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Examining the effects of an eco-driving message on driver distraction

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ABSTRACT

This paper examines the effects of an eco-driving message on driver distraction. Two in-vehicle distracter tasks were compared with an eco-driving task and a baseline task in an advanced driving simulator. $N = 22$ subjects were asked to perform an eco-driving, CD changing, and a navigation task while engaged in critical manoeuvres during which they were expected to respond to a peripheral detection task (PDT) with total duration of 3.5 h. The study involved two sessions over two consecutive days.

The results show that drivers' mental workloads are significantly higher during navigation and CD changing tasks in comparison to the two other scenarios. However, eco-driving mental workload is still marginally significant ($p \sim .05$) across different manoeuvres. Similarly, event detection tasks show that drivers miss significantly more events in the navigation and CD changing scenarios in comparison to both the baseline and eco-driving scenario. Analysis of the practice effect shows that drivers' baseline scenario and navigation scenario exhibit significantly less demand on the second day. Drivers also can detect significantly more events on the second day for all scenarios. The authors conclude that even reading a simple message while driving could potentially lead to missing an important event, especially when executing critical manoeuvres. However, there is some evidence of a practice effect which suggests that future research should focus on performance with habitual rather than novel tasks. It is recommended that sending text as an eco-driving message analogous to the study circumstances should not be delivered to drivers on-line when vehicle is in motion.

1. Introduction

While concern about the potential for drivers to be distracted by in-vehicle devices is not new, the recent growth in the range and availability of devices has increased to potential for distraction. As long ago as 1915 it was believed that vehicles' windscreen wipers could potentially distract or hypnotise drivers (Karlsson, 2005), while nowadays listening to music, changing CDs, or even using a navigation system are considered as everyday driving activities. The potential danger of these "everyday" tasks is still being debated, while at the same time questions are being raised about the comparative effects of new in-vehicle devices. One category of such new devices provides eco-driving assistance by presenting the driver with information to reduce fuel consumption while driving. This is a worthy objective in terms of its contribution to environmental sustainability, but it is also possible that using these devices may divert attention to a degree which increases the likelihood of a crash. Attention is necessary to perform driving tasks safely (Castro, 2009). Momentary lapses can affect safe driving in practice (Victorian Automobile Chamber of Commerce, 2005). Distraction effects seem to be common events for road users, however, not all of them lead to traffic crashes (Castro, 2009), and since drivers experience distracting activities as a common part of everyday driving they may consider them unimportant.

Regan et al. (2011) assert that existing driver distraction definitions are not consistent and their relationships are not clear, and propose an alternative definition. They define driver inattention as "insufficient or no attention to activities critical for safe driving" (2011, p. 1780) and offer Driver Diverted Attention as a synonym for driver distraction. They define Driver Diverted Attention as "the diversion of attention away from activities critical for safe driving towards a competing activity, which may result in insufficient or no attention to activities critical for safe driving" (Regan et al., 2011, p.1780). While the term "distraction" has been used in this paper, it takes the same of Driver Distracted Attention. The contribution of distraction to crashes generally has been established. A naturalistic study found that about 78% of crashes and 65% of near-crashes involved inattention as a contributing factor (Klauer et al., 2006). The percentage figures may seem high, but in the study, inattention included fatigue, general inattention to the road, and distraction or secondary task demand (Regan et al., 2009). In the '100-Car Naturalistic Driving Study', it was found that distraction was a contributing factor in 23% of crashes and near-crashes (Young and Lenné, 2010). An earlier study estimated that between 13% and

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50% of all crashes occurred due to driver distraction or inattention (Lee, 2007). An investigation using the Crashworthiness Data System (CDS) in the US found that distracted drivers were 50% more prone to be seriously injured or killed in their crashes, compared to attentive drivers (Ranney, 2008).

Different in-vehicle devices place different kinds of demand on drivers. Distraction has been categorised into four different types: visual, auditory, bio-mechanical (physical) and cognitive distraction (Young et al., 2003). Visual distraction occurs when, instead of focusing visual attention on the road, distracted drivers look at another target for a certain period. Similarly, auditory distraction occurs when the driver focuses their attention on auditory stimuli instead of on the road environment. Biomechanical or physical distraction happens when drivers manipulate an object by hand(s) rather than keeping their hands on the steering wheel, and cognitive distraction can be defined as any thoughts that attract the driver's attention in a way that they are not able to drive safely anymore (Young and Regan, 2007). Many in-vehicle devices involve the potential for more than one type of distraction. In particular visual distraction may occur when carrying out tasks that also involve physical and cognitive distraction. Since there are no metrics for assigning a level of distraction to a particular device, the distraction caused by a new device is more readily understood by comparison with the distraction caused by more familiar devices and task. Accordingly, the primary purpose of this research was to conduct a driving simulator study to compare the level of distraction associated with an analogue of an eco-driving system with the level of distraction associated with changing a CD and a navigation task analogue. For reasons outlined in Section 3, a secondary purpose was to investigate the practice effect associated with this particular methodology.

