Text messaging while driving: its effects on driving performance and text messaging behaviour

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Abstract

Objective: This research investigated the effects of text messaging on simulated driving performance and text messaging behaviour. **Background:** In a limited number of studies, text messaging while driving has been shown to cause impairments in driving performance. However, drivers' strategic behaviour to balance the two tasks is still not fully understood. **Method:** Sixteen participants used a mounted touchscreen which simulated a touchscreen mobile phone to read and respond to text messages in both single task (driving) and dual-task (text messaging while driving) conditions in a fixed-base driving simulator. **Results:** Driving performance was significantly impaired when text messaging while driving, such that lateral deviation increased by 280% from the single-task to the dual-task condition. In addition, participants changed their text messaging behaviour by shortening the length of their replies and typing at a slower speed. **Conclusion:** Text messaging while driving has a severe negative effect on drivers' ability to maintain a central lane position. Attempts to reduce the workload of the text messaging task by typing shorter messages did not mitigate the effects of text messaging while driving. **Application:** The results provide further evidence for the detrimental effects of text messaging on driving performance and highlight the effects of multitasking on the text messaging task. This has potential implications for road safety measures and future in-car device development.

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1 Introduction

In the UK, the use of any hand-held communications device while driving a vehicle is illegal, punishable by a monetary fine and 3 penalty points added to the driver's licence. Despite severe punishments and government warnings to discourage drivers from using mobile phones while driving, it is clear that this activity still takes place. Many surveys have attempted to assess the percentage of drivers using mobile phones while driving. Although a government survey by the Department for Transport put the figure at a conservative 1.4% ("Seatbelt and mobile phone use surveys", 2010), a recent Yougov poll found that 31% of drivers admitted to taking a phone call while driving and 22% admitted to making a call ("One driver in 20", 2010).

Driving is a safety critical task where the attention, visual and motor skills of the driver are needed constantly. Mobile device use while driving was deemed a dangerous enough activity that it was banned in the UK in 2003. However, the use of hands-free kits remain legal, suggesting that the act of operating the mobile device is more distracting than the act of holding a conversation. The law also failed to take into account situational context: it is reasonable to query whether using a mobile phone during a traffic jam is as dangerous as using one while travelling at 70 mph on a motorway.

The rise in popularity and ubiquity of mobile phones in recent years has meant that they are always with us; anyone carrying a mobile phone is reachable wherever and whenever they have a signal. In the modern world, being constantly connected to family and friends and the almost limitless amount of information on the World Wide Web is a great convenience afforded by advances in modern technology. Despite these advantages, mobile devices also have the potential to distract us when performing safety critical tasks.

Various academic research has been conducted into the use of secondary in-car devices while driving. This research has consistently shown that the use of such devices can have a dangerous effect on driving performance and increase the likelihood of having an accident (Drews & Strayer, 2008; Horrey, Wickens, & Consalus, 2006).

Research on the use of mobile phones while driving has mainly focused on the act of dialling a telephone number (Brumby, Salvucci, & Howes, 2009; Salvucci, 2001; Salvucci & Macuga, 2002) (either dialling the number directly or searching a number from an address book) and having a conversation. There has been limited research on text messaging specifically and how this activity affects driving performance; the various factors which affect the success of both activities simultaneously is still not fully understood (Drews et al, 2009). In particular, there has been a lack of research focusing on the strategies people adopt when trying to balance text messaging and driving. This is despite statistics which suggest that text messaging while driving is almost as common as having phone conversations while driving: a Yougov poll found that 28% of drivers confessed to reading a text while driving and 18% said they had responded to one ("One driver in 20", 2010).

One reason for this lack of research may be due to the only recent rise in popularity of text messaging. Mobile phone interfaces have continually evolved to make input easier and faster: a standard numeric keypad requires the user to press each number multiple times for one character; a numeric keypad with predictive text (e.g. T9) software only requires one key press per letter; phones with full qwerty keyboards allow a separate key press per letter as on a standard computer keyboard; phones with touchscreen qwerty keyboards can be language independent and change on-screen keys according to context, for example showing a ".com" button when typing an email.

The act of text messaging shares common ground with other in-car secondary tasks, but is also different in some ways. To demonstrate this, we shall examine the act of dialling a telephone number. The driver has the phone number memorised and has to enter the phone number using the keypad with one hand, while steering with the other hand. Motor skills are divided between the two tasks, preventing the driver from performing many driving-related tasks such as changing gears while operating the device. Entering the phone number also requires the driver's vision and attention; when looking at the phone, pressing a key and looking at the display, the driver cannot see what is happening on the road and cannot perceive and react to hazards such as a pedestrian crossing the road or the car in front performing an emergency brake. However, the driver can choose which strategy to adopt when dialling while driving: for example, dialling one number at a time and interleaving attention back to driving frequently, or dialling all numbers at once and not interleaving attention at all, or any other variation of strategy. Research has shown that cognitive constraints such as the representational structure of the phone number can have an effect on the strategy adopted (Brumby, Salvucci, & Howes, 2009).

The issues described so far are common to both dialling a phone number and text messaging, as well as operating a satellite navigation system or in-car entertainment system. However, text messaging differs to dialling in that there is a further element of choice, in addition to choice of interleaving strategy: the driver can choose what to write in the text message. Unlike with phone number dialing, the driver can choose how to long to make the message, how much information to include, and how to represent the information. When responding to a message, the driver can also choose when to start typing a response. Various factors may affect driving performance and text messaging choice and performance in this scenario. One of these factors is the difficulty of the driving task: for example, do drivers send shorter messages and react slower when driving at high speed compared to low speed? Another factor is frequency of text messaging: for example, do drivers react quicker if a new incoming message is received immediately after a response has just been sent? How does driving performance change as a result of these factors? A better understanding of questions such as these may help the design of safer systems.

This dissertation investigates how task difficulty and task frequency affect driving performance, text messaging performance, and strategy choice. Section 2 presents a review of relevant literature in the use of in-car devices while driving, with a particular focus on text messaging. Section 3 describes the method of a controlled laboratory experiment that investigated driver behaviour when responding to text messages while driving in a fixed-base driving simulator. Section 4 presents a summary of the results of the experiment and section 5 discusses the findings in relation to current literature, as well as discussing implications for the design of mobile and in-car devices. Limitations of the study are acknowledged and future areas of research are identified.

2 Literature review

2.1 Text messaging while driving

In the limited number of empirical studies which have focused exclusively on the effects of text messaging on driving, all have shown text messaging to have adverse effects on various metrics of driving performance.

Drews, Yazdani, Godfrey, Cooper, & Strayer (2009) conducted a study into the effects of text messaging on participants' performance in a high-fidelity driving simulator. In the experiment, pairs of participants exchanged text messages with one another with the goal of arranging an evening activity, while one participant drove along a freeway road behind a leading pace car. The leading car braked intermittently to assess the impact of text messaging on participant's ability to react to road events. Results showed a significant decrease in driving performance across all measured metrics: under the dual-task condition compared to the baseline single-task driving condition, participants had slower brake onset times, more lane departures, reduced lane maintenance overall, and notably a six-fold increase in crash rate. Interestingly, participants increased their following distance in the dual-task condition; this may have been a conscious or unconscious attempt to create a safety buffer with the leading car to reduce crash likelihood. However, this strategy proved inadequate, as evidenced by the high crash likelihood.

A study focusing specifically on young drivers found similar results. Hosking, Young, & Regan (2009) investigated the effects of text messaging on the driving performance of young novice drivers. Young drivers were chosen as they were found to be more willing to text than experienced drivers, while not having the experience necessary to drive with limited attentional resources. Young drivers were also considered more vulnerable to distraction: it was predicted that more resources would be allocated to driving, leaving fewer resources for secondary tasks and thus impacting driving performance when tasks needed to be balanced. The experiment involved participants text messaging while driving in a driving simulator, with 8 test events to evaluate participants' driving performance. Results found a significant increase in the number of missed lane changes in the car-following event; an increase in the number of lane excursions overall; and an increase in drivers' mean time headway (distance from leading car) and time headway variability overall. This increase in mean time headway mirrors the behaviour seen in the Drews et al. study, where participants created a safety buffer behind the leading car. In addition, eye movement analyses (recorded using eye-tracking software) found a significant increase in the proportion of time looking inside the vehicle, an increase in the number of in-vehicle glances, and an increase in the length of time of in-vehicle glances.

