Text Messaging During Simulated Driving

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Objective: This research aims to identify the impact of text messaging on simulated driving performance. **Background:** In the past decade, a number of on-road, epidemiological, and simulator-based studies reported the negative impact of talking on a cell phone on driving behavior. However, the impact of text messaging on simulated driving performance is still not fully understood. **Method:** Forty participants engaged in both a single task (driving) and a dual task (driving and text messaging) in a high-fidelity driving simulator. **Results:** Analysis of driving performance revealed that participants in the dual-task condition responded more slowly to the onset of braking lights and showed impairments in forward and lateral control compared with a driving-only condition. Moreover, text-messaging drivers were involved in more crashes than drivers not engaged in text messaging. **Conclusion:** Text messaging while driving has a negative impact on simulated driving performance. This negative impact appears to exceed the impact of conversing on a cell phone while driving. **Application:** The results increase our understanding of driver distraction and have potential implications for public safety and device development.

INTRODUCTION

In recent years, a noticeable shift in potentially distracting activities of drivers has taken place. In the past, drivers often engaged in more traditional distracting activities, such as consuming beverages or food. However, with the availability of mobile technologies, such as cellular phones, global positioning systems, and entertainment systems, additional sources of distraction are readily available and widely used by drivers. The present article focuses on one of these technologies: the cellular phone.

In their seminal study, Redelmeier and Tibshirani (1997) evaluated the cell phone records of 699 individuals who were involved in motor vehicle crashes during a 14-month time period. The authors found that almost a quarter of these individuals used their cellular phone in the 10 min preceding the crash and that using a cell phone while driving was associated with a fourfold increase in the likelihood of being involved in a crash (see also Violanti, 1998).

Strayer and Johnston (2001) demonstrated in a series of studies that participants engaged in cell phone conversations were more likely to miss traffic signals and reacted to the signals that they did detect more slowly than drivers who were not conversing on cell phones. This work also demonstrated that there was no difference between use of handheld and hands-free cell phones in terms of their impact on driving performance (see also McEvoy et al., 2005). By contrast, listening to radio broadcasts or books on tape did not impair driving performance. Additional research explored the mechanisms leading to the impairments observed in cell phone drivers. Strayer, Drews, and Johnson (2003) demonstrated that drivers conversing on a cell phone show signs of inattention blindness, processing up to 50% less of the information in their environment than a driver who is not engaged in a cell phone conversation (see also Strayer & Drews, 2007).

However, not all types of conversations have the same influence on driving performance, as was recently demonstrated by Drews, Pasupathi, and Strayer (2008). Drews and his collaborators demonstrated that there is a difference between

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passenger conversations and cell phone conversations, wherein passenger conversations, unlike cell phone conversations, do not impair driving performance.

Overall, there is little doubt that conversing on a cell phone significantly degrades driving performance (Drews & Strayer, 2008; but see Shinar, Tractinsky, & Compton, 2004). However, with the emergence of text messaging, another, potentially more dangerous source of distraction emerged. With the increasing availability of text messaging in newer generations of cell phones, the frequency of this activity has skyrocketed. For example, according to a survey conducted by Telstra in Australia (Telstra, 2003), 30% of the respondents admitted to having sent text messages while driving a vehicle, and almost 20% regularly send text messages while driving. Text messaging is increasingly popular in the United States and worldwide. According to a survey conducted by CTIA in 2005, there were 81 billion text messages sent in the United States; however, in 2008, the number of send text messages exceeded 1 trillion (CTIA, 2009).

One likely reason for the popularity of text messaging is related to human factors improvements in the interface, resulting in the emergence of simpler and potentially more convenient methods of text entry (most recently, full text entry). One development for text entry is the "text on nine keys" (T9) predictive text entry system. T9 entry uses a large dictionary to disambiguate an entry according to the most likely intention to write the current entry, on the basis of previous input. The system uses the nine numerical keys of a cell phone that have assigned three to four different letters to them. The older multitap mode (Alpha mode) uses the same number of keys, but here a letter is entered by pressing a key repeatedly (e.g., for entering the letter *s*, the *7* key has to be pushed four times. Because of a reduction of required key taps, the T9 entry system allows users to enter text about twice as fast as did the Alpha mode. The T9 system facilitates the entry of text messages; however, the cognitive effort associated with receiving and processing of text messages is not affected by this development.

