et al. 1991, Hindmarch et al. 1992). It is possible that the limited task demand created by the LCT on its own is insufficient for an impairment effect to be shown at the level of intoxication achieved.

Criticism of alcohol trials

There are a number of important caveats that must be considered when benchmarking IVIS performance to alcohol impairment. Although the impairments caused by IVIS can be as significant as those associated with driving while legally intoxicated, the mechanisms that underlie these phenomena are fundamentally different. Driving while using an IVIS is a measure of a driver's ability to accommodate two tasks (divided attention) whereas alcohol acts as a central nervous system depressant. Alcohol directly and continuously impairs a driver's cognitive functioning over the period of intoxication; concurrent phone use may momentarily generate higher levels of task demand, but it does not generally impair driving behaviour and performance continuously.

Using the benchmarking technique it will not be possible to assess all the effects on safety in driving from the distraction caused by IVIS, as it is necessary to consider a participant's exposure to distraction. Whereas alcohol intoxication imposes a continual risk, distraction imposes only momentary risk. Redelemeir and Tibshirani (1997a, 1997b) concluded that cumulative risks associated with alcohol intoxication are much greater than those associated with using a mobile phone. The most significant factor in this difference is the relatively short duration of most mobile phone calls compared with the number of hours in which alcohol stays in the bloodstream (Carsten and Brookhuis 2005). When engaging in an IVIS task, drivers can disengage from the task as workload increases. This is illustrated in this study through increased total task times in the four IVIS conditions despite no differences in LCT performance. If participants were constantly engaged in these tasks it could be expected that there may be differences in mean deviation from the normative model across the four tasks as they are designed to differ in terms of difficulty. In contrast, alcohol-intoxicated drivers cannot disengage from being impaired in situations of increased workload. Alcohol-intoxicated drivers may also consume amounts that result in blood alcohol concentrations far exceeding the legal driving limit.

Pettitt et al. (2005, p. 11) define distraction as a "delay by the driver in the recognition of information necessary to safely maintain the lateral and longitudinal control of the vehicle (the driving task) (*impact*), due to some event, activity, object or person, within or outside the vehicle (*agent*), that compels or tends to induce the driver's shifting attention away from the fundamental driving tasks (*mechanism*), by compromising the driver's auditory, biomechanical, cognitive or visual faculties, or combinations thereof (*type*)". Considering this definition in terms of alcohol intoxication, the impact of alcohol (*agent*) on driving performance is primarily poorer lateral and longitudinal control of the vehicle (other impacts associated with alcohol include increased speed variability (Gawron and Ranney 1988), increased reaction times (Zwahlen 1976) and increased brake reaction time and body sway (Liguori and Robinson 2001)). This is due to the consumption of alcohol, and the driver's subsequent intoxication through the metabolism of alcohol (*mechanism*). By compromising the biomechanical and cognitive abilities of the driver (*type*) performance is reduced. In contrast, in terms of IVIS use, the impact of IVIS (*agent*) on driving performance is primarily poorer lateral and longitudinal control of the vehicle (other impacts associated with IVIS use include variability in speed (Chiang et al. 2001), reduction in the useful field of view (Ward et al. 1995), slower driving with greater variation in accelerator position and speed (Rakauskas et al. 2004) and increase in brake response times (Hancock et al. 2003). This occurs through the division of attention (*mechanism*) by compromising the physical capabilities and visual performance of the driver (*type*). Discussing the two phenomena in these terms suggests strong similarities even though the mechanisms and agents by which these impacts occur are different.

Despite the criticism of alcohol trials, the comparison between alcohol-impaired driving performance and the impairment due to secondary [IVIS] tasks will continue to attract researchers' interest. This is because clear social norms, legal limits to blood alcohol content for drivers and the established impact of alcohol on driving-related psychomotor skills can be used as a frame of reference for comparison of the distraction potentially caused by IVIS and other devices. Any activity, including the introduction of IVIS, that causes a change in safety-related driving behaviour equal to or greater than that induced by alcohol intoxication, should be of concern to society.

Conclusion

Driving while intoxicated is a clearly established hazardous activity. The results of this study have demonstrated that the performance of tasks central to the functioning of in-vehicle information systems impair drivers significantly more than alcohol intoxication at the UK drink driving limit. If it is accepted that performance at this limit is unacceptable then it must be concluded that the completion of some IVIS tasks while driving is also unacceptable and it is clear that further research is needed to quantify the demand of different IVIS tasks to determine what tasks are safe to execute while the vehicle is in motion and what tasks are not.

