The Effects of Visual and Auditory Information Processing in Simple and Complex Driving Scenarios

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Abstract

This study compared the effects of text-based (visual) information exchange and hands-free cell phone (auditory) ‘conversation’ on driving performance under low and high workloads. Performance was compared across four conditions created by crossing Presentation Method (Text vs. Cell) with Driving Complexity (Urban vs. Rural). Driving consisted of (a) maintaining speed and lane position in a medium-fidelity driving simulator, (b) responding to visual probes, and (c) braking in response to unexpected events. The secondary (‘conversation’) task was 20 Questions, which required the participant to answer Yes/No questions by either listening to the experimenter and making a verbal response over a hands-free headset in the Cell condition or by reading and pressing a button on an in-cabin touch screen in the Text condition. For most measures, driving performance was significantly worse in the Text condition than in the Cell condition under both high (Urban) and low (Rural) driving complexity scenarios, thus indicating that using text-based interfaces impairs driving more severely than talking on a hands-free cell phone. Moreover, for at least one driving performance measure (i.e., detecting visual probes), an interaction between Driving Complexity and Presentation Method was observed. The difference between the number of visual probes missed in the Text and Cell conditions was significantly greater in the high (Urban) Driving Complexity condition than in the low (Rural) Driving Complexity Condition.

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The proliferation of portable communication devices in day-to-day use has greatly facilitated time and location-independent information exchange. In order to allow the user to take full advantage of their capabilities, technologies have been adapted for use in many novel environments such as motor vehicles. As a result, many vehicles are equipped with hardware that allows the driver to make phone calls, read maps, navigate, play music and respond to text messages while driving. Many driving studies (e.g., Brown, Tickner & Simmons, 1969; Horberry, Anderson, Regan, Brown & Triggs, 2006; Törnros & Bolling, 2006) have assessed the effects of hand-held and hands-free cell phone conversations on driving performance. Cell phone conversations have been shown to increase reaction times to events on the road (Charlton, 2009) and reduce the number of objects attended to in the visual scene (Strayer, Drews & Johnston, 2003). Indeed, the effects of cell phone conversation have been equated to those observed while driving under the influence of alcohol (Strayer, Drews & Crouch, 2006). This evidence has led to legislation restricting cell phone use in several jurisdictions, which has subsequently contributed to an increase of text messaging while driving.

Text messaging is becoming a widespread alternative to talking on a cell phone, especially in the context of operating a motor vehicle because it allows the driver to circumvent cell phone laws. Other in-cabin technologies such as navigation systems, entertainment consoles and taxi dispatch hardware also rely on text-based interfaces.

Although text messaging tasks have been studied in isolation (Faulkner & Culwin, 2004), and the effects of in-cabin navigation technologies have been examined (Srinivasan & Jovanis, 1997), comparatively little research has investigated this issue by considering the effects of generic text-based information processing on driving. The purpose of this thesis is therefore to investigate the effects of text-based (visual) information exchange on driving performance, and compare it to the effects of cell phone (auditory) conversation.

Cell phone use and verbal communication have been widely studied as a form of driving distraction. As early as the late 1960s, Brown et al. (1969) conducted a study on driving while engaged in a telephone conversation. Participants drove a car on a closed track and had to decide whether they could drive through gaps between obstacles, which were clearly configured to be either too small or large enough to drive through. One of the conditions included a verbal reasoning test. Participants heard a sentence describing the ordering of two letters (e.g., “B is preceded by A”) over a hands-free headset, followed by a sequence of letters (e.g., “AB”). They then determined whether the sequence of letters accurately represented the information conveyed in the sentence and answered “True” or “False” over the headset. Their driving performance was measured by the number of gaps correctly judged, the number of gaps successfully navigated, the overall time taken to complete 20 laps, and the frequency of use of the steering wheel and pedals. The telephone task was scored by measuring the time taken to respond to each sentence and the overall accuracy of judgements. The study determined that drivers made significantly more driving judgement errors while engaged in the verbal reasoning task and they had significantly more trouble successfully navigating the obstacles. The authors concluded that auditory information processing has detrimental effects not only on processing visual information but also on driving performance.

Brown et al.'s (1969) study hinted at the detriments that concurrent tasks have on driving, thus inspiring a series of studies on cross-modality interference, including driving while listening to music (Dibben & Williamson, 2007), driving while under the effects of alcohol (Maisto, Galizio & Connors, 2008) and driving while engaged in cell phone conversation (Strayer, Drews & Johnston, 2003). The latter authors reported several experiments on the failure of visual attention while driving and talking on a cell phone. Using a driving simulator, participants followed a pace car and were instructed to depress a brake pedal when the pace car's brake lights illuminated. Half of the trials were single-task and involved only driving while the other half included a cell phone conversation task. In the conversation task, participants conversed with a confederate on topics of interest to the participant using a hands-free cell phone. Measures of driving performance included braking reaction times and speed maintenance. Fixation and heads-up time was measured using an eye-tracker. Finally, a measure of visual attention was obtained when participants were unexpectedly asked to recall billboards displayed in the scenario. In the dual-task condition, participants were slower to react to the pace car braking and were slower to accelerate back to highway speeds. Moreover, participants recalled billboards less accurately when engaged in conversation even though fixation patterns across the two conditions were statistically identical. It was therefore argued that cell phone conversations impair visual recognition memory. Strayer et al. (2003) proposed that the impaired recall of billboard information was due to inattentional blindness, which occurs when a visual stimulus is not attended to even though it is clearly visible and perhaps even fixated upon. This could be due both to visual attention being focused elsewhere and to cross-modality interference (e.g., engaging in a verbal task). For example, evidence for inattentional blindness in the context of driving would occur when a driver fails to notice a traffic light changing because they are focused on other elements in the visual scene or engaged in a demanding concurrent task. Strayer et al. (2003) surmised that the conversation task impaired participants' ability to attend to unimportant visual information (i.e., roadside billboards) such that attention to important cues (i.e., pace car braking, speed limit signs) was preserved.