Regan, Young, Lee, and Gordon (2008) provided a similar distinction of activities involved in interacting with a cell phone by conducting a task analysis of steps involved in talking on a cell phone. Drawing from Wickens and Horrey's (2008) model, Regan et al. quantified the impact of individual actions on driving performance. According to Regan et al., manual entry of information (dialing a number) has the most negative impact on driving performance. Thus, even with improvements in text entry technology, there is good reason to hypothesize that text messaging, with its repeated text entry, should negatively affect driving performance. Additional support for this hypothesis comes from studies that focused on the interaction with other nomadic devices while driving. These studies, which often investigated the biomechanical aspects of driver distraction, indicate that manipulation of navigation systems (Tsimhoni, Smith, & Green, 2004), DVD players (Hatfield & Chamberlain, 2005), and radios (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Wikman, Nieminen, & Sumala, 1998) result in negative changes of driving behavior. Such changes manifest in increases in lane position deviations, reduction in driving speeds, and, often, changes in glance behavior, for example, more time with eyes spent off road (for a review, see Bayly, Young, & Regan, 2008).

A different prediction on the impact of text messaging on driving performance can be made on the basis of the asynchronous nature of text messaging. As Jamson, Westerman, Hockey, and Carsten (2004) pointed out, the locus of control of text messaging compared with talking on a cell phone while operating a motor vehicle is driver controlled; that is, the driver can choose when to enter a text message, whereas a driver talking on a cell phone is more pressured into "maintaining a particular pace of response" (p. 626). This situation provides drivers with the possibility of choosing times of relatively little demand of the driving task (little surrounding, smooth flowing traffic) for text messaging. The consequence might be that that driving performance is affected only minimally and potential changes in performance show only during short periods of text messaging. Thus, the potential impact of text messaging may show a different pattern than the impact of conversing on a cell phone: During an exchange of text messages,

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there might be times when a driver is waiting for a message, allowing focusing on driving, whereas at other times, text message entry might negatively affect driving performance.

Unfortunately, there is only very little empirical work on text messaging while driving. One of the few studies was done by Hosking, Young, and Regan (2009), who examined the impact of text messaging on driving performance by recording eye movements in a high-fidelity driving simulator. In Hosking et al.'s study, 20 young, novice drivers (less than 6 months of driving experience) were exposed to a number of safety-related events (e.g., a pedestrian appears from behind a car) during a driving task, which also included car following and lane changing. Both activities of retrieving and sending text messages negatively affected driving performance. For example, the driver's ability to control lateral vehicle position and responses to traffic signs were significantly impaired during the messaging activity. Also, during this activity, the driver's eyes focused less often on the road compared with the control condition. However, the driving speed of the distracted drivers did not differ from their speed in the control condition, although the following distance increased. The increase in following distance was interpreted by the authors as an example of the drivers' attempting to compensate for the increased distraction while driving. Overall, the changes in driving performance are similar to the findings in the context of cell phone conversations while driving (i.e., changes on the operational and tactical levels; Drews et al., 2008).

Similarly, Kircher et al. (2004) focused on receiving text messages while driving in a simulator. Ten experienced drivers received text messages while driving in the simulator. Participants were instructed to retrieve the messages and to respond to them *verbally*. Effects on driving behavior were measured in terms of time for braking onset. While participants were reading text messages, the braking times were significantly longer and drivers drove slower than in baseline driving conditions.

One question that is still unanswered is related to the issue of the impact of text messaging on driving performance and accident rates. As outlined earlier, there are different predictions that can be made on the impact of text messaging while driving. Given the task analysis performed by Regan et al. (2008), text messaging should result in a significant reduction in driving performance. Another reason for such a prediction is that text messaging not only requires central attentional processing but also requires additional focusing on the phone during the process of composing or reading messages. Therefore, it is likely that the impairments associated with text messaging while driving will be comparable to or even higher than those found when drivers converse on cell phones, given the increase in processing demands.

Alternatively, it is possible that because text messaging is a more internally controlled task, drivers may strategically chose times of low task demand associated with the driving task to perform text entries, resulting in little or no impact on overall driving performance.

The current research pursues two objectives: First, the study seeks to establish the impact of text messaging in simulated driving on driving performance and safety, therefore replicating and extending the findings of Hosking et al. (2009). Second, this research aims to estimate the impact of text messaging during simulated driving on accident rates and, furthermore, the reason for any observed impairments in driver performance. In particular, we hypothesize that the dual-task combination of driving and text messaging may place additional demands on visual attention that result in participants' switching attention between activities rather than simultaneously sharing attention between the two tasks.