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References

Aeron-thomas, A., Astrop, A. and Jacobs, G. 2000. *Estimating global road fatalities*. TRL report 445. Crowthorne, UK: TRL.

Altmann, E.M. and Trafton, J.G. 2002. Memory for goals: An activation-based model. *Cognitive Science*, 26: 39–83.

Arnedt, J.T., Wilde, G.J.S., Munt, P.W. and MacLean, A.W. 2001. How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task? *Accident Analysis and Prevention*, 33(3): 337–44.

Borkenstein, F.R., Crowther, R.F., Shumate, R.P., Zeil, W.B. and Zylman, R. 1964. *The Role of the Drinking Driver in Traffic Accidents*. Bloomington, IN: *Department of Police Administration.*

Brouwer, I.G. 2004.The Widmark formula for alcohol quantification. *South African Dental Journal*, 59(10): 427–28.

Bruyas, M.P., Brusque, C., Tatttegrain, H., Auriault, A., Aillerie, I. and Duraz, M. 2008. Consistency and sensitivity of lane change test according to driving simulator characteristics. *IET Intelligent Transportation Systems*, 2: 306–14.

Burns, P.C., Parkes, A., Burton, S., Smith, R.K. and Burch, D. 2002.*How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol*. TRL report 547. Crowthorne, UK: TRL.

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

Campbell, J.L., Carney, C., and Kantowitz, B.H. 1997. *Draft Human Factors Design Guidelines for Advanced Traveller Information Systems (ATIS) and Commercial Vehicle Operations (CVO)*. Washington, DC: US Department of Transportation, Federal Highway Administration.

Carsten, O. and Brookhuis, K. 2005. Issues arising from the HASTE project. *Transportation Research Part F: Traffic Psychology and Behaviour,* 8(2): 191–96.

Chesher, G. and Greeley, J. 1992. Tolerance to the effects of alcohol. *Alcohol, Drugs and Driving* 8(2): 93–106.

Chiang, D.P., Brooks, A.M. and Weir, D.H. 2001. *An experimental study of destination entry with an example automobile navigation system.* Society of Automotive Engineers, paper 20011-01-0810.

Chiang, D.P., Brooks, A.M. and Weir, D.H. 2004. On the highway measures of driver glance behaviour with an example automobile navigation system. *Applied Ergonomics*, 35: 215–23.

Dingus, T.A. 1988. *Attentional Demand for an Automobile Moving-Map Navigation System* (unpublished PhD dissertation). Blacksburg, VA: Virginia Polytechnic Institute and State University, Department of Industrial Engineering and Operations Research.

Dott, A.B., and McKelvey, R.K. 1977. Influence of ethyl alcohol in moderate levels on the ability to steer a fixed-base shadowgraph driving simulator. *Human Factors*, 19: 295–300.

Dragutinovic, N. and Twisk, D. 2005. *Use of Mobile Phones While Driving – Effects On Road Safety; A Literature Review.* R-2005-12. Leidschendam: SWOV.

Dubowski, K.M. 1985. Absorption, distribution and elimination of alcohol: Highway safety aspects. *Journal of Studies on Alcohol*, 10: 98–108.

Emerson, V.J., Holleyhead, R., Isaacs, M.D.J., Fuller, N.A. and Hunt, D.J. (1980). The measurement of breath alcohol: The laboratory evaluation of substantive breath test equipment and the report of an operational police trial. *Journal of the Forensic Science Society*, 20(1): 3–70.

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

European Commission 2006. *Commission Recommendation of 22 December 2006 on safe and efficient in-vehicle information and communication systems: Update of the European Statement of Principles on human machine interface*. Commission document C (2006) 7125, final. Brussels: EC.

Fillmore, M.T. and Vogel-Sprott, M. 1999. An alcohol model of impaired inhibitory control and its treatment in humans. *Experimental and Clinical Psychopharmacology*, 7(1): 49–55.

Fillmore, M.T. and Vogel-Sprott, M. 2000. Response inhibition under alcohol: Effects of cognitive and motivational conflict. *Journal of Studies on Alcohol*, 61(2): 239–46.

Frick, U., Rehm, J., Knoll, A., Reifinger, M. and Hasford, J. 2000. Perception of traffic accident risk and decision to drive under light alcohol consumption. *Journal of Substance Abuse,* 11(3): 241–51.

Friel, P.N., Baer, J. and Logan, B.K. 1995. An evaluation of the reliability of Widmark calculations based on breath alcohol measurements. *Journal of Forensic Science*, 40(1): 91–94.

Gawron, V.J. and Ranney, T.A. 1988. The effects of alcohol dosing on driving performance on a closed course and in a driving simulator. *Ergonomics*, 31(9): 1219–44.