Brown et al. (1969) and Strayer at al. (2003) demonstrated that the processing of auditory information increases cognitive load while driving when compared to conditions which do not involve such processing. While important, these findings raise more questions rather than recommend solutions. For instance, it remains unclear what aspects of cell phone conversation are responsible for the most significant and dangerous detriments in driving performance, or if there is a way to minimize these detriments with the advancement of new technology. Drews, Pasupathi and Strayer (2008) attempted to determine whether cell phone conversations impair driving performance to a greater extent than a passenger conversation. Participants drove on a simulated highway with other traffic until they came to an exit, which they were instructed to take. The cell phone task consisted of naturalistic conversation about 'close calls' on the road with a passenger or over a headset with a partner in a different location. Driving performance measures included lane position and maintenance, speed, following distance, as well as taking the correct exit. The study found that drivers had more trouble maintaining lane position and increased following distance in the cell phone condition compared to the passenger condition. Furthermore, fewer drivers took the correct exit while engaged in cell phone conversation. The authors concluded that cell phone conversation impairs driving performance more severely than conversing with a passenger.

Crundall, Bains, Chapman and Underwood (2005) also reported that cell phone conversation impairs driving performance to a greater extent than passenger conversation. They hypothesised that passenger conversation produced smaller impairments due to the passenger's awareness of road conditions and their choice to suppress conversation in more cognitively demanding driving situations. In this study, participants completed 20-mile circuits in their own cars in three different conversation conditions – talking on a hands-free cell phone, talking to a passenger and talking to a blindfolded passenger. There were four circuit types (rural, dual carriageway, suburban and urban), which placed varying degrees of cognitive demands on the driver (rural was designed to have the lowest while urban the highest). The study measured the number of utterances, words per utterance, as well as the total number of questions asked in the conversation. They reported that both the driver and the passenger reduced the pacing of conversation on more demanding road types in the sighted passenger condition, thus supporting the conversation suppression theory. However, in the cell phone condition, when the partner had no access to information about the road, the conversation remained at intensity levels comparable to easier conditions, increasing the cognitive load on the driver. Crundall et al. (2005) concluded that since cell phone conversations cannot benefit from driving condition cues, they remain more dangerous and distracting than in-car conversations by virtue of being more demanding of the driver's attention at all times.

While cell phone conversation and auditory information processing has been extensively studied, far fewer studies exist on text-based information processing while driving. Those that do exist tend to focus on particular applications (e.g., text-based navigation or entertainment systems) rather than on the textual modality itself. For instance, Horberry et al. (2006) compared an auditory distraction task (hands-free cell phone conversation) to a visual/manual task (interacting with an on-board entertainment system) in terms of their effects on hazard avoidance. They reported that the visual/manual task resulted in slower response times to scripted entities crossing the road than the auditory task. They argued that this difference was due to the driver having to look down and away from the road to complete the visual/manual task.

Srinivasan and Jovanis (1997) conducted a comparison study on several in-car navigation methods, including an audio navigation system, a heads-up electronic map and a standard paper map. Participants were asked to drive a simulated road network while attending to changing visual information. Their change detection reaction times were measured. The results showed that participants were fastest to detect changes when guided by an audio system, slower when using heads-up and heads-down maps or turn-by-turn displays, and slowest when using a paper map, hinting at the fact that textual information processing may be more cognitively demanding than auditory processing even without a heads-down component.