In an earlier small-scale study featuring 10 participants, Kircher et al. (2004) conducted an experiment focusing only on receiving text messages, with participants responding to the text message verbally. Results found a significantly increased braking time for one of the four simulated hazard conditions, with no other significant effects found. However, this could be due to the small sample size and the use of experienced drivers, whose driving skill were at a level where a secondary task did not noticeably impact driving performance.

Clearly, the driving conditions used by Drews et al. in their experiment were much more extreme than typical everyday driving. Participants drove in two scenarios: in each scenario, the leading pace car braked at 42 randomly selected intervals, providing a total of 84 opportunities for each participant to crash. Coupled with the high speeds typically encountered on a freeway, this highly dangerous condition of a frequently braking lead car could be part of the reason for the poor driving performance found when participants were text messaging while driving.

Hosking et al.'s study deliberately focused on young inexperienced drivers who were found to be more willing to text message while driving. Their prediction that young novice drivers would lack the skill necessary to perform a secondary task without adverse effects on driving performance was found to be correct. However, surprisingly, analyses of participants' driving performance in response to three hazard conditions (traffic light, pedestrian crossing the road, and a right-turning car) found no significant effects on braking reaction times when text messaging while driving. The authors note limitations in methodology as possible reasons for this, including participants learning to expect hazards and the experience the participants had with text messaging. It should be noted that the text messaging task was very simple: participants only had to respond to text messages with one-word replies. This may also have been a factor in participants' success in responding to road hazards.

2.2 Manual input while driving

Despite the lack of research specifically in the area of text messaging while driving, we can also draw on studies which feature other manual input tasks while driving.

Tsimhoni, Smith, & Green (2004) compared input methods for address entry on an in-car navigation system. One of the input methods assessed was a touchscreen keyboard, very similar to a mobile phone with an on-screen touchscreen keyboard. A driving simulator study found a serious degradation of vehicle control when using the touchscreen for manual input while driving, with increases in lateral deviation and lane departures from the single-task driving condition. Furthermore, the address entry task also took significantly longer to complete. However, task differences may mean the results here cannot be directly applied to text messaging while driving. In the address entry task, participants retrieved addresses from a separate memo display before typing them using the touchscreen. In a text messaging task, this is similar to reading an incoming message, but text messaging also requires more cognitive effort to think of a response and hold it in working memory before typing it out. Therefore the effects of text messaging may be even greater than those of address entry while driving.

Dialling a telephone number is also a task similar to text messaging. Research has consistently shown the detrimental effects of dialling on driving performance (Brumby, Salvucci, & Howes, 2009; Salvucci, 2001; Salvucci & Macuga, 2002). See Collet, Guillot, & Petit (2010) for a comprehensive review of epidemiological, psychological, behavioural and physiological studies on the impact of mobile phone use on driving performance. Regan, Young, Lee, & Gordon (2008) also performed a task analysis of the steps involved in talking on a mobile phone, finding that the act of manually dialling a phone number has the most detrimental impact on driving performance. These findings suggest that text messaging, which features prolonged periods of manual input of complex information, may significantly impair driving performance.

2.3 Task difficulty

Research has shown that the demands of the driving task and the demands of the secondary task have an effect on driving performance when multi-tasking (Horrey & Wickens, 2004; Lee, Regan, & Young, 2008). In the Drews et al. study, the high frequency with which participants had to brake may have had an effect on the resulting findings: high task difficulty may have contributed to the high crash rate found in the dual-task condition. The simplicity of the text messaging task, only requiring participants to give one-word replies, may have been a factor in Hosking et al.'s study: the low difficulty of the text messaging task may have contributed to participants' successful driving performance in the dual-task condition. Therefore, task difficulty - both of the driving task and the text messaging task - may be an important factor in determining the extent to which text messaging while driving affects driving performance.

Driving speed was used to manipulate driving difficulty in an experiment by Brumby et al. (2009) to investigate strategy adaptation in a dual-task setting involving dialling a telephone number while driving. Results found a significant effect of speed on driver's ability to maintain a central lane position in both the single-task driving and the dual-task dialling while driving conditions. Driving performance was significantly worse when driving at a high speed (55 mph) compared to a low speed (35 mph). The steps involved in text messaging is very similar to dialling in that both tasks require manual input from the driver and therefore a sharing of visual attention and motor skills. It is therefore reasonable to assume that different driving speeds may have an impact on driving performance when text messaging while driving.

The experiments conducted by Drews et al., Hosking et al., and Kircher et al. all did not place emphasis on the text messaging task: Drews et al. had pairs of participants arranging an evening event via text message, but did not control this task nor report associated measures; Hosking et al. only required participants to reply to text messages using one-word answers; and Kircher et al. did not require participants to reply via text message at all, but simply retrieve the incoming message and respond verbally. Looking at text messaging performance in addition to driving performance may allow us to better understand drivers' behaviour.

2.4 Strategy choice

One area where analysing text messaging performance could be beneficial is strategy selection: how do drivers attempt to balance the two task objectives when text messaging while driving? How does strategy selection change in response to changing the demands of the driving task and the text messaging task? An indication to these answers can be found in Horrey & Lesch's (2009) study which examined whether drivers would strategically select the best opportunities to carry out distracting in-vehicle tasks, given prior knowledge of upcoming road demands. In the experiment, participants drove around a test-track and were instructed to perform an in-vehicle task such as reading a text message; participants had free choice when to carry out the task and knew which sections of the test-track were more difficult to navigate. Results found no strategic adaptation: participants carried out the task regardless of the road demands and did not postpone tasks until they encountered an easier section of the course. This frequently led to driving errors: participants made an error in 19% of the trials, providing evidence that in-vehicle tasks negatively affect driving performance even when drivers have free choice of when to perform them.

Applying these results to specifically to text messaging while driving, this may suggest that regardless of the difficulty of the driving task, drivers would not alter their text messaging behaviour, with subsequent detrimental effects on driving performance. On the other hand, if drivers do strategically adapt to the demands of the driving task, then in difficult conditions such as driving at a high speed, we would expect reaction times to text messages to be longer, messages to be shorter, and typing speed to be slower, as more focus is given to the driving task in order to maintain lane position.

2.5 Current study

The first goal of this study is to provide further empirical evidence in support of or against the claim that text messaging while driving has a detrimental effect on driving performance. To simplify the experiment, lateral deviation from the centre of the lane will be the only measure of driving performance used. Unlike braking reaction times, lateral deviation does not depend on external events such as road hazards which are difficult to simulate realistically.

The second goal of this dissertation is to explore factors which may have an effect on the extent to which text messaging affects driving performance. Driving speed will be manipulated in order to change the difficulty of the driving task. Delay times between incoming text messages will be changed in order to vary the frequency of the text messaging task.

The third goal of this dissertation is to investigate strategy selection. To facilitate this, attention will be paid to the performance of the text messaging task in addition to the performance of the driving task. It is hoped this approach will capture any performance trade-offs which may or may not differ between the task types, driving speeds, and text message delay times.

3 Method

3.1 Participants

16 postgraduate students from UCL took part in the experiment. All participants held a valid UK driving license with a mean driving experience of 6.46 years (standard deviation = 3.33). All participants were screened for normal or corrected to normal visual acuity. Ages of participants ranged from 22 to 37 years, with a mean of 27.56 years (standard deviation = 4.1). 10 participants were male. Participants were not paid nor did they receive course credit for taking part in the experiment. Participants were warned not to take part if they suffered from motion sickness.