Gelau, C., Henning, M.J. and Krems, J.F. 2009. On the reliability of the occlusion technique a tool for the assessment of the assessment of the HMI of in-vehicle information and communication systems. *Applied Ergonomics*, 40: 181–84.

Goujon, S. 2001. *First evaluation of possible occlusion technique criteria.* LAB PSA, Peugeot-Citroen/Renault. Workshop on Occlusion, Torino, Italy, 12–13 November 2001.

Green, P. 1998. *Visual and Task Demands of Driver Information Systems* (Technical Report UMTRI-98-16), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Hancock, P.A. Lesch, M. and Simmons, L. 2003. The distraction effects of phone use during a crucial driving manoeuvre. *Accident Analysis and Prevention*, 35: 501–14.

Harbluk, J.L., Burns, P.C., Lochner, M. and 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*. Washington, DC: Stevenson.

Harbluk, J.L., Mitroi, J.S. and 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.

Hindmarch, I., Bhatti, J.Z., Starmer, G.A., Mascord, D.J., Kerr, J.S. and Sherwood, N. 1992. The effects of alcohol on the cognitive function of males and females and on skills relating to car driving. *Human Psychopharmacology* 7(2): 105–14.

Horberry, T., Stevens, A., Robins, R., Cotter, S. and Burnett, G. 2007. *Development of an occlusion protocol with design limits for assessing driver visual demand*, PPR 256. Crowthorne, UK: TRL.

Howat, P., Sleet, D. and Smith, I. 1991. Alcohol and driving: Is the 0.05 per cent blood alcohol concentration limit justified? *Drug and Alcohol Review* 10(2): 151–66.

International Standards Organisation, ISO 16673 Road vehicles – Ergonomic aspects of transport information and control systems – Occlusion method to assess visual demand due to the use of in-vehicle systems, Geneva, Switzerland, 2007.

ISO 26022: 2010. Road vehicles – Ergonomic aspects of transport information and control systems – Simulated lane change test to assess in-vehicle secondary task demand. Geneva, Switzerland: International Organization for Standardization.

Laberge-Nadeau, C., Maag, U., Bellavanc, F., Lapierre, S. D., Desjardins, D., Messier, S. and Sidi, A. (2003).Wireless telephones and the risk of road collisions. *Accident Analysis and Prevention*, 35: 649–60.

Lansdown, T.C., Brook-Carter, N. and Kersloot, T. 2004. Distraction from multiple in-vehicle secondary tasks: vehicle performance and mental workload implications. *Ergonomics*, 47(1): 91–104

Lansdown, T.C., Burns, P.C. and Parkes, A.M. 2004. Perspectives on occlusion and requirements for validation. *Applied Ergonomics*, 35(3): 225–32.

Laurell, H. 1977. Effects of small doses of alcohol on driver performance in emergency situations. *Accident Analysis and Prevention*, 9: 191–201.

Lenné, M.G., Dietze, P., Rumbold, G.R., Redman, J.R. and Triggs, T.J. 2003. The effects of the opioid pharmacotherapies methadone, LAAM and beprenorphine, alone and in combination with alcohol, on simulated driving. *Drug and Alcohol Dependence*, 72(3): 271–78.

Lenné, M.G.,Triggs, T.J. and Redman, J.R. 1997.Time of day variations in driving performance. *Accident Analysis and Prevention*, 29(4): 431–37.

Liguori, A. and Robinson, J.H. 2001. Caffeine antagonism of alcohol-induced driving impairment. *Drug and Alcohol Dependence*, 63: 123–29.

Mattes, S. (2003). The lane-change-task as a tool for driver distraction evaluation. In *Quality of Work and Products in Enterprises of the Future*, H. Strasser, K. Kluth, H. Rausch and H. Bubb (eds.). Stuttgart, Germany: Ergonomia.

Mattes, S. and Hallén, A. 2009. Surrogate distraction measurement techniques: The Lane Change Task. In *Driver Distraction: Theory, Effects and Mitigation,* M.A. Regan, J.D. Lee and K.L. Young (eds). London: CRC Press/Taylor and Francis.

McEvoy, S., Stevenson, M., McCartt, A., Woodward, M., Haworth, C., Palamara, P. and Cercarelli, R. 2005. Role of mobile phones in motor vehicle crashes resulting in hospital attendance: A case-crossover study. *BMJ*, 428: 331.

McKnight, J.A. and McKnight, S.A. 1993.The effect of cellular phone use upon driver attention. *Accident Analysis and Prevention*, 25: 259–65.