There is evidence that the difficulty of the driving scenario can compound (i.e., interact with) impairments induced by driver distraction tasks. Studies such as Törnros and Bolling (2006), Crundall et al. (2005) and Horberry et al. (2005) have investigated the effects of driver distraction tasks in simple and complex driving scenarios. In these studies, complex driving scenarios included more traffic, more hazards or events to attend to, more navigational uncertainty, and a greater need for braking and re-acceleration. Törnros and Bolling (2006) chose rural scenarios as their low-complexity driving conditions and urban scenarios as high-complexity driving conditions. In their study, participants drove a simulated 70 km route which included two low-complexity sections (rural with 90 and 70 mph speed limits) and three high complexity sections (urban simple, urban medium and urban complex), which differed in the amount of oncoming traffic, the number of traffic lights, and the presence of other vehicles in the participant's lane. Throughout the scenarios, there were scripted critical events (e.g., cyclists crossing the road or traffic lights turning red) which required overt responses. Drivers simultaneously engaged in a serial addition task (see Brookhuis, de Vries & de Waard, 1991) on a hands-free or hand-held cell phone. Measures of driving performance were average driving speed and reaction times and hit rates to visual probes (drivers responded to visual stimuli by pressing a finger-mounted button). The authors found that participants missed significantly more visual stimuli in the urban complex condition, regardless of whether they used a hands-free or hand-held cell phone. The authors also found a large main effect of environment on reaction times – participants were much faster to react to stimuli in the low-complexity conditions. Horberry et al. (2005) also used critical events (e.g., a pedestrian standing on or crossing the roadway, a car reversing down a driveway) as measures of driving performance and found significant effects of participant age and entertainment system versus hands-free conversation when a critical event occurred. These two studies outlined the basic methods for increasing driving complexity in a simulated scenario – additional traffic, decision-making and unexpected critical events. The current study will use these methods to manipulate driving complexity by inducing higher cognitive loads.

In most driver distraction studies, participants have little control over the pacing of the distraction task, and no strategic control over whether to engage in potentially hazardous behaviour. Therefore, it may be argued that these impairments would be less dangerous in a real driving situation because drivers would strategically avoid distracting behaviours when faced with a more taxing driving condition. Horrey and Lesch (2009) conducted a study in which participants drove a minivan on a closed track with sections of varying cognitive demand. They had to navigate through gaps between obstacles, complete turns, obey traffic light signals and obey a pace clock task. Meanwhile, they were given a list of four in-cabin tasks to complete by the end of the trial (i.e., a short phone conversation, reading a text message, looking up a stored address and picking up an object from the floor of the vehicle). They had the freedom to initiate these tasks at any time during the course, like they would in a real driving scenario, and also had the option to pull over to the side of the road in a section of the course. The results showed that even though drivers were familiar with the circuit and the changing road demands and had the opportunity to strategically postpone tasks or initiate them in low-demand sections, they did not adjust their behaviour based on the driving conditions. Furthermore, they consistently chose to engage in the secondary tasks after they had begun driving even though they had the opportunity to complete them while stopped. These findings suggest that drivers do not select appropriate coping strategies when performing distracting tasks and that drivers may be susceptible to engaging in them as they occur (e.g., immediately responding to a text messages, even under high-workload driving conditions). Therefore, even though experimenter-paced distraction tasks are not as realistic as participant-paced ones, they do not yield significantly different results, and they do allow for more experimental control.

Another consideration when assessing the impact of cell phones on driving is the type of conversation task used. While many studies have used naturalistic conversation (e.g., Charlton, 2009; Strayer et al., 2003; Strayer & Johnston, 2001), an effort to control conversation for difficulty, intensity and pacing has spurred researchers to use other conversation tasks, including verbal reasoning (Brown et al., 1969), competitive games (Crundall et al., 2005), shadowing and word generation (Strayer & Johnson, 2001). Robert, LeBlanc, Brown and Herdman (2008) conducted a suitability study for the use of the 20 Questions game as a proxy for conversation. In 20 Questions, one person thinks of an item (e.g., “bottle” or “tiger”), and the other person asks yes/no questions about the nature of the item (e.g., “Is it a living thing?” or “Is it red?”). The game ends when the item is guessed or twenty questions have been asked. Initially a popular travelling game, it has been used in childhood development research as a measure of strategic performance (Alexander, Johnson, Leibham & DeBauge, 2005) and problem-solving (Thornton, 1999). In Robert et al.’s (2008) study, participants asked and answered questions while driving on a simulated course. The study revealed that asking questions had a greater negative impact on driving performance than answering questions, but, overall, 20 Questions produced a similar pattern of results as other conversation tasks while also preserving naturalistic conversation’s interactivity, generativity, lexical access and pacing while being easily scripted and controlled.

The purpose of the current study is to investigate the relative impact of processing verbal and text-based information on driving performance and to determine how these two information presentation modalities are modulated by driving complexity. Participants engaged in simulated driving in a fixed-base driving simulator, obeying the rules of the road and adhering to a posted speed limit. Driving performance was assessed in four conditions created by crossing Presentation Method (Cell vs. Text) with Driving Complexity (Rural (low) complexity vs. Urban (high) complexity). Measures of driving performance included lane position maintenance, speed maintenance, response times and hit rates to visual probes, and braking response times to unexpected events. While driving, participants engaged in the 20 Questions task, which has been shown to be a viable alternative to natural conversation (Robert et al., 2008), by answering a pre-scripted sequence of questions asked by the experimenter. In the Cell condition, participants listened and responded to questions asked by the experimenter over a headset. In the Text condition, they read and responded to questions displayed on an in-cabin touch screen by pressing a “yes” or “no” button that appeared on the screen. A hands-free cell phone and a simple textual interface was used to avoid hardware-specific effects. It was hypothesised that driving performance would be worse in the Text condition than in the Cell condition. Moreover, it was predicted that this effect would increase as driving complexity increased. That is, Presentation Method (Cell vs. Text) would interact with Driving Complexity.