3.2 Equipment

A low-fidelity fixed-base driving simulator was used, which consisted of: an Apple Mac Mini; the driving simulator software; a Logitech driving wheel; and a 30 inch LCD screen as the main display, at a resolution of 1280 x 800. A mobile phone simulator was used, which consisted of: a 7 inch LCD touch-screen as the secondary display and input device, at a resolution of 800 x 600; and text messaging software created using Java and modelled on the Apple iPhone's text messaging system. The secondary display was positioned to the left of the main display, approximately where a real mobile phone would be mounted to a vehicle's centre console.

To make the text messaging task as realistic as possible, questions sent to participants as text messages were created from Thurlow & Brown's (2003) analysis of communication orientations and themes in text messages. The analysis identified key categories of text messages such as informational-practical (e.g. asking where a place is) and practical/social-arrangement (e.g. arranging the time to meet for an activity). Question types were balanced across all conditions in the experiment in order to remove the likelihood that a set of questions in one particular condition would elicit shorter or longer responses, or be more or less difficult to process and respond to.

3.3 Design

The single-task trials were used to obtain baseline measurements of driving and text messaging performance.

In the dual-task trials, a 2x2 within-subjects design was used, with all participants carrying out all conditions of the experiment. The conditions were systematically counter-balanced to account for order effects; 4 participants carried out the experiment for each order of conditions. The independent variables were driving speed (slow: 30mph and fast: 70mph) and the time delay between text messages (short: 3 seconds and long: 15 seconds).

For the single-task driving and dual-task conditions, the dependent variable was: root-mean-squared error (RMSE) lateral deviation (metres).

For the single-task text messaging and dual-task conditions, the dependent variables were: text message verbosity (number of characters, reaction time (time from the incoming message being displayed to the participant's first key press), response time (time from the participant's first key press to their last key press), and typing speed (number of characters per second).

3.4 Procedure

Participants were first given an information sheet describing the purpose of the experiment and asked to sign a consent form. They were given the opportunity to ask questions before the experiment started.

The practise trials allowed participants to gain familiarity with the driving simulator and the mobile phone simulator. Participants practised for one trial each of driving at slow speed, driving at fast speed, and text messaging.

In the driving single-task, participants had to steer an auto-accelerating car, travelling at a constant speed, down a straight road (the middle lane of a three lane motorway). Traffic cones were displayed at the lane boundaries to discourage lateral movement. Steering to maintain a central lane position was the only driving task; no pedals were used.

In the text messaging single-task, participants received text messages on the touch-screen secondary display, which simulated a touch-screen mobile phone. A received text message was signified by a beeping sound to alert the participant, with the text message instantly appearing on the display. The secondary display featured a on-screen 'QWERTY' keyboard which was used by participants to type in their responses. A 'send' button was used to confirm the sending of a response. After a response was sent, and after a delay period (3 seconds or 15 seconds depending on delay condition), participants were sent another message to respond to. There were a total of 3 incoming messages per trial. Participants were instructed to respond to all 3 messages per trial, but were not given any instructions on when to respond, nor what to type in response.

In the single-task trials, participants performed the driving or texting tasks in isolation: 2 trials each of driving at slow speed, driving at fast speed, text messaging with a short delay, and text messaging with a long delay. In each driving trial, participants drove for 20 seconds, followed by feedback on their RMSE lateral deviation. In each text messaging trial, participants responded to 3 text messages, followed by no feedback.

In the dual-task conditions, participants performed the driving and texting task simultaneously: driving and texting at slow speed and high speed, with short and long delays between text messages. Each trial was followed by feedback on their RMSE lateral deviation. In total, each participant completed 8 dual-task trials: 2 trials x 2 driving speeds x 2 text messages delays. In the dual-task trials, each participant responded to a total of 24 text messages: 8 dual-task trials x 3 messages per trial.

4 Results

The dependent measures of interest varied depending on the trial type. For the driving single-task: the RMSE lateral deviation of the participant's vehicle from the centre of the lane was the only dependent variable; for the text messaging single-task: the message length, reaction time, response time, and typing speed of the participant were the dependent variables. For the dual-task trials, all dependent variables were of importance.

Data from one participant was excluded from data analysis due to having a mean driving score of more than two standard deviations above the mean for all participants.

From a total of 180 (4 single-task and 8 dual-task trials per participant; 15 participants) trials involving the touchscreen and the custom-made text messaging software, data from only one trial was excluded from analysis; this was due to a touchscreen malfunction during a text messaging single-task trial. The trial had to be interrupted to reset the touchscreen, leading to artificially inflated reaction and response times, hence why the data was excluded.

The next sections describe the results of a detailed statistical analysis of the data obtained from the experiment. Unless otherwise stated, a two-way repeated-measures ANOVA with variables of driving speed (fast; slow) and text message delay (long; short) was used for statistical analyses. Both variables were analysed as within-subject variables. An alpha level of .05 was used throughout.

4.1 Driving performance

The only dependent variable on which driving performance was measured was the RMSE lateral deviation across the trial. The driving simulator logged the lateral deviation of the participants' vehicle from the centre of the lane at a rate of 200Hz. The RMSE of these cumulative lateral deviation samples was then calculated over the the duration of the trial.

The first analysis compared driving performance between the two task types and driving speeds. The second analysis compared driving performance between the dual-task conditions of driving speed and text message delay.

4.1.1 Effect of multi-tasking on driving performance

Analysis compared driving performance between the single-task driving condition and dual-task text messaging while driving condition under differing driving speeds. Figure 1 shows the effects of task type (single-task; dual-task) and driving speed (slow; fast) on participants' RMSE lateral deviation. Lateral deviation was significantly lower in the single-task condition (M = .320m, SD = .095m) compared to the dual-task condition (M = .906m, SD = .370m), $F(1{,}14) = 50.8$, $p < .001$. This shows that participants' driving performance was better when only driving, compared to text-messaging while driving.

Analysis also showed that there was no main effect of driving speed on lateral deviation ($p = .353$). There was also no significant interaction between driving speed and task type, $p = .342$.

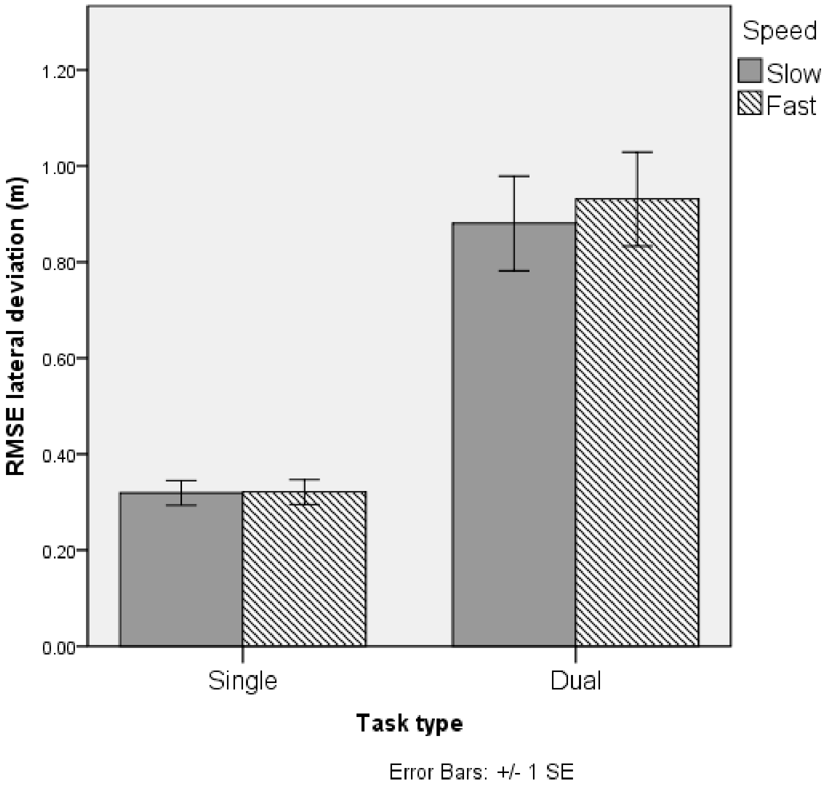

Figure 1: Effect of task type and driving speed on RMSE lateral deviation

4.1.2 Effects of driving speed and text message delay on driving performance in the dual-task condition

Figure 2 shows the effect of driving speed and text message delay on driving performance (RMSE lateral deviation) in the dual-task condition. There was a significant main effect of text message delay (long; short) on driving performance ($F(1,14) = 11.3$, $p = .005$); participants' deviation was lower in the long delay condition ($M = .820$m, $SD = .368$) compared to the short delay condition ($M = .992$, $SD = .434$). This shows that participants' driving performance was better when there were long delays between incoming text messages, compared to short delays between incoming text messages. However, there was no significant main effect of driving speed on driving performance, $p = .320$. Furthermore, there was no significant interaction between driving speed and text message delay, $p = .317$.