2. Distraction contributed by navigation, CD changing and eco-driving systems

One of the causes of driver distraction is in-vehicle driver assistant systems (Horberry et al., 2006; Lee et al., 2008; Lee, 2007). In most developed countries, advanced in-vehicle systems have become as prevalent as ABS or seatbelts. Car manufacturing companies have focused more on in-vehicle driver assistance systems (Castro, 2009) and promoted them as a privilege through the media. However, there is little understanding of the side effects of most new technologies on safe driver performance. For instance, in a recent study, it was found that in-vehicle activities such as looking for a song in an iPod are cognitively demanding and could potentially impair drivers' performance (Mouloua et al., 2011). Many studies have shown that, regardless of the type of technology, some level of driver distraction is created by the use of in-vehicle technologies.

In one study, destination entry in a visual/manual systems showed a higher possible distraction than a voice activated system. There was evidence of "longer completion times, more frequent glances at the device, longer eyes-off-road times, and a greater number of lane exceedances" (Ranney, 2008, p. 16).

Tuning the radio and changing CDs in vehicles are common event during driving. About 92% of drivers were observed, in a naturalistic study, using audio devices while driving (Ranney, 2008). It has been shown that operating a CD player can be even more distracting than eating or dialling a mobile phone while driving (Ranney, 2008). Adjusting the radio/cassette/CD has been found to be a contributing factor in about 11% of all crashes, in contrast with 1.7% for talking/listening/dialling on a mobile phone (Chisholm et al., 2008). This is a relatively high figure and suggests that it is common to be distracted by this particular task. In particular, operating a CD player has been shown to increase risk of crashes several times (Klauer et al., 2006).

Devices which provide drivers with instant feedback on fuel economy performance are called "eco-driving" systems or "smart driving" tools (Barkenbus, 2010). Stillwater and Kurani (2012) also define eco-driving style as driving strategy adaptation (choosing more eco-friendly acceleration, speed, and braking) to decrease energy consumption. A few studies have been conducted on eco-driving systems. 'Foot-LITE' is a prominent project on eco-driving. It aims to develop an on-board eco-driving system which will attempt to persuade drivers to drive greener and safer through instant real-time advice on driving style and post driving feedback for longer-term suggestions and information (Young et al., 2011). Birrell and Young (2011) reviewed two prototype designs of eco-driving systems to determine their distraction and driver workload. Their results showed that real-time smart driving did not increase driver workload or adversely affect driver distraction. However, the distraction effect decreased driver mean speed. They concluded that in-vehicle information systems do not increase drivers' workload and thus, do not make them distracted, if appropriately designed. In a Ph.D. study, Stillwater (2011) concluded that "Real-time feedback seemed to have the strongest association with behaviour change, although distraction and confusion about the feedback were persistent issues" (Stillwater, 2011, p. 63). Using hybrid interfaces, Hallihan et al., 2011 found that hybrid interfaces could potentially improve fuel efficiency. However, they could also be distracting to drivers as they "spent significantly less time looking to the road ahead while driving with the interface than without it" (Hallihan et al., 2011, p. 74). In another project, GERICO, Barbé and Boy (2006) designed an on-board system to optimise fuel consumption. There are various types of eco-driving systems which have different types of "eco-driving displays", built-in and after-market devices and also eco-driving applications on smart phones. This study will investigate distraction by one type of these devices in which an eco-driving message is sent to drivers by an online text to make recommendations about eco-driving related behaviour (i.e. braking, overtaking and over-speeding behaviour relevant to eco-driving).

3. Practice effect

The practice effect has rarely been considered in previous distraction studies. One interesting study by Shinar et al. (2005) investigated the effect of practice on a phone call task while driving over five successive days. They postulated a learning process for both the driving itself and the distraction task. In other words, practice makes drivers more competent in the main task, while distraction can be decreased by practice with the distracting task. They observed that over five sessions practice, performance of the driving measures improved. In particular, a learning effect was observed on the mean and standard deviations of lane position, steering angle, and speed (Cooper and Strayer, 2008). However, in another mobile phone study, Cooper and Strayer (2008, p. 893) found that "practice is unlikely to eliminate the disruptive effects of concurrent cell phone use on driving."

Strayer et al. (2011) assert that practice makes driver performance better in some instances. They agree that "A necessary condition for improvement is a consistency in the environment that can be capitalised upon with practice" (Strayer et al., 2011, p. 49). This contingent vision of the practice effect was reflected by Chisholm et al. (2008) in another simulator study in which 19 participants completed experimental sessions in six successive weeks. While using an iPod, drivers were asked to engage in a number of critical events, which included a pedestrian entering the roadway, a vehicle pullout, and a lead vehicle braking. Hazard responses, variation in steering wheel angle, and eye movement, were analysed. Chisholm et al. (2008) concluded that multi-interaction tasks, such as performing complex iPod tasks, harm perceptions and responses of drivers to hazards and raise the frequency of collisions. Although practice reduced the problem of slow responses to driving hazards somewhat, the decrement remained high relative to the baseline condition.