Method

Participants

Sixteen adults participated for 1.5% course credit. Participants were fluent in English and held a valid driver's licence. They were also assumed to have normal or corrected-to-normal visual acuity.

Design

A 2 (Driving Complexity: Rural vs. Urban) x 2 (Presentation Method: Cell vs. Text) repeated measures design was used. The four conditions were counterbalanced using a Latin Square design whereby each of the four conditions occurred an equal number of times across all possible presentation orders. Presentation Method (Cell vs. Text) was grouped so that every participant switched Presentation Method halfway through the experiment. Half the participants received the Cell condition first, while the other half received the Text condition first. Driving Complexity (Rural vs. Urban) was fully counterbalanced such that the Rural and Urban conditions alternated during the experiment. Half the participants received the Rural condition first, while the other half received the Urban condition first.

Materials

The experiment used a medium-fidelity, fully configured, DriveSafetyTM 500c driving simulator. A cut-down passenger vehicle consisting of the driver's seat and controls was mounted on a fixed-base platform in front of a three-screen projection system subtending a visual angle of 21.8° vertically and 90° horizontally. Imagery from the rear-view mirror and both side mirrors was superimposed on the projection screens at appropriate locations. Engine and external environment noise was relayed through speakers mounted inside the cabin to increase simulation fidelity. Driving scenarios were constructed using the Tool Command Language (TCL) scripting language under a PC-based Linux platform. Driving conditions were optimal (i.e. dry road surface, excellent visibility). There was no external traffic. Participants responded to visual probes by depressing a button on a finger switch that was affixed to the participant's left thumb.

The experimenter was seated such that they could not be seen by the participant and used a standard keyboard to "type" the questions in the Text condition and a standard mouse and headset to record the participant's responses in the Cell condition. The 20 Questions task was written in Visual Basic using E-Prime software. In the Cell condition, questions asked by the experimenter and participants' responses were relayed via a digital cordless phone to simulate the sound quality of a hands-free cellular phone. The cordless phone was connected to a stereo microphone headset at the participant's end and to the stimuli-generating PC at the experimenter's end. In the Text condition, the same information was relayed using a dashboard-mounted 8-inch widescreen LCD touch-sensitive monitor, affixed to the simulator cabin's central instrument panel such that it was clearly visible to the participant. The monitor subtended a horizontal angle of 42° and a vertical angle of 27°.

Procedure

The participant was seated in the simulator's cabin and outfitted with the finger switch, headset and microphone. They familiarized themselves with the simulator controls by driving through two three-minute practice scenarios, one as it would appear in the Rural condition and one as it would appear in the Urban condition. Then, they were introduced to the 20 Questions task with a practice round of five questions, presented once over headset as in the Cell condition and once on the touch screen as in the Text condition.

In the Rural condition, the track consisted of alternating straight stretches of road and gentle turns with a constant speed limit of 50 mph. In the Urban condition, intersections controlled by a four-way stop were connected by straight sections of road with a 40 mph speed limit. Upon approaching an intersection, a green arrow was presented on the central monitor indicating the direction in which the participant should proceed following a full stop (i.e., left, right or straight). A scripted entity (i.e., pedestrian, bicycle or car) crossed the road in front of the participant a total of six times during the Urban condition of the experiment (three times in the Text condition and three times in the Cell condition). The participant was instructed to depress the brake pedal whenever this occurred. Entities that did not cross the road were displayed as foils such that the participant could not anticipate making responses.

In each of the four conditions, the participant was instructed to accelerate to the speed limit, which was displayed in the bottom-right hand corner of the central screen for the first 10 seconds of each condition. While driving, participants responded to visual probes (i.e., small red squares) that were presented randomly once every 4-6 seconds in one of six possible locations on the central screen.

In the Cell condition, a pre-recorded sound file for an item (e.g., “chair”) was presented on the participant’s headset. The item could be repeated if the participant did not hear it. The experimenter then asked the participant the pre-scripted sequence of questions about the item over headset at an approximate rate of one question every five seconds. The participant responded by saying “yes”, “no” or “I don’t know” into the headset's microphone. The experimenter recorded the participant's response by clicking on the appropriate button on their screen.

In the Text condition, the item was displayed on the touch screen in the cabin and remained visible until the participant touched the screen. The experimenter then pseudo-typed the first question on their keyboard and "sent" the question to the participant's touch screen by pressing the Enter key. The experimenter attempted to maintain the same question rate as in the Cell condition. After the question appeared on the participant's touch screen, three equal-sized yellow buttons labelled "YES", "NO" and "?" appeared under the question. The participant responded by touching the appropriate button. Responses were automatically recorded.

Results

Visual Probes

Reaction times

Only reaction times (RTs) corresponding to visual probes that were responded to within 2000 ms of their onset (i.e., 'hits') were included in this analysis. Visual probe RTs were analysed using a 2 (Driving Complexity: Rural vs. Urban) x 2 (Presentation Method: Text vs. Cell) repeated measures analysis of variance (ANOVA). As can be seen in Figure 1, there was a significant main effect of Driving Complexity – responses to probes were significantly faster in the Rural condition (716 ms) than in the Urban condition (781 ms), $F(1, 15) = 56.6$, $MSE = 1187$, $p < 0.001$. There was also a main effect of Presentation Method, with responses being significantly faster in the Cell condition (705 ms) than in the Text condition (792 ms), $F(1, 15) = 52.0$, $MSE = 2384$, $p < 0.001$. There was no interaction between Driving Complexity and Presentation Method ($F < 1$).

