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An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance

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Abstract

In this on-road experiment, drivers performed demanding cognitive tasks while driving in city traffic. All task interactions were carried out in hands-free mode so that the 21 drivers were not required to take their visual attention away from the road or to manually interact with a device inside the vehicle. Visual behavior and vehicle control were assessed while they drove an 8 km city route under three conditions: no additional task, easy cognitive task and difficult cognitive task. Changes in visual behavior were most apparent when performance between the No Task and Difficult Task conditions were compared. When looking outside of the vehicle, drivers spent more time looking centrally ahead and spent less time looking to the areas in the periphery. Drivers also reduced their visual monitoring of the instruments and mirrors, with some drivers abandoning these tasks entirely. When approaching and driving through intersections, drivers made fewer inspection glances to traffic lights compared to the No Task condition and their scanning of intersection areas to the right was also reduced. Vehicle control was also affected; during the most difficult cognitive tasks there were more occurrences of hard braking. Although hands-free designs for telematics devices are intended to reduce or eliminate the distraction arising from manual operation of these units, the potential for cognitive distraction associated with their use must also be considered and appropriately assessed. These changes are captured in measures of drivers' visual behavior.

Keywords: Driving; Distraction; Driver visual behavior; Road safety

1. Introduction

Hands-free and voice-based technologies are increasingly popular choices for telematics interfaces (ITSA, 2005; PR Newswire, 2005). The obvious safety advantage of these technologies is that drivers can interact with in-vehicle devices using spoken commands and listening to output without having to direct their visual attention away from the road to the interior of the vehicle. Given that hands-free and speech-based devices largely eliminate the distraction resulting from visual/manual interaction, it is often assumed that their use does not impact driver behavior and safety. This assumption is reflected in current North American legislation regulating the use of cell phones while driving, which is largely directed at banning hand held, but not hands-free, devices (Sundeen, 2005).

Driver distraction is an acknowledged safety problem with serious consequences (e.g., Strayer et al., 2006). Considerable research has accumulated documenting the dangers arising from visual/manual distraction inside the vehicle. The recently released naturalistic study of 100 instrumented vehicles (the "100 Car Study") reported that driver inattention to the roadway was a contributing factor to 78% of the crashes and 65% of the near-crashes observed in that study (NHTSA, 2006). Green (1999) produced an extensive review and analysis of in-vehicle tasks that draw drivers' visual attention away from the road. Wierwille and Tijerina (1998) found that they were able to use the visual requirement (glance length and number of glances) for the use of in-vehicle devices, incorporated with the frequency of in-vehicle device use, to predict crash rates. A clear, logical connection relates this research to safety concerns: when you are looking inside the vehicle, you are not looking at the road.

The connection between the use of hands-free or speech-based interfaces and driver distraction is less obvious, but research pointing to "cognitive distraction" as a road safety concern is accumulating. The Insurance Institute for Highway

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Safety reported that when drivers use a cell phone while driving there is a four-fold increase in the likelihood of a crash serious enough to require medical attention (McEvoy et al., 2005). This study also concluded that using a hands-free phone was not any safer than hand-held.

A number of simulator studies have examined the impact of cognitive distraction on driver behavior. Strayer and Johnston (2001) found that participants engaged in cell phone conversations during a tracking task were more likely to miss traffic signals and reacted to signals they did detect more slowly than when they were not engaged in cell phone conversations. The effects were similar for both hand held and hands-free phone configurations. In a later study, participants exhibited an 18% increase in brake reaction times when talking on hands-free cell phones compared with driving without a cell phone (Strayer and Drews, 2004).

The research has expanded beyond cell phones to the larger domain of interfaces for in-vehicle use in general. Lee et al. (2001) reported a 300 ms delay to the braking of a lead vehicle when drivers used a speech-based email system while driving a simulator. In a later simulator study, Harbluk and Lalande (2005) observed reductions or delays in the detection of visual stimuli in the side mirrors when drivers interacted with a speech-based email system.

In an attempt to better understand the visual behavior of drivers, Recarte and Nunes (2000) examined the effects of performing concurrent cognitive tasks on drivers' eye fixations while driving on-road. An experimenter seated in the vehicle interacted with the drivers, asking them to perform verbal and spatial-imagery tasks. Recarte and Nunes reported that drivers' visual functional-field was reduced vertically and horizontally. In addition, during the spatial-imagery task, fixations were longer and glance frequency to mirrors and the speedometer decreased. In a later experiment, they reported that performing demanding cognitive tasks while driving reduced drivers' detection performance for lights displayed in the vehicle and on the windshield (Recarte and Nunes, 2003). The findings from their previous study, reductions in inspections for the mirror and speedometer, were also replicated.

The present experiment was designed to further investigate the impact of performing demanding cognitive tasks (without visual/manual distraction) on driver behavior and performance. The primary questions of interest were:

(1) What are the changes in driver visual behavior that arise as a consequence of using hands-free devices while driving?
(2) How are these changes reflected in drivers' visual behavior at intersections?
(3) Is vehicle control (braking) affected by these activities?
(4) Are drivers sensitive to the increased task demands as reflected in drivers' ratings of workload, safety and distraction?

There were a number of critical considerations in the design of the study. All task interactions took place via the technology in the vehicle (in this case a cell phone) rather than interacting with an experimenter in the vehicle. The mode of interaction was entirely hands-free via speakerphone with a person at a remote location. Drivers did not have to look away from the road or interact manually with an interface. Given the importance of vision in driving, the primary measures of interest were measures of drivers' visual behavior. The participants drove on-road in real city traffic. This provided increased ecological validity and also permitted an assessment of drivers' visual behavior with respect to safety-relevant objects in the driving environment (intersections and traffic lights) as well as general evaluations of scanning patterns out the windshield and to the mirrors and instruments. Measures of braking behavior were collected, as were drivers' self evaluations with respect to workload, safety and distraction.