As noted above, there is little existing research into eco-driving systems. The possibility that the practice effect is contingent on the nature of the task and system is an issue common to all studies of this kind, however many simulator studies report the results of a single session as if there is no practice effect. While it was not a primary objective of this study, the authors believe it is important to draw attention to the need to account for a practice effect.

4. Research method

The research was conducted using the CARRS-Q Advanced Driving Simulator, described below. The study investigated the distraction due to reading an eco-driving message compared with the level of distraction caused by two other in-vehicle tasks, including changing CDs in a CD player and entering a five digit number in a PDA and a baseline condition.

These in-vehicle tasks are not exact duplicates of real world tasks. For example, entering a five digit number into navigation system is a simple navigation manipulation task. Entering an actual address into the system may require much more time. Similarly, the eco-driving task used here involves simple reading eco-driving messages and responding rather than real fuel estimation, driver behaviour analysis and choice of the best eco-driving advice in term of the classification of modalities of distraction, the eco-driving task is a cognitive/visual distracter, whereas CD changing is a manual/visual/auditory distracter and the navigation is manual/visual/cognitive distracter. The three tasks were designed to be simple and approximately the same time was required to complete each tasks in the stationary condition. The following questions were the focus of the research:

- Does the use of an eco-driving message distract drivers in a driving simulator more than two other in-vehicle activities (changing CDs and entering a number in a PDA)?
- Is there a practice effect which reduces the level of distraction under the study circumstances?

The simulator was programmed with a road network based on actual road network in the northern suburbs of the greater metropolitan area of Brisbane. The network was simplified to meet the constraints of the terrain creation software in SCANeR®II and the goal of the study. The length of the route was nearly 15 km and it took around 14 min to complete each trial drive for scenarios and familiarisation sessions. The speed limit for the simulation was set at 80 km/h. In addition to ordinary signs, a few signs were also designed to instruct drivers to commence their manoeuvres in predefined locations. All signs, terrains and scenarios were designed, created and tested number of times, and necessary changes were made. Core communication system between the PDA application, driving simulator software (SCANeR®II) and synchronisation software (RTmaps) was implemented to suit study requirements.

The study involved four scenario conditions (applied for an entire route) and five manoeuvre conditions (applied twice within each route). The four scenario conditions were:

- Baseline scenario (without distracting activities)
- Eco-driving scenario
- CD changing scenario
- Navigation scenario

The five manoeuvres that required actions comprised of lane changing, overtaking, commence braking for roundabouts, commence braking for intersections and travelling in a straight pathway without any specific manoeuvre as a baseline drive. Each participant was asked to execute a manoeuvre twice at different locations on each rout drive. The location of the start point for each manoeuvre was notified to drivers by a relevant installed roadside sign. All participants managed to finish all sessions except one who was not able to execute her overtaking task in the navigation scenario at the first location.

In addition to task performance, eco-driving task measurement was undertaken. Measuring mental workload is a common practice in driver distraction studies and there is anecdotal evidence that using more demanding in-vehicle tasks increases driver mental workload (de Waard, 1996). The measure of workload is based on mental demand estimation by participants. Conceptually it is a relative measure defined as the ratio of demand to allocated resources (de Waard, 1996). Subjective workload is a self-reported measure in which participants rate their perceived level of mental workload. The DALI (driving activity load index) is a recently developed multidimensional workload measure to evaluate the level of workload related with secondary tasks, and is an amended version of NASA-TLX. The six factors making up the mental workload score in DALI are adapted from the driving context: effort of attention, visual demand, auditory demand, temporal demand, interference, and situational stress (Pauzie, 2008).

4.1. Recruitment procedure

Drivers were required to have a current valid driver's licence. Young participants (18–23) were also required to have held their licence for less than 3 years and to have driven less than 10,000 km per year. Middle aged (25–66) drivers were required to have held their licence for more than 5 years and to have driven more than 10,000 km/year. Criteria are included to distinguish between young/inexperienced drivers and middle aged/experienced drivers. It was also a requirement that they should not have had experience in a driving simulator previously.

Overall, 22 participants were recruited. They were approached using a flyer and invitation letter on QUT campuses and via the CARRS-Q website. In addition, a media release reported in local newspaper to attract enough participants for the study. The age range was from 18 to 66 years (mean age 33.50, standard deviation 13.866). Six out of 22 were young drivers (mean age 20, standard deviation 2.098, range 18–23), and 16 were middle aged drivers (mean age 38.56, standard deviation 12.941, range 25–66). Similarly, 17 out of 22 were male (mean age 31.76, standard deviation 14.990, range 18–66) and whereas five were female (mean age 39.40, standard deviation 7.369, range 31–47).

While it would have been desirable to have a higher number of participants, it is common for simulator studies to have a small sample size, due to the high resource demands involved in these studies. Examples include: research into speech-based interaction with in-vehicle computers with 24 participants (Lee et al., 2001); a study of the effects of naturalistic cell phone conversations on driving performance, also with 24 participants (Rakauskas et al., 2004); research into the effects of iPod use on driver performance with 17 participants (Salvucci et al., 2007); an examination of the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance using 31 participants (Horberry et al., 2006); and a study of the effects of cell phone conversations on younger and older drivers using 40 participants (Strayer and Drew, 2004). In our study each participant had to commit 4 h over two days for a modest incentive (see below), and we believe this contributed to the difficulty in recruiting participants. We return to the issue of sample size and composition in Sections 5.7 and 8.3.