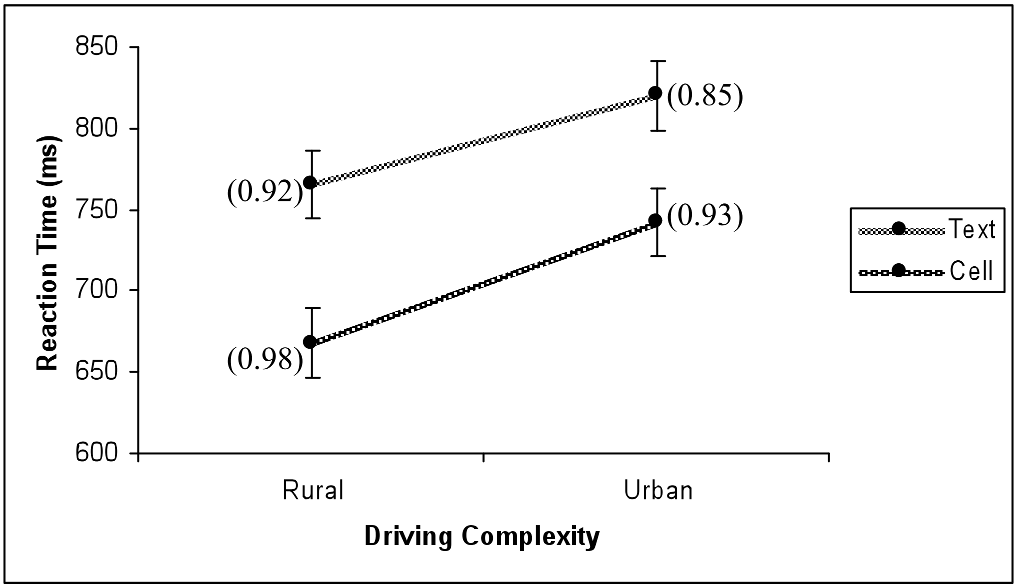

Figure 1. Mean Visual Probe Reaction Times (and hit rates) as a function of Driving Complexity and Presentation Method. Masson and Loftus' (2003) 95% Confidence Intervals correspond to the RT data.

Hit Rates

Responses to visual probes that occurred within 2000 ms of their onset were logged as hits. Hit rates are the number of successful hits divided by the total number of visual probes presented. Mean hit rates were analysed using the same ANOVA reported for the RT data. The hit rate was significantly higher in the Rural condition (0.947) than in the Urban condition (0.893), yielding a main effect of Driving Complexity, $F(1, 15) = 27.7$, $MSE = 0.002$, $p < 0.001$. There was also a main effect of Presentation Method, with significantly more hits in the Cell condition (0.955) than in the Text condition (0.885), $F(1, 15) = 28.4$, $MSE = 0.003$, $p < 0.001$. Furthermore, as predicted, the interaction between Driving Complexity and Presentation Method was significant, $F(1, 15) = 8.76$, $MSE = 0.000$, $p < 0.05$. The difference in hit rates between the Cell and Text conditions was significantly greater in the Urban condition than in the Rural condition (See Figure 1).

Lane Deviation

Lane deviation was measured as the difference between the centre of the lane and the position of the vehicle in the lane. These data were analysed using Root Mean Square Error (RMSE), which represents the average absolute difference (in metres) between the observed lane position and the optimal lane position. The same analysis reported for the visual probe data was used here. Although there was a main effect of Driving Complexity, it was opposite from the predicted direction in that lane deviations were *greater* in the Rural condition (0.43 m) than in the Urban condition (0.32 m), $F(1, 15) = 44.07$, $MSE = 0.004$, $p < 0.001$. The effect of Presentation Method was not significant, $F(1, 15) = 1.76$, $MSE = 0.004$, $p > 0.20$, nor was the interaction between Driving Complexity and Presentation Method ($F < 1$) (See Figure 2).