METHOD

Participants

Participants in this study were 40 young adults ranging in age from 19 to 23 years; 21 years was the average age. Among the participants, 20 were women and 20 were men. All participants had normal or corrected-to-normal visual acuity, normal color vision (Ishihara, 1993), and a valid, nonprobationary driver's license. Participants had an average of 4.75 years of driving experience (range 3 to 7 years). Participants were recruited in a total of 20 friend dyads (i.e., participants' friends who have known each other for more than 1 year) and received

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course credit for participation. On the basis of questionnaire data collected at the beginning of the study, the participants can be considered experienced in sending text messages. In the questionnaire, 90% responded that they send text messages more than three times a day on a regular basis. All participants responded that they would either likely or surely read a text message received while driving a vehicle. The large majority of participants (90%) responded that they send text messages while driving more than once a week.

Stimuli and Apparatus

A PatrolSim™ mid- to high-fidelity driving simulator, manufactured by L3 Communications I-Sim, was used in the present study. The simulated vehicle is based on the vehicle dynamics of a Crown Victoria model with automatic transmission built by the Ford Motor Company. The simulator consists of three screens providing a front view and two side views to the driver (the visual field is approximately 180°) and includes rear view and side view mirrors. The simulator uses a fixed base, that is, it does not simulate motion of a real vehicle.

To evaluate driving performance, a freeway road that simulated a 32-mile multilane rural and urban beltway with on and off ramps, overpasses, and two- and three-lane traffic in each direction was used. A pace car, programmed to travel in the right-hand lane, braked intermittently throughout the scenario. Twenty-two distracter vehicles were programmed to drive between 5% and 10% faster than the pace car in the left lane. This manipulation produced the impression of a traffic flow of varying density in the left-hand lane, creating times of higher and lower demand on the driver. Two driving scenarios (one requiring driving in the opposite direction of the other), counterbalanced across participants and experimental condition, were used in the study. Measures of real-time driving performance, including distance from other vehicles, brake inputs, and steering inputs, were sampled at 60 Hz and stored for later analysis.

Because familiarity with a particular model of cell phone can potentially have an impact on text messaging performance, participants used their own cell phones to send and receive text messages in this study, as they are highly familiar with the user interface implemented in their cellular phone and the way text messages are displayed and text is entered. Baseline performance for text messaging indicated that participants took an average of 57 s ($SD = 21$) to enter the following pangram: "The quick brown fox jumps over the lazy dog." All participants used T9 for text entry.

Procedure

The experiment was conducted in a single session. After participants answered a series of questionnaires concerning the frequency of text messaging while driving, the dyad received instructions about the text-messaging task, which consisted of exchanging text messages with the goal to plan an evening activity together. For this purpose, the nondriving member of the dyad was provided with information about potential activities, such as the movie theater, concert, and sports programs and a number of restaurants. One participant of the dyad was randomly selected to drive the simulator vehicle while the other member sent messages containing information related to available evening activities to the driver. The driver was instructed to drive safely and to follow all the traffic rules. In addition, in the dual-task condition, drivers were instructed to exchange text messages with the goal of planning an evening activity together. Following this instruction, the designated driver was familiarized with the driving simulator using a standardized adaptation sequence, reported in more detail elsewhere (Drews et al., 2008).

Each driving participant was tested in a baseline driving condition, a text-messaging-and-driving condition, and a baseline text-messaging condition (with the last condition to assure that participants were fluent in text message entry). The order of the conditions was counterbalanced across participants. During driving, the participant's task was to follow the pace car driving in the right-hand lane of the highway. In each scenario, the pace car was programmed to brake at 42 randomly selected intervals and would continue to decelerate until the participant depressed the brake pedal, at which point the pace car would begin to accelerate to normal freeway speeds. If the participant failed

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to depress the brake, he or she would eventually collide with the pace car. The brake lights of the pace car were illuminated throughout the deceleration interval. Thus, each scenario provided 42 opportunities to measure participants' response to the lead vehicle's braking in front of them. Participants in the dual-task condition received and composed text messages while operating the vehicle. Because they used their own cellular phones, the messages were displayed on the specific model's display. Also, participants needed to manually manipulate their cell phones while receiving and composing messages, which was in almost all cases done by holding the cell phone up with the right hand at the height of the steering wheel.

RESULTS

The results for the driving performance measures are shown in Table 1. We performed the analyses using a repeated-measurement ANOVA with driving condition as a repeated measurement factor.