Only one of the participants reported having used an eco-driving system, four reported often changing their CDs while driving, and seven reported using their navigation system often or very often while driving.

To thank participants (other than first year Psychology students seeking course credit), as well as to reimburse them for their travel costs (e.g., taxi costs), for each 1.5–2 h session, participants who completed the 14 min familiarisation session were offered $10 cash. For those participants who completed the entire driving session, a further $20 was offered to thank them for the time they provided to participate in the study. For their participating in the two sessions, over 2 days, a total of $60 was offered. In addition, first year Psychology students were offered the opportunity to gain course credit for participating in the study.

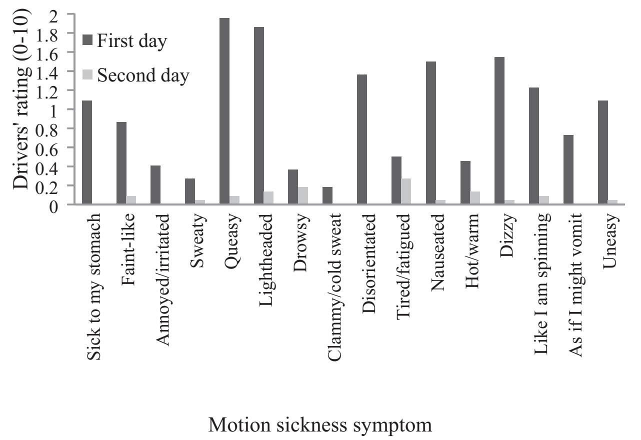

Fig. 1. Driving simulator's average motion sickness symptom changes in two days.

4.2. Study procedure

Total time of the test was approximately 2 h for the first day and 1.5 h for the second day. A familiarisation session was completed by all participants on the first day and before the actual driving sessions. After completing the familiarisation session, and in compliance with standard operation procedures for the simulator (approved by QUT's Human Research Ethics Committee (No. 1000001292)), a simulator motion sickness questionnaire (Brooks et al., 2010), was given to participants to evaluate whether they were able to continue with the experiment. Six participants experienced discomfort either after finishing the familiarisation session or just after a few seconds on the first day, however they elected to continue. A significant relationship was found between motion sickness rating and missed response counts, $t(21) = -12.976$, $p < .05$. Similarly, there was a significant relationship between motion sickness rating and DALI rating, $t(21) = -11.676$, $p < .05$. Therefore, driving mental workload and performance seem to be affected by simulator discomfort on the first day.

Participants were instructed to drive as they normally would, and to maintain the vehicle close to the speed limit (80 km/h). Before starting each scenario, participants filled out DALI mental workload questionnaires. This also provided an opportunity to rest before commencement of the next scenario. The baseline scenario was always first in all sessions. Other scenarios were presented randomly, and in each session the participants drove the four scenarios one each.

Before commencing the second day trials, but after the familiarisation session, participants were asked to fill out another motion sickness questionnaire. Fig. 1 shows symptom of motion sickness on both days. It shows that symptoms of motion sickness decrease dramatically on the second day. However, average ratings for some items, in particular "drowsy" and "tired/fatigued", show that some of the symptoms remained to some extent in participants after a day. In any case, no means exceeded two.

All participants were able to complete the second day session except one who still felt uncomfortable hours after the first day, and therefore did not undertake the sessions on the second day.

4.3. Peripheral detection task

A secondary visual task, the peripheral detection task (PDT) was selected due to its common use in simulator studies (Birrell and Young, 2009) and because it is very sensitive measure of driver workload (2000). Red dots were programmed to appear on the right hand side of the simulator screen in a designated area ranging horizontally between 74 and 81% of screen length (5–25°) above the eyes of the subject and to the right hand side of the drivers' eyes between 49 and 57% of screen height (2–5°). The red dot was big enough to be easily visible and appeared on the screen randomly every 3–6 s for about 1–2 s. Throughout different driving scenarios, these red dots appeared on the front screen. The driver was instructed to respond to the red dots as soon as they noticed their appearance by engaging a high beam flash. If participants could not see red dots at all or did nothing, the Missed Response Count value increased by one.

5. Apparatus

5.1. Advanced driving simulator

Driving simulators have been recognised as useful tools for researching driver behaviour without endangering road users in completely controlled environments (Lee, 2002; Shechtman et al., 2009). Because fidelity to real word driving is important (Regan et al., 2009), we used Queensland's new state-of-the-art advanced driving simulator. The simulator consists of a motion system, providing motion with 6 degrees of freedom and is capable of supporting a load of up to 1500 kg. Six workstations, each with 1 Gb graphics card, provide running components of the simulation software in a distributed fashion. Three projectors display the forward image, projecting on three flat 4 m × 3 m screens at 1400 × 1050 resolution to give a forward field of view of approximately 180° horizontal and 45° vertical. A complete Holden VE Calais vehicle body provides a realistic control cabin. Stereo simulation sound is generated using the vehicle's existing speaker system and an additional subwoofer to produce engine and external sounds, including Doppler effect.