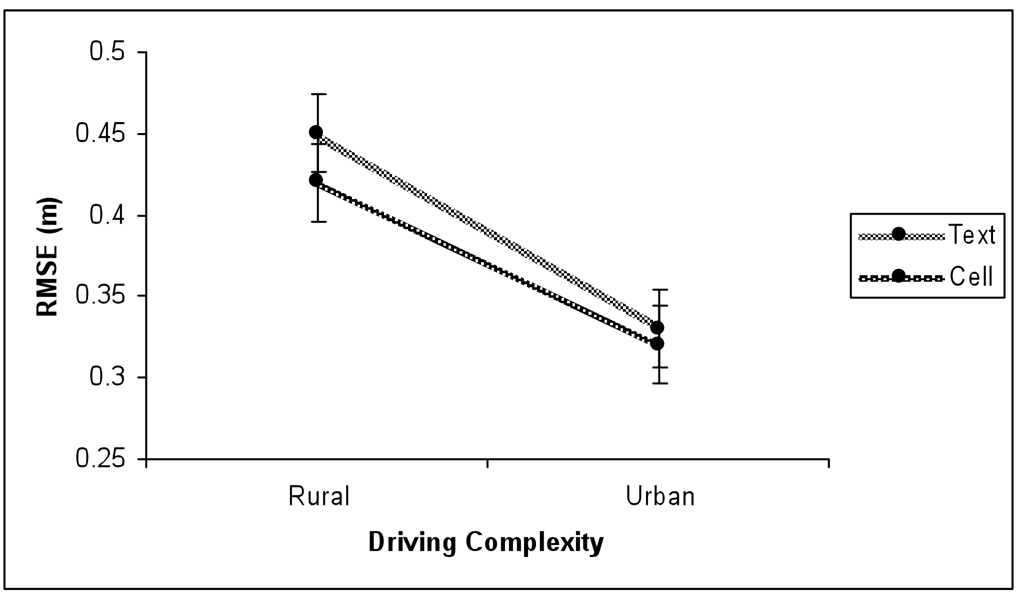

Figure 2. RMSE and 95% Confidence Intervals for Lane Deviation as a Function of Driving Complexity and Presentation Method.

Speed Maintenance

Speed maintenance was only measured in the Rural condition and was calculated using RMSE for the difference score between the observed speed and the posted speed limit (50 mph). The data were analysed using a paired-samples t-test. The main effect of Presentation Method was not significant (t < 1).

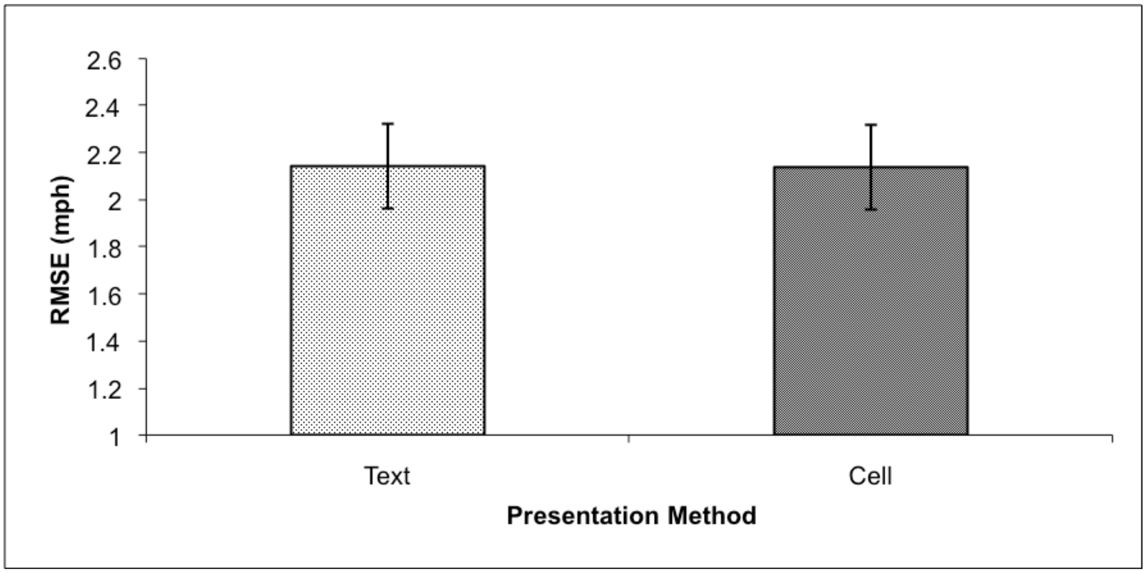

Figure 3. RMSE and 95% Confidence Intervals for Speed Maintenance as a Function of Presentation Method.

Braking Event Response Times

Response times to scripted events in the Urban condition were defined as the time between the onset of the event (e.g., a pedestrian beginning to cross the road) and the time at which the brake pedal was depressed to at least 20% of its full capacity. The data were analysed using a paired-samples t-test, which, due to a programming error, was only recorded for twelve of the sixteen participants. There was a significant main effect of Presentation Method, with participants taking significantly more time to respond in the

Text condition (1682 ms) than in the Cell condition (1478 ms), $t(11) = 2.76$, $p < 0.05$ (see Figure 4).