Brake Onset Time

The first ANOVA analyzed the brake onset time for participants in both conditions. The results of the analysis indicated a significant effect of condition, $F(1, 19) = 12.5$, $p < .01$. As shown in Table 1, participants were 0.2 s slower in responding to the brake onset when driving and text messaging compared with the single-task, driving-only condition. A more detailed analysis of the braking reaction time focused on vincentized cumulative distribution functions (CDFs) for each condition, which are presented in Figure 1. In the figure, the reaction time at each decile of the distribution is plotted, and it is evident that the dual-task CDF is systematically displaced to the right, indicating slower reactions compared with those in the single-task condition. To quantify the differences between both conditions, we performed a series of *t* tests for each decile comparing the single- and the dual-task conditions. The results of this analysis indicated that the dual-task performance differed from single-task performance for all deciles except the first: *t*-values for the each of the deciles, $t(19) = -1.7$, $p > .1$; $t(19) = -2.1$, $p < .05$; $t(19) = -3.5$, $p < .01$; $t(19) = -3.6$, $p < .01$; $t(19) = -3.1$, $p < .01$; $t(19) = -4.7$, $p < .01$; $t(19) = -4.5$, $p < .01$; $t(19) = -4.3$, $p < .01$; $t(19) = -4.3$, $p < .01$; $t(19) = -3.8$, $p < .01$.

TABLE 1: Means and Standard Deviations of Driving Performance for Each Experimental Condition

	Condition	
Variable	Single Task	Dual Task
Brake onset time (ms)	881 (349)	1,077 (380)
Following distance (m)	29.1 (9.7)	34.3 (12.6)
Standard deviation of following distance (m)	11.9 (6.3)	17.9 (9.5)
Minimal following distance (m)	9.0 (3.0)	6.8 (2.3)
Lane crossings (per kilometer)	0.26 (0.3)	0.49 (0.5)
Lane reversals (per kilometer)	10.5 (4.4)	13.2 (4.1)
Gross lateral displacement (m)	4.3 (1.3)	5.4 (1.9)

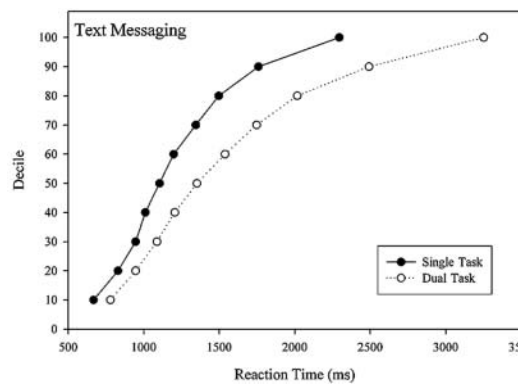

Figure 1. Binned reaction times for single- and dual-task conditions.

The next analysis focused on the specific activities involved in text messaging following the task analytic approach of Regan et al. (2008). For this purpose, video-based coding of three text-messaging activities at the time the lead vehicle was braking was performed: The first activity involves entering a message (mean frequency = 14; *SD* = 6.2), the second activity involved receiving and reading a text message

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(mean frequency = 1.2; $SD = 1.2$), and the third activity included times when participants were not engaged in either of the two activities (i.e., participants were driving but not interacting with the cell phone; mean frequency = 15.7; $SD = 8.0$). Table 2 provides the average reaction times to the onset of a braking light for each activity. A repeated-measure ANOVA revealed a significant effect of activity, $F(2, 10) = 20.4$, $p < .01$. Post hoc tests indicated significant faster reaction times for driving only compared with entering, $t(17) = 4.5$, $p < .01$, and receiving and reading, $t(11) = 4.7$, $p < .01$, but no significant difference between entering and reading of text messages, $t(11) = 1.975$, $p = .074$.