5.2. Driving lab simulator

Before implementing of the research in the advanced driving simulator, a test-run was designed and conducted using a fixed-base low-fidelity driving simulator using the same software as advanced driver simulator.

5.3. Communication system and data synchronisation

In order to send distracting messages to drivers, a communication system was designed using RTMaps software. The software is primarily designed to connect devices together through a computer. It can synchronise and connect simulation software, SCANeR II, and applications written for the PDA through a router. The PDA was programmed using Microsoft embedded visual C++. It was also

Fig. 2. Position of PDA holder in front of windscreen.

necessary to develop another component (SKD) to synchronise locations which message had to be sent to the PDA in SCANeR II and RTMaps. The application on the PDA was activated for 15 s unless drivers finished the task of interacting with it in less time.

5.4. Eco-driving system

Eco-driving message were sent to drivers on a PDA mounted in front of the windscreen as shown in Fig. 2. Fig. 3 shows a typical eco-driving message in the PDA.

5.5. Navigation system

An application was programmed to pop up on the PDA screen. As with the eco-driving message, it was displayed when drivers were close to installed signs in order to be sure that drivers executed the manoeuvres at the designated locations. The navigation application had an image of current location of the driver, a box to enter the five digit number (86349) and an "OK" button. Drivers were asked to touch "OK" after entering the number.

5.6. CD player

Two CDs were provided with two well-known music pieces. The songs played repeatedly when drivers were driving. One of

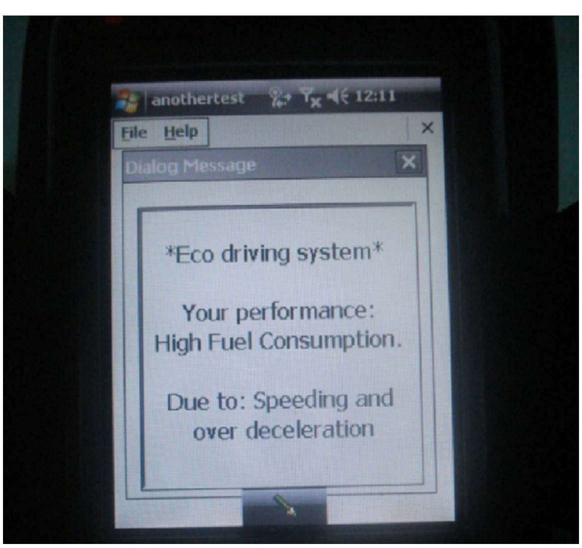

Fig. 3. Eco-driving messages on PDA.

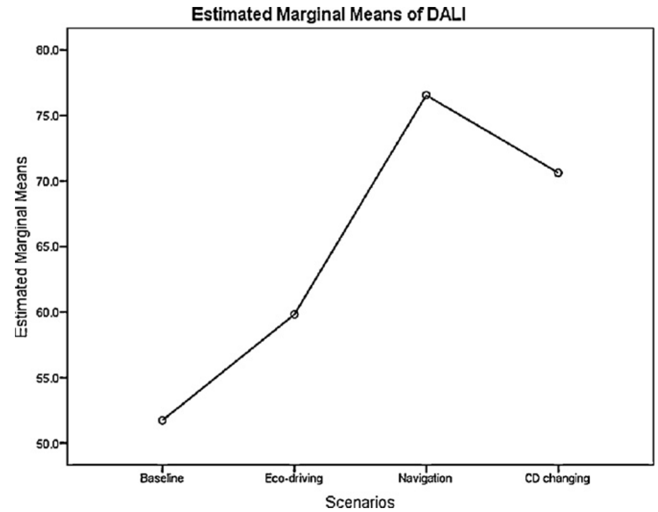

Fig. 4. DALI mental workload for entire network across scenarios.

the CDs was located in the car's middle console and the other one was playing in the CD player when drivers were required to start the CD changing scenario. A vocal message activated so that participants executed their manoeuvres in designated locations. The vocal message was "please change your CD here".

5.7. Data analysis

The study design is reflected in the analysis, where we have used within factors measures analysis i.e., repeated measures mixed ANOVA, since the objective and subjective variables were measured in all four scenarios using the same participants. In addition, as an explanatory investigation, two between factors measures, age groups (18–24 years old and 25–66 years old) and gender (male and female) were chosen for further exploratory analysis. The results of Mauchly's Test of Sphericity for all variables of repeated measures within scenarios were checked. If the assumption of sphericity was violated for any of the variables, the Greenhouse–Geisser correction method was used. In the study, if $p < .05$ for a particular measure, the effect of the measure is reported as a significant result (Field, 2009). We note that "just because a test statistic is significant does not mean that the effect it measures is meaningful or important" (Field, 2009, p. 56), so we have also reported the effect size. In most cases the effect size was sufficient to justify reporting the results as significant.