Milgram, P., and van der Horst, R. 1984. *Field-sequential colour stereoscopy with liquid crystal spectacles.* Proceedings Fourth International Display Research Conference. Paris: Societe des electriciens, des electronicienset des radio-electroniciens**.**

Monk, C.A. and Kidd, D.G. 2007. *R we fooling ourselves: does the occlusion technique short change R estimates?* Proceedings of the fourth international driving symposium on human factors in driver assessment, training and vehicle design. Iowa City, Iowa: University of Iowa Public Policy Center.

Moskowitz, H., Burns, M.M. and Williams, A.F. 1985. Skills performance at low blood alcohol levels. *Journal of Studies on Alcohol*, 46(6): 482–85.

Noy, Y.I., Lemoine, T.L., Klachan, C. and Burns, P. 2004. Task interruptability and duration as measures of visual distraction. *Applied Ergonomics*, 35: 207–13.

Parkes A.M. and Hooijmeijer V. 2000. *The Influence of the Use of Mobile Phones on Driver Situation Awareness.* Driver Distraction Internet Forum. Available at http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/Topics013040229.htm. Accessed on 24 June 2005.

Parks, V., Leister, C., Patat, A., Troy, S., Vermeerren, A., Volkerts, E.R. and Verster, J.C. 2002. Effects of ethanol at a blood alcohol concentration of 0.4 g/L on actual driving and memory. *European Neuropsychopharmacology*, 12(3): 432–33.

Pettitt, M., Burnett, G., Bayer, S. and Stevens, A. 2006. Assessment of the occlusion technique as a means for evaluating the distraction potential of driver support systems. *IEE Intelligent Transportation Systems*, 153(4): 259–66.

Pettitt, M., Burnett, G. and Stevens, A. 2005. *Defining Driver Distraction*. 12th World congress on Intelligent transport systems, San Francisco, November 6–10. CD Rom Custom Number: 2586, ERTICO, B-1050 Brussels. www.ertico.com.

Pettitt, M., Burnett, G. and Stevens, A. 2007. *An extended keystroke level model (KLM) for predicting the visual demand of in-vehicle information systems*. Proceedings of the SIGCHI conference on Human Factors in computing systems, San Jose, CA.

Rakauskas, M.E., Gugerty, L.J. and Ward, N.J. 2004. Effects of naturalistic cell phone conversations on driving performance. *Journal of Safety Research*, 35: 453–64.

Rakauskas, M.E. and Ward, N.J. 2005. Behavioral effects of driver distraction and alcohol impairment. Proceedings of the 49th annual meeting of the Human Factors and Ergonomics Society, Orlando, FL.

Redelmeier, D.A. and Tibshirani, R.J. 1997a. Association between cellular-telephone calls and motor vehicle collisions. *New England Journal of Medicine*, 336(7): 453–58.

Redelmeier, D.A. and Tibshirani, R.J. 1997b. Is using a car phone like driving drunk? *Chance*, 10: 5–9.

Redelmeier, D.A. and Tibshirani, R.J. 2001. Car phones and car crashes: some popular misconceptions. *Canadian Medical Association Journal*, 164(11): 1581–82.

Reed, N. and Robbins, R. 2008. *The effect of text messaging on driver behaviour: A simulator study*, PRR 367. Crowthorne, UK: TRL.

Rolle, C. 2006. *Augmented reality for driving assistance in cars – usability tests.* Unpublished seminar report, TechnischeUniversitatMunchen, January 2006. Online at http://campar.in.tum.de/twiki/pub/Chair/TeachingWS05DrivingAssistanceHauptseminar/Usability_Tests_Report.pdf.

Sexton, B.F., Tunbridge, R.J., Brook-Carter, N., Jackson, P.G., Wright, K., Stark, M.M. and Englehart, K. 2000. *The Influence of cannabis on driving*, PRR 477. Crowthorne, UK: TRL.

Sexton, B.F., Tunbridge, R.J., Board, A., Jackson, P.G., Wright, K., Stark, M.M. and Englehart, K. 2002. *The influence of cannabis and alcohol on driving*. TRL, PRR 543. Crowthorne, UK: TRL.

Shinar, D., Tractinsky, N. and Compton, R. 2005. Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis and Prevention*, 37: 315–26.

Simpson, H. 1985. Polydrug effects and driving safety. *Journal of Alcohol, Drugs and Driving*, 1: 17–44

Society of Automotive Engineers 1998. *SAE Standard for Calculating the Time to Complete In-Vehicle Navigation and Route Guidance Tasks (SAE J2365),* Committee Draft of November 23. Warrendale, PA: Society of Automotive Engineers.