TABLE 2: Means and Standard Deviations of Observations and of Reaction Times for Activities in the Text Messaging Condition

	Dual Task		
Variable	Reading/ Receiving	Entering	Driving Only
Obervations per participant	1.2 (1.2)	14.0 (6.2)	15.7 (8.0)
Brake onset time (ms)	1,645 (140)	1,301 (158)	973 (63)

Following Distance

The average following distance for the single-task and for the dual-task condition is presented in Table 1. The ANOVA for average following distance revealed that the difference between the single-task condition and the dual-task condition was significant, $F(1, 19) = 16.4$, $p < .01$. Similar to the data on cell phone use while driving (see Strayer et al., 2003), participants who were text messaging while driving increased the following distance to the lead vehicle. In addition, an ANOVA for the standard deviation of following distance was also significant, $F(1, 19) = 18.4$, indicating that when participants texted with their friends, they exhibited significantly increased variability in car-following behavior. An ANOVA of the minimum following distance in single- and dual-task conditions also found significantly smaller minimum following distance in the dual-task condition, $F(1, 19) = 7.5$, $p < .05$, as shown in Table 1. Thus, text-messaging drivers increased their following distance (on average), exhibited greater following distance variability, and showed a smaller minimum following distance than did the drivers in the single-task condition. Overall, text messaging while driving caused a more varied following distance profile than did the driving-only condition.

Lane Maintenance

An ANOVA of lane crossings found that text-messaging drivers exhibited more instances of inadvertent lane departures compared with drivers in the single-task condition, $F(1, 19) = 5.38$, $p < .05$. Texting drivers also displayed a greater number of lane position reversals, that is, a change of the direction of lateral vehicle heading from drifting left to drifting right, $F(1, 19) = 15.2$, $p < .01$. This higher frequency of lane position reversals is analogous to the often-reported finding that secondary task distraction increases steering reversals (Knappe, Keinath, Bengler, & Meinecke, 2007; McLean & Hoffmann; 1975). Finally, an ANOVA of gross lateral displacement compared the total lateral distance traveled between single- and dual-task conditions and found a significant effect of text messaging, $F(1, 19) = 7.19$, $p < .05$.

Combined with the analysis of vehicle-following characteristics, these findings suggest that text messaging impairs both forward and lateral vehicle control.

Collisions

The final analysis examined the number of vehicle collisions in the present study. We observed a total of seven collisions that were caused by individual participants (each collision was caused by a different participant). It is noteworthy that six (86%) of the crashes occurred in the dual-task condition, that is, while participants were text messaging while operating the vehicle. Only one accident occurred in the single-task driving condition. A comparison of accident rates in both conditions using a one-sided McNemar χ^2 test revealed a significant difference ($\chi^2 = 4.33$, $p < .05$) in crash rates, reflecting the sixfold increase of

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crashes when participants were text messaging while driving.

DISCUSSION

Overall, an intriguing picture emerged as a result of this simulator study that allows characterizing the influence of text messaging on driving performance.

One of the observations is that text-messaging drivers substantially increase their average following distance to a lead vehicle. This behavior has been interpreted as an attempt by drivers to reduce the likelihood of getting into a crash (e.g., Strayer et al., 2003). Thus, it is possible that text-messaging drivers may be aware of the increase in risk associated with text messaging (see American Automobile Association, 2007, for data on teenagers), and they either consciously or unconsciously compensate for this increase by creating a "safety buffer." However, given the increase in crash risk, the strategy of creating such a safety buffer appears to be inadequate.

To further explore why driving while text messaging is impaired to such an extent, we return to our analysis of the reaction time distributions (cf. Figure 1). By computing the ratio of dual-task reaction time to single-task reaction time at each decile, we can provide an estimate of the relative costs of text messaging. In Figure 2, the resulting dual-task/single-task reaction time ratio is plotted. For comparison purposes, we have plotted the dual-task/single-task reaction time ratios for hands-free and handheld cell phone conversations from Cooper and Strayer (2008; see also Strayer, Crouch, & Drews, 2006).

The 40 participants from this study are similar to the current participants in age (average 23 years) and driving experience (7 years with a driver's license). Also, the driving scenarios are identical in terms of traffic density and task difficulty. The data compared here are the aggregated data of the specific experimental conditions (i.e., individual activities are not analyzed). In Figure 2, a ratio of 1.0 would indicate no impairment to reaction time. It is evident that all activities involving the concurrent use of a cell phone increase the dual-task/single-task ratio. Interestingly, the functions for handheld and hands-free cell phone conversations are relatively vertical, indicating a

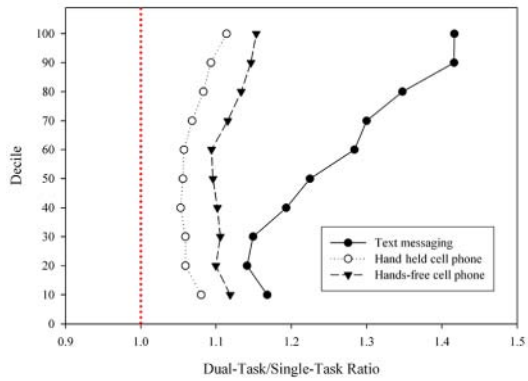

Figure 2. Dual-task/single-task ratio for three different experimental conditions.

systematic shift in the reaction time distribution by about 10% (but only a modest change in the shape of the distribution, which suggests that the combined distributions are similar). By contrast, text messaging clearly has the highest dual-task/single-task ratio, and the difference grows rather strikingly across the deciles of the distribution. This increase suggests that the ratios result from a combination of two distributions (e.g., normal and exponential distribution) into an ex-Gaussian distribution.