6. Results of data analysis for the first day (entire road network)

6.1. DALI mental workload

The repeated measures mixed ANOVA tests whether there are differences between the DALI mental workload across the four scenarios. The results show a significant difference in drivers' mental workload between the scenarios $F(3, 57) = 15.862$, $p < .05$, $\mu_p^2 = .455$, observed power (OP) = 1.000 (Fig. 4). Results showed that both navigation (76.68, 17.25) and CD changing (71.32, 16.78) scenarios are significantly different in mental workload when compared with baseline scenarios (52.11, 20.42) using the Bonferroni correction. There is also a significant difference between the eco-driving scenario (59.80, 23.18) and the navigation system (76.68, 17.25). However, no significant differences were found between baseline (52.11, 20.42) and eco-driving scenarios (59.80, 23.18), nor between eco-driving (59.80, 23.18) and CD changing scenarios (71.32, 16.78). In addition, DALI mental workload was not found to

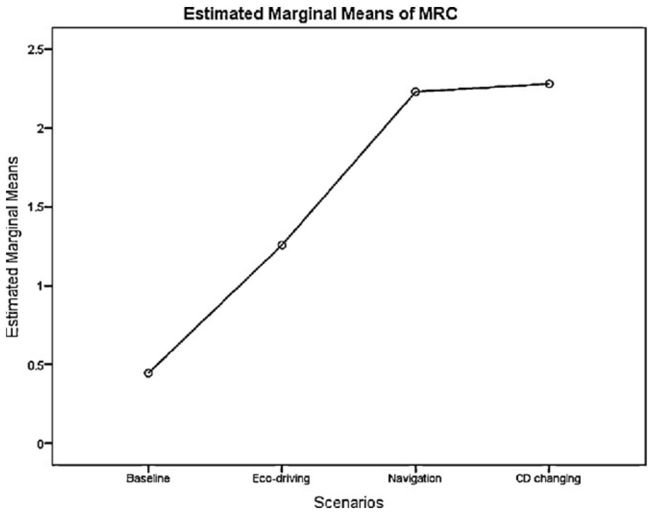

Fig. 5. Missed response counts for entire network across scenarios.

be significantly different between navigation (76.68, 17.25) and CD changing (71.32, 16.78) scenarios.

6.2. Missed response count

There were significant differences between the scenarios in their MRC, $F(3, 57) = 13.571$, $p < .05$, $\mu_p^2 = .417$, OP = 1.000. Pair-wise comparisons were undertaken to identify where the differences occurred between scenarios. Both baseline (25.77, 8.574) and eco-driving (28.32, 11.227) scenarios are significantly different from both navigation (38.55, 13.900) and CD changing (37.18, 16.939) scenarios. However, no measurable differences were found between baseline (25.77, 8.574) and eco-driving (28.32, 11.227) scenarios, and similarly for navigation (38.55, 13.900) and CD changing (37.18, 16.939) scenarios (Fig. 5).

7. Analysis of the practice effect (entire road network)

Twenty-one of the 22 participants completed the second day. One of the participants reported experiencing driving simulator discomfort after finishing the first day and was not happy to continue and do the same tasks for the second day.

7.1. DALI mental workload

The repeated measures mixed ANOVA used to determine the significant differences in the DALI mental workload over 2 consecutive days for each of the scenarios. The results are presented below for each of the scenarios.

7.1.1. Baseline scenario

The results show a significant difference in drivers' mental workload between day 1 (mean = 52.43, standard deviation = 20.86) and day 2 (36.94, 17.87) in the baseline scenario, $F(1, 18) = 35.185$, $p < .05$, $\mu_p^2 = .662$, OP = 1.000. Using a Bonferroni pair-wise comparison, it was confirmed that drivers' mental workload was significantly higher on the first day (mean difference = 15.722, range: 10.580–20.864). However, no significant differences were found as a result of between factors analyses of gender or age groups.

7.1.2. Eco-driving

The results show no significant difference in drivers' mental workload between day 1 (mean = 59.87, standard deviation = 23.75) and day 2 (59.29, 23.55) in the eco-driving scenario, $F(1, 18) = 0$, $p = .984$, $\mu_p^2 = .0$, OP = .050. No significant differences were also found as a result of between factors analyses of gender or age groups.

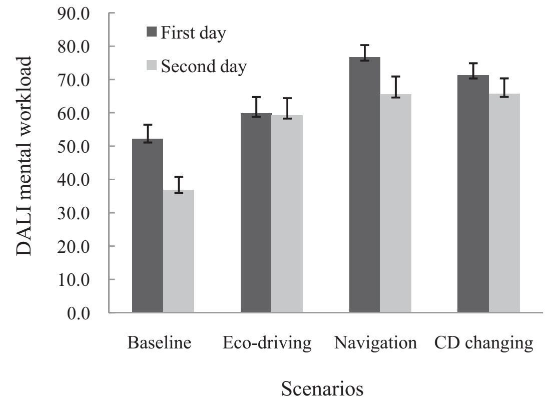

Fig. 6. Effect of practice on drivers' DALI mental workload.