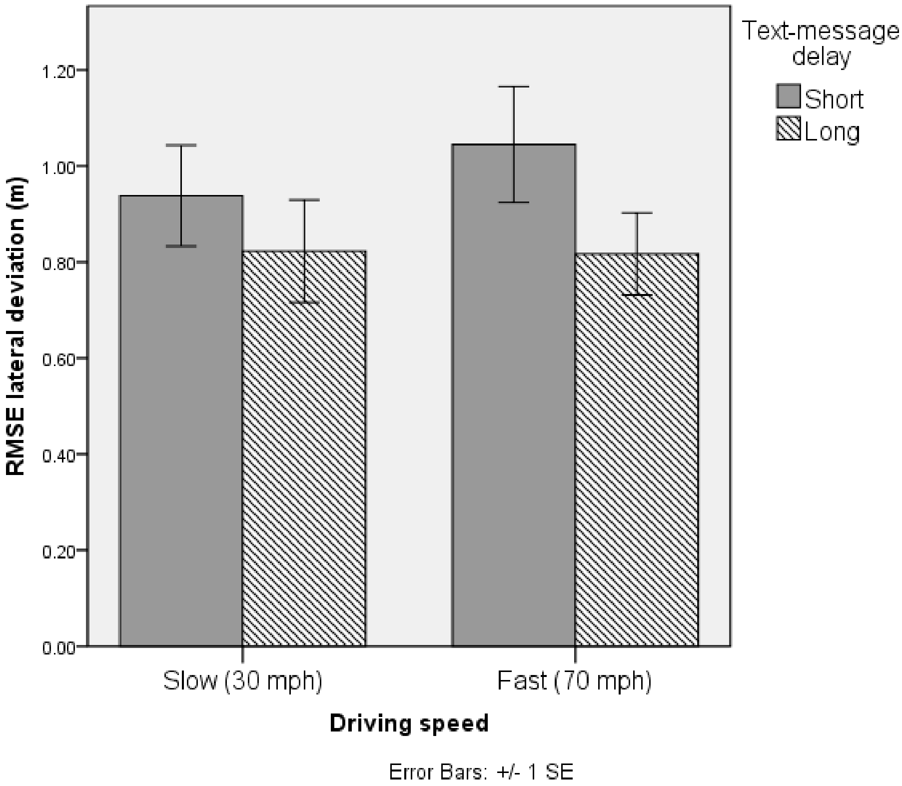

Figure 2: Effects of driving speed and text message delay on RMSE lateral deviation in the dual-task condition

4.2 Text messaging performance

Text messaging performance was measured using multiple dependent variables: message length, reaction time, response time, and typing speed. A full description of these variables can be found in the Method section in section 3.

The first analysis compared text messaging performance between the two task types and text message delay times. The second analysis compared text messaging performance between the dual-task conditions of driving speed and text message delay.

4.2.1 Effect of multi-tasking on text messaging performance

Analysis compared text messaging performance between the single-task text messaging condition and dual-task text messaging while driving condition under differing text message delay times. Analysis showed significant main effects of task type (single; dual) on the dependent variables of message length, reaction time, and typing speed.

Figure 3 shows the mean message lengths for the single-task and dual-task conditions under the short and long text message delay times. There was a significant main effect of task type on message length: message length was statistically significantly lower in the dual-task condition (M = 15.9, SD = 7.23) compared to the single-task condition (M = 28.0, SD = 12.1), $F(1,14)$ = 32.8, $p < .001$. This shows that participants typed shorter messages when text messaging while driving, compared to only text messaging. There was no significant main effect of driving speed on text message length, $p = .302$. There was a significant interaction between task type and driving speed, $F(1,14) = 5.41$, $p = .036$.

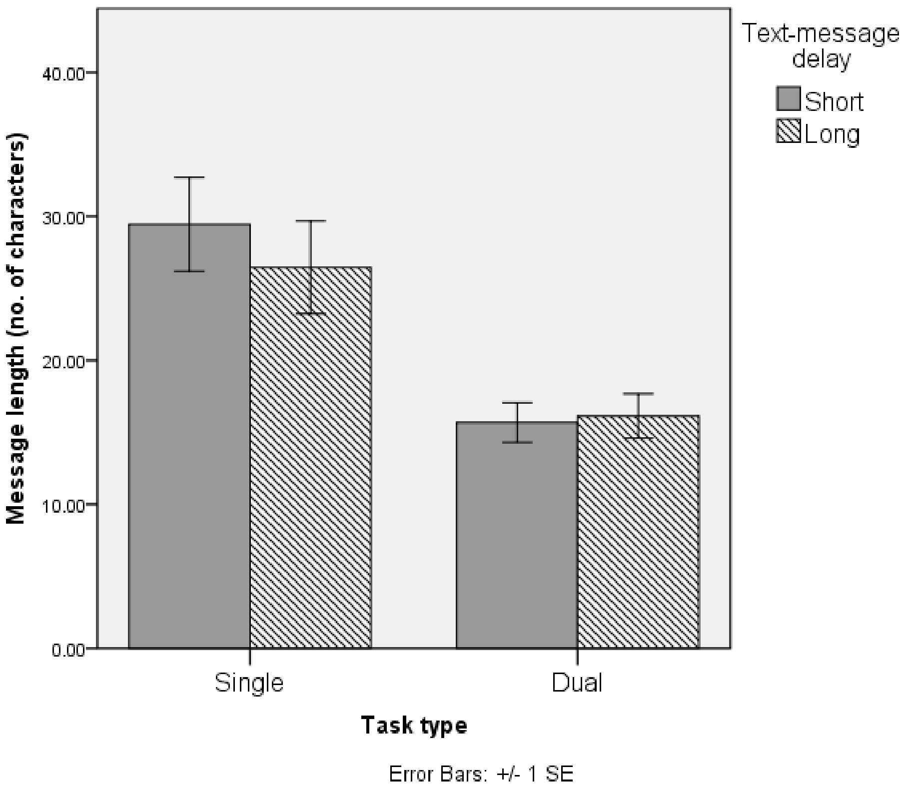

Figure 3: Effect of task type and text message delay on message length

Figure 4 shows the mean reaction times for the single-task and dual-task conditions under the short and long text message delay times. There was a significant main effect of task type on reaction time: reaction time was statistically significantly higher in the dual-task condition (M = 8.72s, SD = 2.86s) compared to the single-task condition (M = 4.49s, SD = 1.73s), $F(1,14) = 49.7$, $p < .001$. This shows that participants took longer to start typing a response to an incoming message when text messaging while driving, compared to only text messaging.

There was also a significant main effect of text message delay time on reaction time: reaction time was lower when there were short delays between incoming text messages (M = 7.04s, SD = 3.37s) compared to long delays (M = 7.58s, SD = 3.41s), $F(1,14) = 7.49$, $p = .016$. This shows that participants reacted quicker to incoming messages when they were received quicker following an outgoing message. There was no significant interaction between task type and text message delay time, $p = .612$.