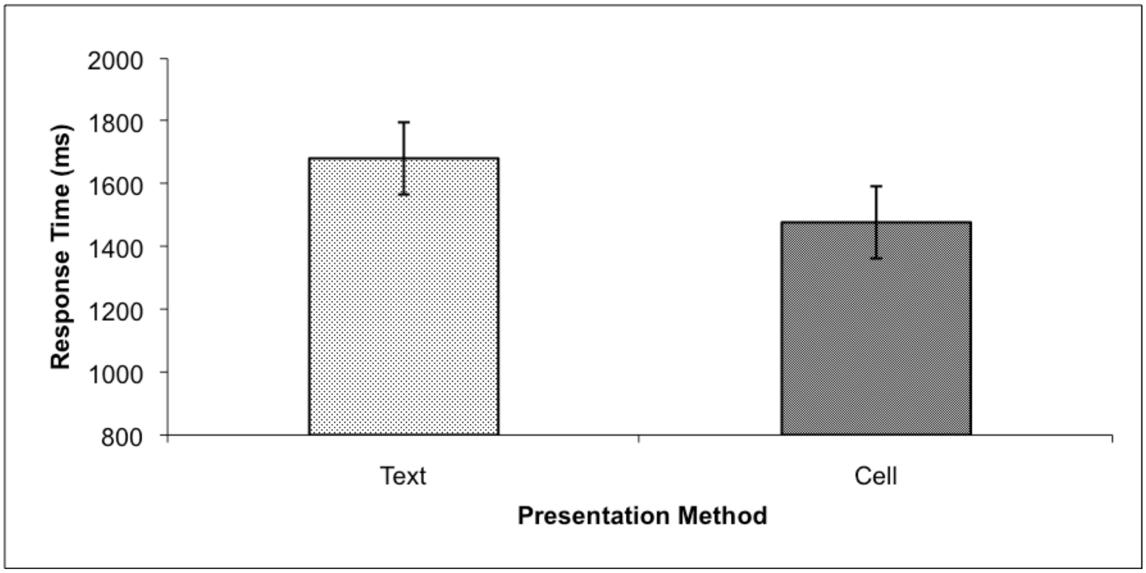

Figure 4. Braking Event Response Times and 95% Confidence Intervals as a Function of Presentation Method.

Discussion

The purpose of the current study was to compare the effects of interacting with a text-based interface to hands-free cell phone conversation on simulated driving performance in simple and complex conditions. This experiment used 20 Questions as a proxy for conversation, which had the advantage of affording the same pacing, immersiveness and conversation complexity across the two presentation methods (i.e., Text vs. Cell), thus allowing for a direct comparison between them. As predicted, the text messaging condition yielded significantly greater driving impairments (i.e., delayed responses and decreased hit rates to visual probes and delayed braking response times) than the cell phone condition. Furthermore, the predicted interaction between Driving Complexity and Presentation Method was observed in one measure of driving performance (i.e., hit rates to visual probes). The higher driving complexity in the Urban condition amplified the difference in hit rates between the Cell and Text conditions when compared to the Rural condition.

The most alarming driving performance detriments were observed in the participants' responses to visual probes. The visual probes were meant to simulate events in the external scene that drivers should have attended to (e.g., a car braking in front of them, a traffic light change). The text-based interface yielded significantly slower response times to the visual probes, hinting at a potentially hazardous decline in visual attention to events in the external scene as compared to cell phone conversation, which has also been shown to impair responses to external events (Brown et al., 1969; Strayer et al., 2003). Furthermore, significantly more visual probes were missed in the text condition than in the cell phone condition, meaning that interacting with a text-based interface not only delays responses to events in the driving scene, but is also more likely to cause drivers to miss them altogether. The interaction between Driving Complexity and Presentation Method for visual probe hit rates indicates that the likelihood of missing an external event when using a text-based interface (relative to using a cell phone) is amplified by higher complexity driving conditions. The braking events yielded another significant detriment to driving performance, with braking responses in the Text condition being significantly slower than in the Cell condition. This result is even more alarming due to the fact that participants were responding not to small, abstract visual probes but to large, life-like entities.

While the visual probes and braking event response time data were consistent with the hypothesis, other measures of driving performance were not. Contrary to expectations, the Text condition did not yield significantly larger lane deviations than the Cell condition. More surprisingly, lane position maintenance was *worse* in the low complexity (Rural) condition than in the high complexity (Urban) condition. These data are inconsistent with several other studies (e.g., Drews et al., 2008) reporting greater lane deviations in conditions with higher cognitive load. This counterintuitive result is most likely explained by an experimental design issue. In the current study, lane deviations were only measured on straight sections of roadway in the Urban condition, whereas it was measured through the entire Rural condition, which included large, rolling turns. Given that it is harder to maintain a centre lane position while turning, comparisons between these two driving conditions (in terms of lane position) are likely invalid.

The finding that Presentation Method did not significantly impair speed maintenance suggests that interacting with a text-based system is no more detrimental to that aspect of driving than talking on a cell phone. This result is inconsistent with the hypothesis forwarded here, as well as with Horberry et al. (2006), who reported that interacting with a text-based entertainment system yielded worse speed maintenance that conversing on a cell phone. Further research is required to pinpoint why some text-based tasks affect speed maintenance whereas others (i.e., the task used here) do not.

The fact that, for most measures, high driving complexity yielded worse performance than low driving complexity suggests that the Urban/Rural manipulation used here was successful in inducing higher cognitive load. In the complex driving scenario, this was accomplished using traffic regulation devices (i.e., stop signs), directional uncertainty at intersections, added visual clutter (navigational arrows), and pre-scripted braking events.

While this study has yielded some interesting results, it highlights the need for future studies. For instance, it would be useful to include a baseline condition (i.e., no conversation), against which the different presentation methods could be compared. Further research could use a text-based secondary task that pertained to driving (i.e., heads-down navigation instructions or a navigation system) with more realistic input interfaces (e.g., a touch keyboard, a numeric keypad) to improve ecological validity. It should also be noted that medium-fidelity fixed-base simulators are ill-suited to start-and-stop scenarios due to the effect they have on the participants' vestibular systems, resulting in an increased risk of motion sickness. In future Urban/Rural studies on this type of simulator, experimental designs that require the participant to make frequent stops should be avoided.