7.1.3. Navigation system

Similar to the baseline scenario, participants rated their mental workload as significantly different on day 1 (76.21, 17.54) compared to day 2 (65.62, 24.34) when they were interacting with the navigation system, $F(1, 18) = 8.497$, $p < .05$, $\mu_p^2 = .321$, OP = .787. A Bonferroni pair-wise comparison found the same results as for the baseline scenario, mean difference = 9.893, range = 3.587–16.198, $p < .05$. However, no significant differences were found as a result of between factors analyses of gender or age groups.

7.1.4. CD changing scenario

As for the eco-driving message scenario, drivers did not rate day 1 (70.49, 16.73) and day 2 (65.78, 20.97) as significantly different for the CD changing scenario, $F(1, 18) = 1.687$, $p = .210$, $\mu_p^2 = .086$, OP = .234. No significant differences were also found as a result of between factors analyses of gender or age groups.

Fig. 6 below summarises the practice effect on the DALI mental workload for each of the scenarios.

7.2. Missed response count

7.2.1. Baseline scenario

Results show that participants' MRCs were significantly different on the first day (24.48, 6.194) compared with the second day (17.57, 6.712), $F(1, 18) = 14.115$, $p < .05$, $\mu_p^2 = .440$, OP = .944. The same results were found with a pair-wise comparison, mean difference = 6.611, range = 3.379–9.843, $p < .05$. However, no gender or age differences were found for MRC over the 2 days.

7.2.2. Eco-driving

There was a marginally significant difference for the practice effect for MRC in the eco-driving scenario between day 1 (27.05, 9.749) and day 2 (22.62, 7.318), $F(1, 18) = 4.236$, $p = .054$, $\mu_p^2 = .190$,, OP = .495. A pair-wise comparison supported the result, mean difference = 4.222, range = .356–8.091, $p < .05$. Practice caused drivers to miss fewer events on second day.

7.2.3. Navigation system

Day 1 (36.62, 10.823) and day 2 (26.43, 7.922) were also significantly different in participants' MRC, $F(1, 18) = 35.673$, $p < .05$, $\mu_p^2 = .665$, OP = 1.000. Similarly, practice showed a significant effect using a pair-wise comparison, mean difference = 10.267, range = 6.926–13.607, $p < .05$.

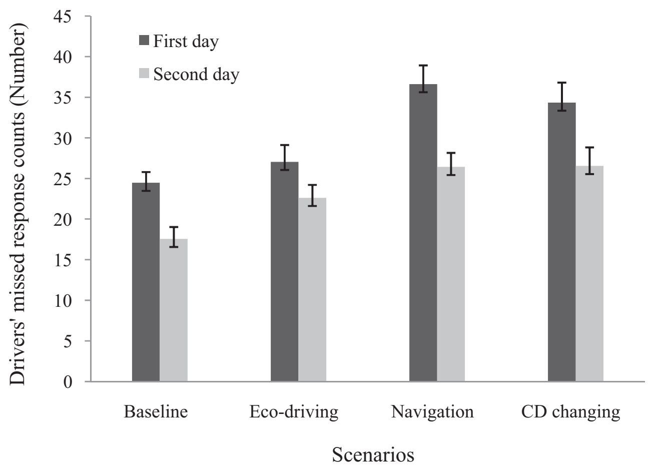

Fig. 7. Effect of practice on drivers' MRCs.

7.2.4. CD changing

Similar to the first three scenarios, in the CD changing scenario, practice decreased MRCs on the second day (26.55, 10.475) when compared with the first day data (34.35, 11.518), $F(1, 18) = 24.880$, $p < .05$, $\mu_p^2 = .594$, OP = .997. A pair-wise comparison suggested the same results, mean difference = 8.100, range = 4.911–11.289, $p < .05$.

Fig. 7 below summarises the practice effect on MRCs for each of the scenarios.

8. Discussion of research outcomes based on research questions

8.1. Does the use of an eco-driving message distract drivers in a driving simulator more than two other in-vehicle activities?

Participants rated mental workload as significantly less in the baseline scenario compared with the navigation system and CD changing scenarios. However, the eco-driving message was not significantly different from the baseline scenario. This suggests that eco-driving messages did not increase drivers' mental workload over the network as a whole. The eco-driving scenario was also significantly different from the navigation scenario but not the CD changing task. Therefore, there is evidence that the eco-driving message induced slightly less mental workload in comparison to the CD changing task, but perhaps not as much as the navigation system. Nevertheless, missed response count was significantly different between the eco-driving scenario and the baseline scenario. Therefore, it appears that drivers' mental workload in the eco-driving scenario was higher than in the baseline scenario, but the same was not found for the CD changing and navigation tasks. In other words, the eco-driving scenario was less mentally demanding than for the two other distracting scenarios. This result is consistent with a previous study by Birrell and Young (2009), who reviewed two prototype designs and examined driver distraction through driver workload. Their results showed that real time smart driving did not increase driver workload. Moreover, while the tasks differed in the kinds of demand they imposed, irrespective of whether they were about eco-driving, navigation, etc., the less active nature of the demands of eco-driving were shown by the research, but demonstrated only modest effects on distraction.