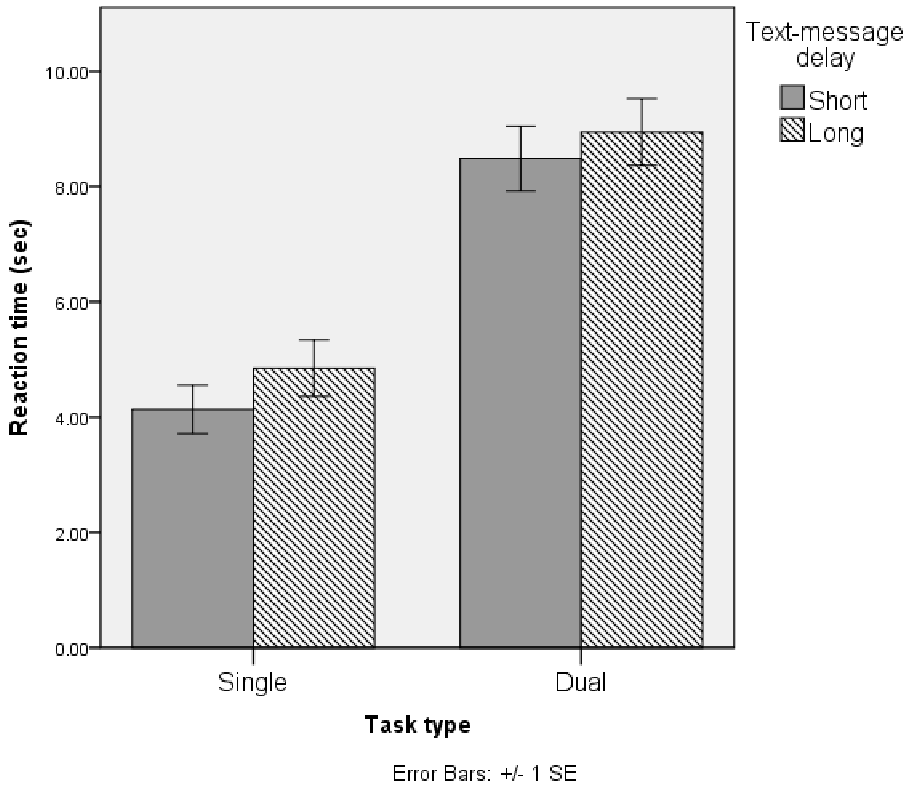

Figure 4: Effect of task type and text message delay on reaction time

Figure 5 shows the mean response times for the single-task and dual-task conditions under the short and long text message delay times. There was no significant main effect of task type on response time, p = .878. Response times for the single-task text messaging condition (M = 28.9s, SD = 10.6s) were approximately the same as the dual-task text messaging while driving condition (M = 29.4s, SD = 13.4s). This shows that participants spent the same amount of time typing in responses regardless of whether multi-tasking or single-tasking.

There was also no significant main effect of text message delay time on response time, p = .858. Participants spent the same amount of time typing in responses regardless of whether multi-tasking or single-tasking. There was a significant interaction between task type and text message delay time, $F(1,14) = 4.93$, p = .043.

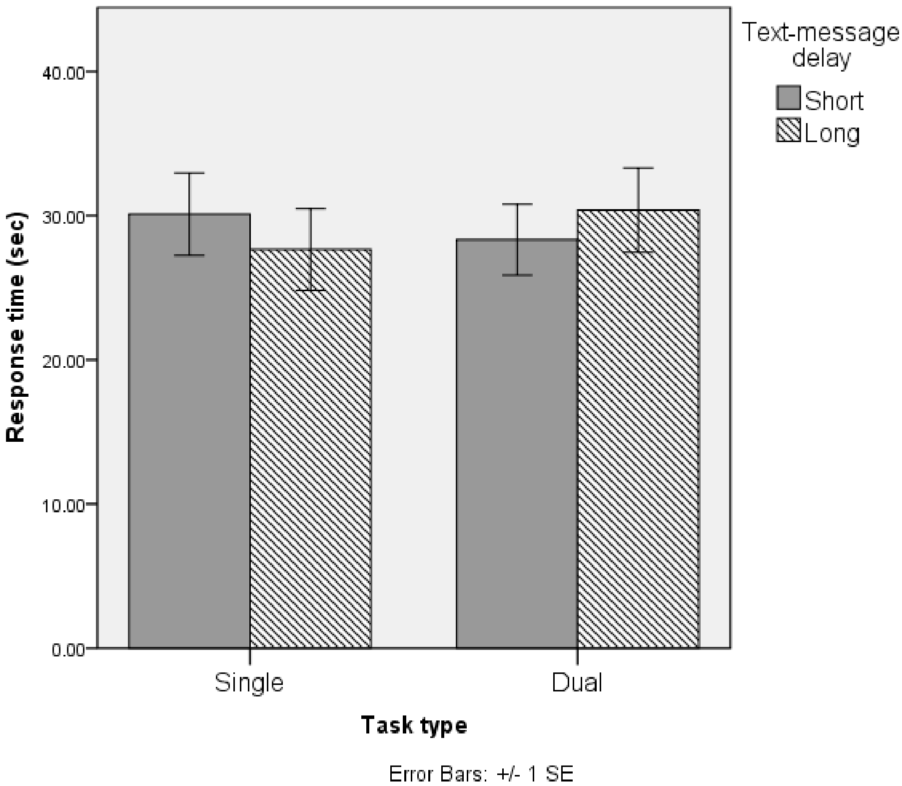

Figure 5: Effect of task type and text message delay on response time

Figure 6 shows the mean typing speeds for the single-task and dual-task conditions under the short and long text message delay times. There was a significant main effect of task type on typing speed: typing speed was statistically significantly lower in the dual-task condition (M = .674, SD = .133) compared to the single-task condition (M = 1.19, SD = .239), $F(1,14) = 82.1$, $p < .001$. This shows that participants typed slower when text messaging while driving, compared to only text messaging. There was no significant main effect of driving speed on typing speed, p = .383. There was no significant interaction between task type and driving speed, p = .718.

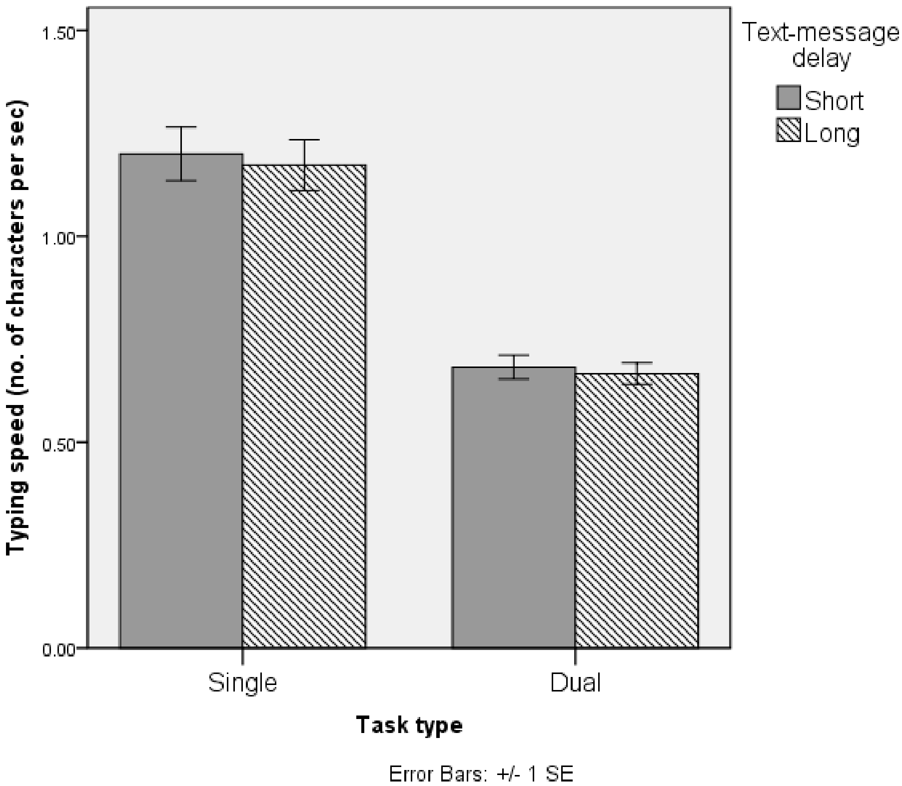

Figure 6: Effect of task type and text message delay on typing speed

In summary, participants took longer to react to text messages, typed shorter responses, and typed slower in the dual-task condition compared to the single-task condition. However, there was no difference in response time, the time it took to type in and send a response.