Society of Automotive Engineers. 2002. *SAE Recommended practice calculation of the time to complete in-vehicle navigation and route guidance tasks. (SAE J2364).* Warrendale, PA: Society of Automotive Engineers.

Starmer, G.A. 1989. Effects of low to moderate doses of ethanol on human driving-related performance. In *Human Metabolism of Alcohol: Vol. I. Pharmacokinetics, Medicolegal Aspects, and General Interests,* K.E. Crow and R.D. Batt (ed.). Boca Raton, FL: CRC Press.

Steele, C.M. and Josephs, R.A. 1990. Alcohol myopia: Its prized and dangerous effects. *American Psychologist*, 45: 921–33.

Stevens, A., Bygrave, S., Brook-Carter, N. and Luke, T. 2004. *Occlusion as a technique for measuring in-vehicle information systems (IVIS) distraction: a research literature review.* TRL Report 609. Crowthorne, UK: TRL.

Strayer, D.L., Drews, F.A. and Crouch, D.J. 2003. Fatal distraction? A comparison of the cell-phone driver and the drunk driver. In *Driving Assessment 2003: International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design,* D.V. McGehee, J.D. Lee and M. Rizzo (eds). Public Policy Center, University of Iowa.

The Road Vehicles (Construction and Use) (Amendment) (No. 4) Regulations 2003, The Stationery Office Limited, ISBN 0110480171.

Tijerina, L., Johnston, S., Palmer, E., Winterbottom, M.D. and Goodman, M. 2000. *Driver Distraction with Route Guidance Systems (Technical Report DOT HS 809 069),* East Liberty, OH: National Highway Traffic Safety Administration.

Tijerina, L., Palmer, E. and Goodman, M. 1998. *Driver workload assessment of route guidance system destination entry while driving: a test track study*, Proceedings of the 5th ITS World Congress, Berlin, Germany: VERTIS (CD-ROM).

Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.R., Stansifer, R.L. and Castellan. N.J. 1979. *Tri-Level Study of the Causes of Traffic Accidents: Fina lReport. Volume I: Causal Factor Tabulations and Assessments.* Report No. DOT HS 805 085. US Department of Transportation, Washington, DC

Violanti, J.M. 1998. Cellular phones and fatal traffic collisions. *Accident Analysis and Prevention*, 30(4): 519–24.

Violanti, J.M. and Marshall, J.R. 1996. Cellular phones and traffic accidents: An epidemiological approach. *Accident Analysis and Prevention*, 28: 265–70.

Ward, N.J., Parkes, A. and Crone, P.R. 1995. Effect of Background Scene Complexity and Field Dependence on the Legibility of Head-Up Displays for Automotive Applications. *Human Factors*, 37(4): 735–45.

Watson, P.E., Watson, I.D. and Batt, R.D. 1981. Prediction of blood alcohol concentrations in human subjects: updating the Widmark equation. *Journal of Studies on Alcohol,* 42(7): 547–56.

Waugh, J.D., Glumm, M.M., Kilduff, P.W., Tauson, R.A., Smyth, C.C. and Pillalamarri R.S. 2000. Cognitive Workload while Driving and Talking on a Cellular Phone or to a Passenger. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. http://pro.sagepub.com/content/44/33/6-276.

Widmark, E.M.P. 1932. *Die Theoretischen Grundlagen und die Praktische Verwendbarkeit der Gerichtlichmedizinischen Alkoholbestimmung*. Berlin: Urban and Schwarzenberg.

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

Wynn, T. and Richardson, J.H. 2008. *Comparison of Subjective Workload Ratings and Performance Measures of a Reference IVIS Task*. Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems, HUMANIST publications, Lyon.

Wynn, T., Richardson, J.H. and Stevens, A. 2009. *Driving whilst using In-Vehicle Information Systems (IVIS): Benchmarking the impairment to alcohol*. Proceedings of the First International Conference on Driver Distraction and Inattention; Gothenburg, 28–29 September 2009.

Young, K.L., Lenné, M.G. and Williamson, A.R. 2011. Sensitivity of the lane change test as a measure of in-vehicle system demand. *Applied Ergonomics*, 42(4): 611–18.

Zwahlen, H.T. 1976. The effects of ethyl alcohol on a driver's driving skill, visual perception, risk acceptance, choice reaction times and information processing rates. *Journal of Occupational Accidents*, 1: 21–38.

Zwahlen, H.T., Adams Jr., C.C. and DeBald, D.P. 1988. Safety aspects of CRT touch panel controls in automobiles. In *Vision in Vehicles II*, A.G. Gale and M.H. Freeman (eds). Amsterdam: Elsevier Science.