Despite the partial weak support for distracting effects of eco-driving, strong evidence of distraction was found in the CD changing and navigation system scenarios in comparison with baseline scenarios. Observation of drivers struggling to change CDs and enter the numbers in the navigation system supports the idea that CD changing and using a navigation system while a vehicle is in motion are much more physically demanding than an eco-driving scenario.

It is believed that cognitive distraction degrades drivers' performance much less than visual distraction (Ranney, 2008). In addition, visual distraction causes mostly decrements in drivers' steering wheel control and lateral position control, whereas cognitive distraction has an effect on longitudinal vehicle control (Ranney, 2008). Therefore, it could be concluded that participants in the current study did not cognitively engage in the eco-driving message as the study predicted, and if they had, it would have resulted in a greater degree of driving performance decrements. In addition, due to generally good speed control in all scenarios, it can be argued that cognitive distraction level in all scenarios (including eco-driving) was low because there is anecdotal evidence that when drivers' cognitive mental workload increases up to a certain level, drivers' ability in lateral control improves (Ranney, 2008).

From the perspective of Wickens' Multiple Resource Theory Model, CD changing and navigation scenarios both have visual and manual demands. However, the eco-driving scenario has visual/cognitive demand. The main difference between scenarios is their manual demand, and because this competes with one of the main tasks of the driving task itself, it may affect drivers' performance to a greater degree. To sum up, it is appears that eco-driving is less distracting because it is less manually distracting. However, it is not appeared that drivers had engaged cognitively in the eco-driving system.

8.2. Is there a practice effect which reduces the level of distraction under the study circumstances?

The results show that practice certainly decreased participants' mental workload rating in both baseline and navigation scenarios. However, there were no significant improvements for eco-driving and CD changing scenarios. One possible reason for this could be order of the scenarios. Drivers were required to do the baseline scenario first, and therefore may have rated the baseline mental workload higher on average than if its position had been randomised like the other scenarios. It is also possible that the navigation system proved to be the most sensitive scenario to practice because of the higher differences. However, a MRC comparison between the two days suggests that both navigation and CD changing scenarios could be less mentally demanding with practice. Drivers also showed fewer mistakes in responding to events after they practised.

Previously, Shinar et al., 2005 found that practice decreases driver distraction for mobile phone use, whereas Cooper and Strayer (2008) did not find a practice effect in their study (Cooper and Strayer, 2008). Chisholm et al. (2008) believe that multi-interaction tasks, such as the complex iPod task, harm drivers' perception of and response to hazards and increase the frequency of collisions. Although practice reduced the extent of slow responses to driving hazards somewhat, a decrement remained high relative to the baseline condition (Chisholm et al., 2008).

In general, it is probable that practice can mitigate distraction effects in tasks such as CD changing and entering numbers in a navigation system, but it less likely to decrease in simpler tasks, such as with an eco-driving distracter. The range of characteristics of eco-driving and other tasks studied in simulators means that the practice effect will vary by task, which presents challenges in research design.

In conclusion, it has been found that a practice effect has implications for future research using the simulator – that some degree of practice and familiarisation is needed, otherwise the results are less likely to be valid. From the research, it is not possible to say how long this would be, and it also appears that it depends on the task – a task which is initially less demanding appears to exhibit less of a practice effect.

8.3. Limitations of the research

One of the main limitations of this research relates to the sample size and composition. While more participants would have increased the reliability and generalisability of the results, other steps were taken to address this issue: (i) a repeated measures design was employed, with the underlying assumption that idiosyncratic characteristics of each participant would be controlled for by having each person undergo the same baseline and treatment conditions; (ii) the age difference in the study was well-defined, with young participants being 18–24 years old and older participants being 25–66 years old; and (iii) in Section 5.7 we explicitly identified our gender and age analyses as only “exploratory”. In addition to a larger sample size for future studies, we recommend further studies on age and gender differences to provide more definitive findings.

9. Conclusion and implications

This research confirmed that the eco-driving message presents a distraction risk for drivers, although the risk is not as high as for tasks which involve manual as well as cognitive demands. Because of familiarity of drivers with task occurrence order, they expected to be distracted at particular locations and they also knew beforehand that they would be asked to execute the manoeuvres at these locations. This raises the question of how much mental workload may have been imposed on them if they had not expected to receive messages or if they had been reading an eco-driving message and suddenly had to respond to an event. Despite eco-driving messages apparently being less distracting, they could possibly endanger drivers in critical manoeuvres and locations. More studies are needed on the issue.

The evidence of a practice effect has implications for simulator-based research in general, especially when performance on novel tasks is being compared with familiar tasks. The amount of practice needed to become familiar with the task will vary, and this presents methodological challenges. Overall, the research questions, which had emerged from a review of the literature, proved to be effective at highlighting areas of importance for current and future research and practice.

It is important to note that the study investigated one type of eco-driving system. Other systems may differ in the eco-driving message algorithm, spatial location in the vehicle and so on. Similarly, the tasks are examples or analogues of tasks. Therefore, the study focus was on human machine interface (HMI) tasks with demands analogous to some eco-driving, navigation systems and CD changing tasks.

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