4.2.2 Effects of driving speed and text message delay on text messaging performance in the dual-task condition

Analysis compared the effects of driving speed (slow; fast) and text message delay (short; long) in the dual-task condition on the dependent variables used to measure text messaging performance. In the analysis of typing speed, there was a trend interaction effect between driving speed and text messaging delay, $F(1{,}14) = 3.92$, $p = .068$. There were no other statistically significant effects found.

Figure 7 shows the effects of driving speed and text message delay on the mean message length. There was no significant main effect of driving speed on message length (p = .124) nor text message delay on message length (p = .698). There was no significant interaction between driving speed and text message delay, $p = .293$.

Figure 8 shows the effects of driving speed and text message delay on the mean reaction time. There was no significant main effect of driving speed on reaction time (p = .184) nor text message delay on reaction time (p = .290). There was no significant interaction between driving speed and text message delay, $p = .255$.

Figure 9 shows the effects of driving speed and text message delay on the mean response time. There was no significant main effect of driving speed on response time (p = .630) nor text message delay on response time (p = .171). There was no significant interaction between driving speed and text message delay, $p = .446$.

Figure 10 shows the effects of driving speed and text message delay on the mean typing speed. There was no significant main effect of driving speed on typing speed (p = .141) nor text message delay on typing speed (p = .558).

These results suggest that the independent variables of driving speed and text message delay did not significantly affect participants' text messaging performance in the dual-task condition.