An indivisible element of text-based information processing is heads-down time (time spent not looking at the road), which could cause events to be missed. However, even when a driver is looking at the road (i.e., heads-up), they may not always attend to visual information due to inattentional blindness. Eye tracking data could resolve the issue of whether textual information processing contributes to missed visual events simply by virtue of being a heads-down activity, or whether it is more likely to cause inattentional blindness.

The textual interface in this study was chosen to be as generic as possible, thus it can be argued that the findings reported in this thesis apply to almost any type of in-car text-based information processing, including GPS systems, entertainment consoles, taxicab dispatch systems and text messaging. The results of this study echo the safety concerns associated with many of the in-cabin technologies used today. While cell phone use while driving has been widely studied and its detriments well-established, further research is needed to determine whether text-based technologies are safe for use, and how they can be improved or controlled.

Conclusion

The results of this study indicate that, overall, interacting with a text-based interface impairs driving more severely than talking on a hands-free cell phone. It is argued here that this result is probably not limited to this particular text-based application, hardware configuration or 'conversation' task. Therefore, using most text-based interfaces would be expected to produce similar impairments. This finding has implications for driving safety research and for in-cabin technology legislation. That is, using text-based interfaces while driving is potentially more dangerous than using cell phones, and it should therefore be better understood and controlled.

Manipulating driving complexity through the use of urban and rural scenarios successfully induced differences in cognitive load as indicated by worse driving performance in the high (Urban) workload condition than in the Rural condition. The finding that the type of communication interface being used (Text vs. Cell) interacted with driving complexity suggests that it is important to manipulate driving workload when assessing the impact of other in-cabin technologies. Otherwise, the potential exists to underestimate the negative impact of these technologies on driving performance.

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Appendices

Appendix A: Informed Consent Form

Informed Consent Form

Study: The Effects of Text Messaging on Driving

Faculty Sponsor: Dr. Chris M. Herdman, Department of Psychology
Carleton University, tel. 613-520-2600 x.8122

The purpose of this informed consent form is to ensure that you understand both the purpose of the study and the nature of your participation. The informed consent must provide you with enough information so that you have the opportunity to determine whether you wish to participate in the study. Please ask the researcher to clarify any concerns that you may have after reading this form.

Research Personnel:
In addition to the Faculty Sponsor named above, the following people are involved in this research and may be contacted at any time should you require further information about this study: Principal Investigators: Velian Pandeliev and Matthew Brown, (613-520-2600 x.2496)
Should you have any ethical concerns regarding this study then please contact: Dr. Avi Parush, Chair, Carleton University Ethics Committee for Psychological Research, avi_parush@carleton.ca, ext 6026.
Should you have any other concerns about this study then please contact: Dr. Janet Mantler, Chair, Department of Psychology, janet_mantler@carleton.ca, ext 2648.

Purpose:
The purpose of this study is to examine the effects of text messaging on driving performance.

Task:
In this study, you will be asked to drive a car simulator, obeying the rules of the road and speed limits. You will be driving both in a rural setting at constant speed, and in an urban environment. Occasionally a red square will appear on the screen. When it does, you are to press a button as quickly as possible to indicate that you have seen it. In addition to these tasks, you will be given items that belong to one of five categories and you will answer yes/no questions about the nature of these items posed by the experimenter. In one condition, you will hear the questions and you will respond verbally over a headset. In another condition, you will be presented with the questions on an on-board touch screen and you will respond by pushing a button.

Locale, Duration, and Compensation:
Testing will take place in VSIM 1114 at Carleton University and will take approximately 1 hour. You will receive 1.0% course credit.

Potential Risks/Discomfort:
There are no potential psychological risks associated with participation in this experiment. Please note that your performance on the task in this experiment does not provide an indication of your suitability for university studies. However, if you feel anxious and/or uncomfortable about your performance in this experiment, please bring your concerns to the researcher's attention immediately. In the event that the experiment is terminated you will receive full credit for your participation.

Anonymity/Confidentiality:
All data collected in this experiment will be kept strictly confidential through the assignment of a coded number. The information provided will be useful for research purposes only and you will not be identified by name in any reports produced from this study. Further, the information is made available only to the researchers associated with this experiment.

Right to Withdraw/Omit:
You have the right to withdraw from this experiment at any time without academic penalty. Your participation in this experiment is completely voluntary.

I have read the above description of the study examining the effects of text messaging on driving performance.

Name:______________________________ Date:______________________________

Signature:______________________________ Witness:______________________________

Appendix B: 20 Questions Stimulus List

Practice Group:
Bottle

Group 1:
Strawberry
Chair
Rome
Goat
New York

Group 2:
Elvis Presley
Cookies
Horse
Car
Lawyer

Group 3:
Spaghetti
Vancouver
Beaver
Pencil
Hamburger

Group 4:
Cheerleader
Raccoon
Doughnut
Tiger
Toronto