Indeed, the pattern observed with text messaging suggests a dual-task cost in reaction time that results from two processes, with a smaller 15% cost in the lower deciles of the distribution and a much greater 30% to 45% cost at the higher deciles. The interpretation of a differential dual-task cost receives additional support from the analysis of specific activities involved in text messaging. In the text-messaging condition, participants displayed no impairment during the times when not interacting with their cell phone, $t(18) = 1.1$, $p > .1$, but clear impairments in driving performance when interacting with their cell phone.

The observed performance in the dual-task condition could be accomplished through either a sharing of attentional resources between the concurrent tasks or a switching of attention between the two tasks. Interestingly, the dual-task/single-task ratios suggest different patterns of attentional strategies for cell phone conversations and text messaging. Conversing on a cell phone appears to be more consistent with

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a sharing model of attention, albeit one that is subject to the response selection bottleneck limitations described by Pashler and colleagues (e.g., Levy, Pashler, & Boer (2006); Levy & Pashler, 2008; see also Wickens's [1984] multiple resources model). That is, drivers apparently attempt to divide attention between a phone conversation and driving, adjusting the processing priority of the two activities depending on task demands. By contrast, text messaging appears to be most consistent with a switching model of attention, in which attention is allocated in large part either to driving or to text messaging. When drivers have switched their attention to the text-messaging task, that is, composing or reading or receiving a message, their reaction times to braking events are substantially higher, reflecting a substantial cost of task switching.

The observed changes in reaction time depending on text-messaging task are of interest in this context: Both reading and composing affect reaction times, and a statistical trend indicated that braking times increased more when participants were reading messages. However, it seems too early to draw conclusions based on this trend because of the relative small sample size. If future studies indicate that reading text messages produces larger impairments, then this finding would have important practical implications for in-vehicle technology. For example, systems reading messages out loud could support drivers (Tsimhoni, Green, & Lai, 2001). However, if the impairment associated with reading text messages is a result of the externally controlled event of receiving a text message, then suppressing reception of messages while operating a vehicle might be a better-suited strategy to mitigate the impact of driver distraction.

The simulator data suggest that the crash risk attributable to text messaging while driving is quite substantial. One potential explanation for the number is crashes is that text-messaging drivers tend to decrease minimum following distance in conjunction with a delay in reaction time to imperative events (i.e., median reaction time increased by 30% when text messaging compared with, e.g., a 9% increase when having a cell phone conversation while driving; Strayer et al., 2006). In addition, text-messaging drivers display a pronounced impairment to vehicle control. Indeed, this work documents a substantial decrement in both forward and lateral vehicle control as a result of text messaging.

Overall, the results of this study provide a first glimpse of a theoretical framework to analyze driver distraction. It appears that the type of attentional demand combined with time of exposure determines the severity of driver distraction. Activities such as text messaging that require task switching and are often performed for extended periods severely impair driving performance. Tasks such as talking on a cell phone that require shared attention combined with even higher exposure have similar effects on driving performance, albeit potentially a lower crash risk. Finally, activities that are short in exposure and require either task switching or shared attention appear to have a relatively smaller impact on driving performance.

One of the limitations of this study's findings is that they are based on a simulator study of text messaging. Clearly, there is a need for epidemiological data to validate the reported findings and to further identify the prevalence and risk associated with text messaging while driving. Another potential limitations is that to understand more about the impact of text messaging on driving, more detailed analyses of activities associated with text messaging should be performed in future studies to, for example, assess the impact of text-messaging difficulty and complexity on the safety of vehicle operation.

Overall, the present findings suggest that text messaging while driving is more risky than are many other distracting activities drivers currently engage in. Although conversing on a cell phone is often subjectively perceived as an acceptable risk, there is no doubt that text messaging while driving is a dual-task combination with inherently high risk for the driver and other traffic participants.

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