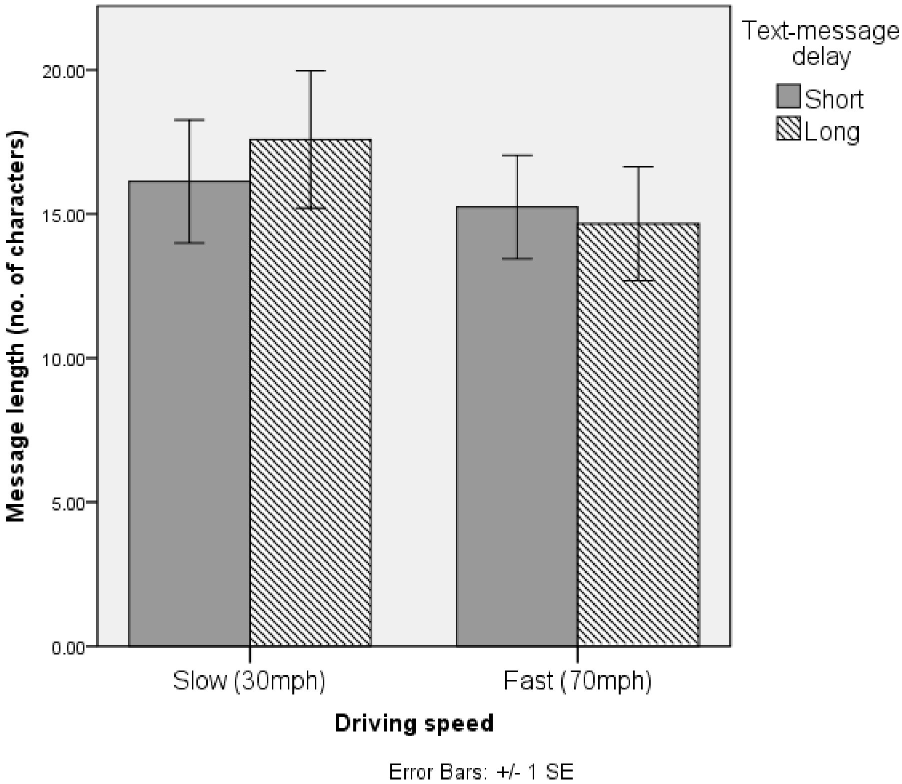

Figure 7: Effect of driving speed and message delay on message length

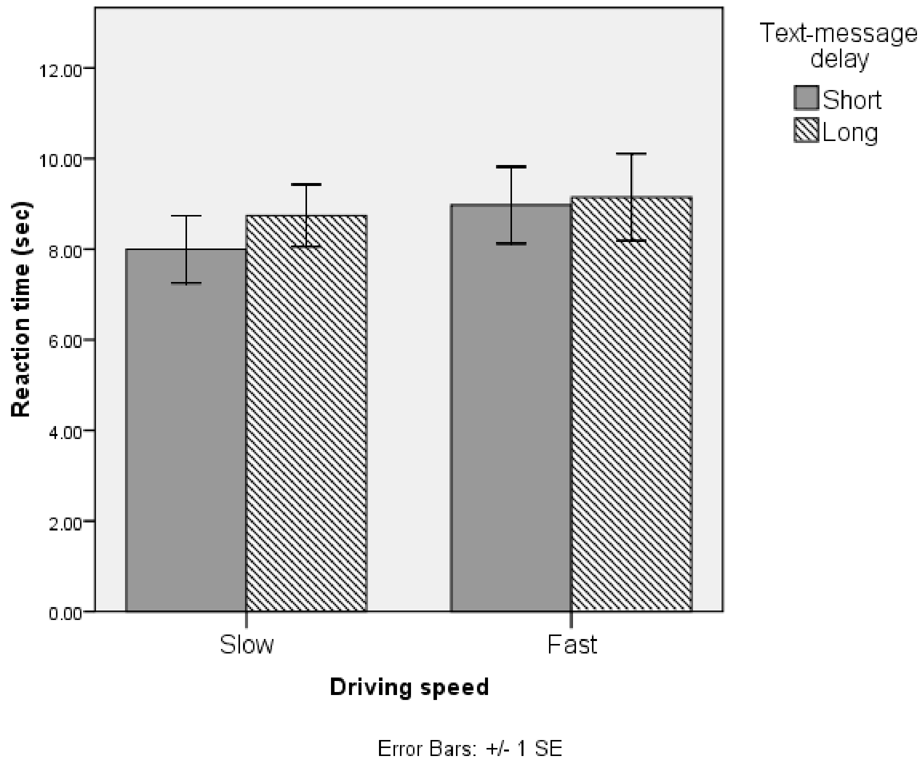

Figure 8: Effect of driving speed and message delay on reaction time

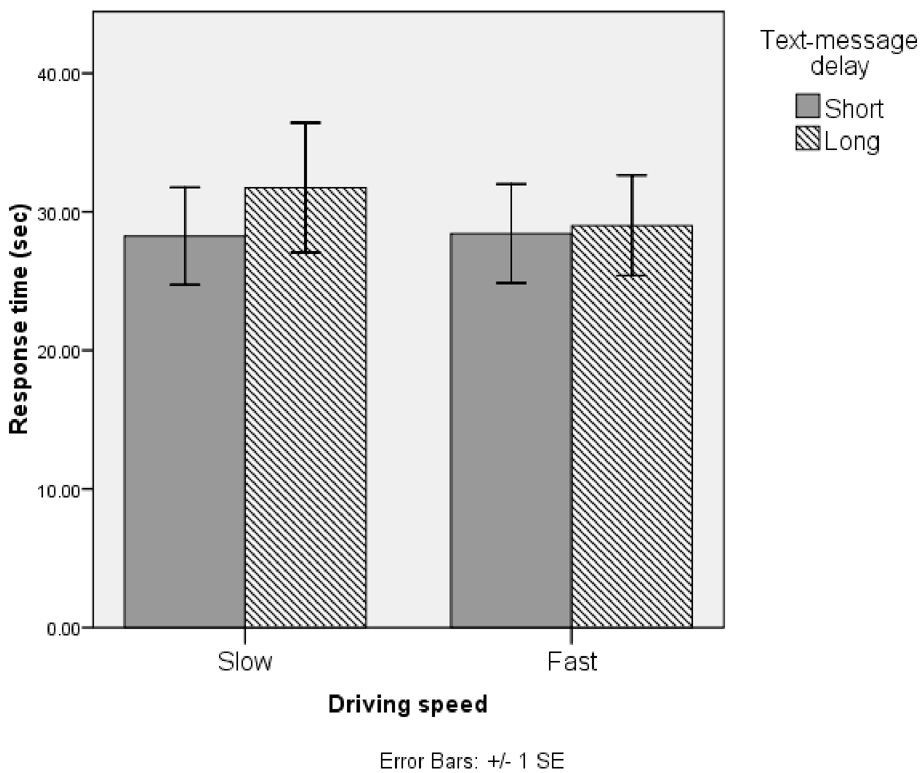

Figure 9: Effect of driving speed and message delay on response time

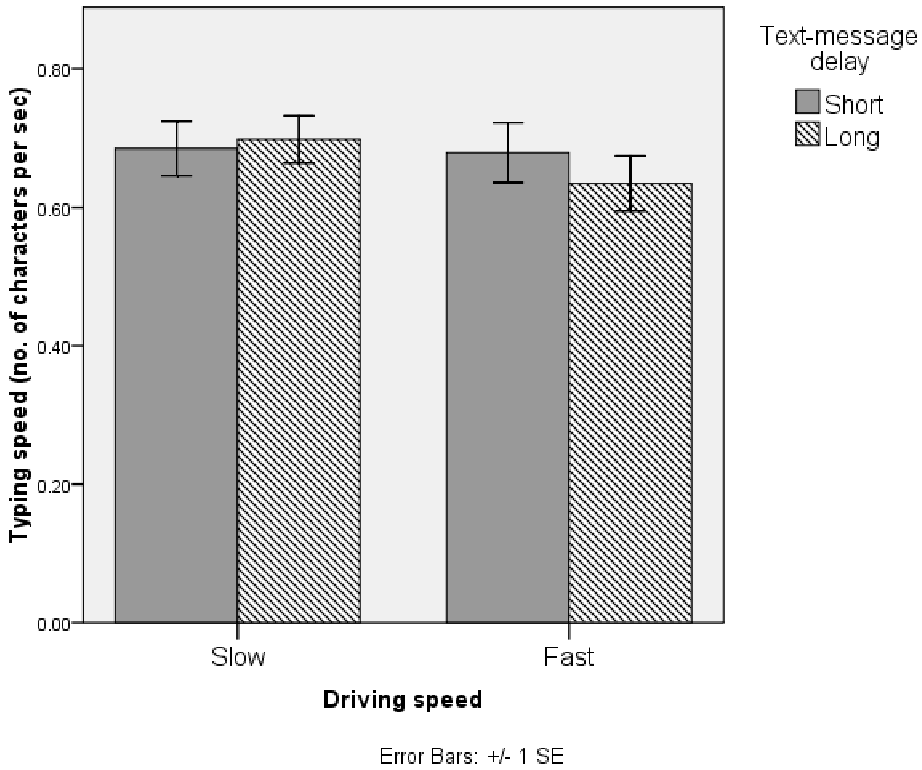

Figure 10: Effect of driving speed and message delay on typing speed

5 Discussion

5.1 Driving performance

The experiment found participants' lateral deviation to be significantly worse when text messaging while driving compared to when driving only. There was a 0.586m increase in lateral deviation from 0.320m in the single-task condition to 0.906m in the dual-task condition; a 280% increase. This supports previous research in this area which has found text messaging to be detrimental to driving performance (Kircher et al., 2004; Drews et al., 2009; Hosking et al., 2009); these studies have highlighted various reasons for this finding, with each having varying levels of applicability in this study.

It is likely that the visual demands of text messaging was a highly important factor in the impairment of driving performance. Due to the position of the touchscreen, participants interleaved visual attention between the touchscreen and the road. Studies have shown the costs of display separation to be greater for head-down displays compared to adjacent displays (Horrey & Wickens, 2004). This suggests driving performance may have improved if participants were allowed to share visual attention between the touchscreen and the road by holding the touchscreen at eye level while driving. The amount of time spent not looking at the road while driving contributes to detriments in driving performance and increases in crash risk (Lansdown, 2001).

Compared to other manual input tasks such as dialling a phone number, text messaging requires additional cognitive resources to process the message and understand its meaning. It is likely the cognitive demands of the text messaging task was a factor in the impairment of driving performance.

As the driving task was simple, requiring participants to only steer the vehicle to correct lane position along a straight road, the sharing of motor skills was unlikely to be an important factor in the impairment of driving performance. The steering wheel could easily be adjusted with just one hand, leaving the other hand free for operating the touchscreen.

The difficulty of the driving task, as modified by the driving speed, did not have an effect on lateral deviation. This was seen in both the single-task and dual-task conditions, and in the combined data. This supports Horrey & Lesch's (2009) findings that drivers do not strategically adapt dual-task strategy according to the demands of the driving task, with subsequent negative effects on driving performance. Further evidence can found in the results obtained for text messaging performance which were the same both driving speeds. This will be discussed in the following section on text messaging performance.

Looking at the data from the dual-task condition only, the text message delay time had an effect on lateral deviation: short delays between incoming messages led to worse driving performance. This shows that the frequency of interruption from the text messaging task affected participants' ability to maintain a central lane position. This is likely a result of participants spending less time correcting the vehicle's position on the road over the course of the trial due to more frequent incoming text messages. However, participants could have chosen to spend the same amount of time on the driving task in both delay conditions: in the shorter delay condition, the text message could have simply been ignored until the participant felt the vehicle was heading in a stable direction. In fact, all text message performance variables were the same in both delay conditions.

5.2 Text messaging performance

An aspect of text messaging while driving which hasn't been studied is performance of the text messaging task. Comparing text messaging performance between the single-task and dual-task conditions, there is a clear detrimental effect of multi-tasking in the dual-task condition. The experiment found participants to type significantly shorter messages when text messaging while driving compared to when text messaging only: there was a 12.1 character decrease in message length from 28.0 characters in the single-task condition to 15.9 characters in the dual-task condition. Reaction time was also significantly longer: there was a 4.23s increase in reaction time from 4.49s in the single-task condition to 8.72s in the dual-task condition. Typing speed was also significantly lower: there was a 0.516 characters per second decrease in typing speed from 1.19 in the single-task condition to 0.674 characters per second in the dual-task condition. Response time, however, was the same across both conditions. It seems likely that message length counterbalanced with typing speed to produce similar response times: typing shorter messages at a slower speed took approximately the same amount of time as typing longer messages at a faster speed.

Participants were given free choice of the content and length of their replies, so the effect of producing shorter messages when text messaging while driving can be seen as a strategy adaptation, whether conscious or subconscious, to reduce the workload of the text messaging task in the dual-task condition. Despite this strategy, driving performance was still severely impaired in the dual-task condition. Longer reaction times are likely to be a result of participants wanting to correct the heading of the car before switching attention to the touchscreen to read and process the text message. Reductions in typing speed are likely to be the result of interleaving attention between the driving task and the text messaging task. If instead participants simply typed the whole text message before returning attention back to the driving task, we would expect typing speeds to be the same in both task conditions, with even more severe impairments to driving performance in the dual-task condition.

Overall, text message delay time also affected reaction time: participants reacted to text messages quicker when there was a shorter delay between incoming messages. Shorter text message delay times would have allowed participants to more easily predict when an incoming message would be received; longer text message delay times would have meant attention being fully focused back onto the driving task, with incoming text messages being more of a surprise. Delay time had no other effect on text messaging performance.

Driving speed had no effect on any variables used to measure text messaging performance. As mentioned earlier, this supports research which has found drivers not to strategically adapt to difficulties in the driving task in dual-task scenarios. If participants did strategically adapt to the fast driving speed, we would expect to see more focus given to the driving task, with subsequently longer reaction times, shorter messages, and slower typing speeds.

5.3 Implications

This study has provided further evidence of the detrimental effects of text messaging on driving performance, supporting the ban on the use of hand-held communications devices while driving. Crucially, the level of impairment was equal regardless of the driving speed, suggesting that it is equally as dangerous to text message at slow speeds and high speeds. One of the reasons for this finding is that drivers did not alter their approach to the text messaging task depending on the difficulty of the driving task. However, this may not be true in real life, where there are real implications for lateral deviation.

The visual demand of the text messaging task was likely the most important factor in influencing driving performance. Simply using a hands-free device may not be sufficient to mitigate the risks of in-car device use; an *eyes-free* device is also important. Indeed, studies have shown driving performance to be the same for drivers using handheld and hands-free mobile phones (Strayer & Johnston, 2001; McEvoy et al, 2006).

The change in text messaging performance shows strategic adaptation sensitive to the text messaging task. A direct design implication of this would be to design mobile phones which explicitly allow the user to reduce the number of key presses, since both T9 predictive text entry and full keyboard entry require the user to carry out one key press per character. Speech based systems are an alternative that is actively being researched, although these systems may place additional cognitive demands on the driver (Jamson, Westerman, Hockey, & Carsten, 2004; Lee, Caven, Haake, & Brown, 2001). If text messaging while driving cannot be completely avoided, it is at least helpful that drivers be educated about the costs and risks associated with interacting with electronic devices while driving. This may encourage a stronger focus on driving and a reduced willingness to reply to text messages until it is safe to do so.

5.4 Limitations

Data from one participant was excluded from analysis because of an average deviation score of more than two standard deviations above the mean across all conditions. This suggests the participant did not learn the driving task sufficiently, or prioritised the text messaging task above the driving task. Due to time limitations and following an analysis of the driving task, it was deemed that two driving practise trials would be sufficient for participants to learn the driving task. Insufficient training may have been the cause of this outlier, and may have led to poorer driving performance overall and an increase in variation of driving performance. Participants were not explicitly told to prioritise the driving task above the text messaging task, but since only driving performance was reported at the end of each trial, it was clear that the driving task should be given more focus to improve lateral deviation.

The small sample size may also have affected the findings from statistical analysis; the low of statistical power of the analysis of the limited data set may have failed to find significant effects, leading to type II errors. However, this aspect of the experiment was unavoidable due to resource constraints restricting the number of participants available and the time available in the laboratory.

The low realism of the driving simulator and text messaging system could have a detrimental impact on the ecological validity of the findings. The driving task was artificially simple and may have not reflected the everyday demands of real life driving, causing multi-tasking to be easier. Conversely, participants frequently reported the steering to be unrealistically sensitive, with small steering adjustments leading to large on-screen movements, increasing the difficulty of the driving task.

Similarly, the text messaging system also had issues with difficulty. Participants frequently complained about the unresponsiveness of the touchscreen, leading to frequent errors and frustration. The touchscreen required relatively long and deliberate presses to register a key press, compared with the responsiveness and accuracy of modern touchscreen phones. The low ease of use of the text messaging system may have increased the difficulty of the text messaging task, leading to modified task performance. In addition, despite a fitting trial in a pilot study, it seems the location and position of the touchscreen was not optimal. The touchscreen was placed approximately where an in-car phone holder would be mounted near to the centre console. However, participants reported that in real life, they would prefer to hold the phone themselves in order to have better peripheral vision of the road. Participants who were not UK citizens also expressed a preference for the touchscreen to be on the right, as they were used to driving left-hand-drive cars.

Aside from technical issues, the study is of course a simulator study which also carries its own limitations. The outcome of the driving task and the text messaging task had no real world effect on the participants, so they were relied upon to perform as realistically as possible. Regardless of the driving performance, there was no physical risk to participants, so it is fair to assume there was more attention given to the text messaging task than in real life where accidents are a very real risk. On the other hand, drivers may have more motivation to engage in text messaging in real life in certain situations. For example, a person driving to an event may receive a text message from their friend telling them the event has changed locations. The new location of the event is highly important information as the driver may need to change driving direction before it is inconvenient to do so, for example exiting a motorway at the next junction. This may give the driver more incentive to focus on text messaging at the expense of driving.

5.5 Future research

One main improvement to this study would be to increase the realism of the driving task. This includes improving the realism of the driving simulator and increasing the variety and difficulty of the driving task itself. Driving is not a simple steering task, and simulator studies should aim to replicate the demands encountered in everyday driving in order to better assess the impacts of engaging in secondary tasks. A more complex driving task would also allow the collection of different types of data to more accurately measure driving performance, such as braking reaction times and lane changing accuracy.

An interesting approach used by Hosking et al. (2009) is the use of eye-tracking software. This allowed for a deeper analysis of driver behaviour by analysing eye movements during the experiment. This would have been beneficial in this study as it would have enabled an analysis of driver interleaving behaviour between the text messaging task and the driving task. Future research could use eye-tracking software to develop a better understanding of visual attention switching when text messaging and driving.

6 Conclusion

A limited number of previous studies have shown the detrimental effects of text messaging on driving performance. This study provided further evidence to these claims, and also investigated the effect of multitasking on text messaging behaviour. Other factors which modified the difficulty of the driving task and frequency of interruption were also explored. Drivers adapted their text messaging behaviour to cope with the demands of balancing the text messaging and driving tasks, however this was not successful in eliminating the impairments in driving performance. The difficulty of the driving task had no effect on any performance criteria, both of the the driving task and the text messaging task. This suggests an insensitivity to the difficulty of the driving task, as seen by Horrey & Lesch (2009). Given the dangers of interacting with in-car devices while driving, particularly those which require frequent visual attention and have the potential to abruptly distract the driver, it is recommended that measures be implemented to reduce these risks to improve driving safety.

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Appendix A

List of text messages

What do you think of the steering wheel?

What do you think of the touchscreen?

Are you sitting comfortably?

What do you think of your phone? I might get the same one.

What do you think of the course? My brother might apply for next year.

What do you think of the iPad? I might get one next week.

What do you think of your area? I might live there next year.

What do you think of your computer? I'm looking to get a similar one.

What do you think of the new iPhone? I might get one for my birthday.

Can you get me a coffee after this? I'll be in the common room.

Can you print something for me? I've sent it to your email.

Can you get my results for me? I can't come in to uni.

Can you get me a snack from the shop? I'll pay you back.

Can you pick up a book from Waterstone's for me? I ordered it yesterday.

Can you pick up my memory stick? I left it in the 6.08 lab.

What are you doing tomorrow night?

What are you doing later?

What are you doing on Sunday?

What are you doing tonight?

What are you doing tomorrow morning?

What are you doing this weekend?

Want to go to a gig next week?

Want to see a movie tonight?

Want to do an experiment together tomorrow?

Want to come to a bbq this weekend?

Want to go for coffee after this?

Want to go for dinner tomorrow night?

How's your day going?

How's your week been?

How's your project going?

How was the journey in today?

How was your weekend?

How was last night?

Where's the Rockefeller building? I'm late for an experiment!

Where's the Main Library? I need to print something.

Where's the Cruciform building? I'm doing an experiment there tomorrow.

Where's the Psychology building? I want to look at the cubicles.

Where's the UCL Union? I've got a meeting there later.

Where's the Jeremy Bentham room? I think I'll work there today.