2. Method

2.1. Participants

Twenty-one participants (9 women and 12 men) aged 21–34 years old ($M = 26.50$, S.D. = 4.71) took part in this study. All held valid drivers licenses, were insured and were experienced drivers (minimum 5 years driving experience; $M = 9.70$, S.D. = 4.26) who drove at least 10,000 km annually. Their vision was good or corrected with contacts. Participants were recruited via an advertisement in a local newspaper and were paid $50.00 for their participation.

2.2. Equipment

Participants drove a 1999 Toyota Camry equipped with a Micro-DAS data collection system (Barickman and Goodman, 1999). The driver side airbag was deactivated and a safety brake was installed on the front passenger side where the experimenter was seated. Participants wore a head-mounted eye tracking system (VISION 2000, El Mar Inc., Toronto, Ontario, Canada), a lightweight (300 g) unit fitted with a visor (70 g) to filter IR (Eizenman et al., 1999). The cell phone (Nokia model 5160) remained in the cradle mounted to the right of the console. Its microphone was attached to the upper left A-pillar and its speaker was mounted under the dash.

2.3. Design, materials, and procedure

A one-way repeated measures design was used where presentation order of task conditions (two levels of cognitive task and the control condition) was counterbalanced across participants.

After a description of the procedure, driver information was collected and the consent form was completed. Participants wore the eye tracker and drove a practice route for 25 min to become familiar with the vehicle, the eye tracker, and the tasks. After a brief break, during which the eye tracker was removed, the eye tracker was calibrated on the participant.

The test route was a 4-km stretch of a busy 4-lane city road on which the drivers drove north and south for a total of 8 km per condition. The posted speed limit was 50 km/h. Each participant completed three drives, one for each of the Easy Task, Difficult Task, and No Task conditions. Math problems were used as the cognitive task. Single digit addition problems (e.g.,

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6 + 9) were used for the easy cognitive task and the difficult cognitive task required drivers to add double-digit numbers that involving carrying (e.g., 47 + 38). The choice of math problems for the cognitive tasks was motivated by the desire for control in the task demands (Geary and Wiley, 1991) and a task that all drivers could perform which did not require training or a history of the participant to manufacture a conversation. Both types of task place demands on short-term memory.

A research assistant located at a remote location conversed with the driver using the cell phone, asking the questions and recording the drivers' responses. After each drive, there was a brief break (10 min) during which the eye-tracking unit was removed. During this rest break the participant completed the NASA TLX (Hart and Staveland, 1988) and two additional questions addressing driving safety (How safe did you feel during the drive?) and distraction (How distracted did you feel from the task of driving?).

3. Results

The impact of performing the cognitive tasks on measures of drivers' visual behavior, vehicle control (braking behavior), and subjective ratings was examined. All 21 participants contributed to each analysis unless otherwise stated. Where appropriate, repeated-measures ANOVA was used. In the situations where the data did not meet the ANOVA assumptions, Friedman's non-parametric ANOVA was used. Tests of means were conducted using *t*-tests or Wilcoxon tests as appropriate. The Modified Bonferroni procedure recommended by Keppel (1982) was used to control the family-wise error rates for the tests of means.

3.1. Analyses of driver visual behavior

These analyses were based on eye tracking data that were available for 97% of the task durations.

3.1.1. Drivers' inspection of areas in the outward view

Fig. 1 depicts the areas of interest in the driver's forward view, outside of the vehicle. The Central Area covers the area in the driver's lane directly in front of the vehicle. The Peripheral Area covers the combined areas off to the left and right.

Fig. 1. Forward driving view: Central and Peripheral Areas.

The mean percentage of driving time spent looking centrally ahead and to the more peripheral areas of the driving scene while driving under the three task conditions was examined. Percentages are based on the time spent looking in the area of interest divided by the total task time for the condition of interest for each participant. (Percentages do not sum to 100 since not all areas are included.) The analysis of these data revealed a significant Area by Task interaction ($F_{(2,40)} = 3.79$, $p < .05$).

The pattern of data for the Central Area indicated that drivers spent increasing amounts of time looking directly ahead as task difficulty increased (mean No Task 78.63, S.E. = ±1.75; mean Easy Task 80.84, S.E. = ±1.70; mean Difficult Task 82.68, S.E. = ±1.82). This was a significant increase from No Task to the Difficult Task ($t_{(20)} = 2.20$, $p < .05$; No Task versus Easy Task $t_{(20)} = 1.52$, $p > .05$), consistent with the interpretation of a narrowing of attentional focus with greater cognitive demand.

The pattern of data for the Peripheral Area reflected the opposite pattern. Drivers reduced their amount of time inspecting the periphery with increased task difficulty as reflected in a significant reduction from the No Task condition (mean 2.82, S.E. = ±.35) to the Difficult Task condition (mean 2.11, S.E. = ±.39; $t_{(20)} = 2.18$, $p < .05$). The comparison of the No Task to Easy Task (mean 2.84, S.E. = ±.39) conditions was not significant ($t_{(20)} = .97$, $p > .05$).

In sum, drivers spent more time looking straight ahead and less time looking to the periphery when performing the most demanding cognitive tasks while driving. These findings are consistent with the idea of a concentration of the visual inspection area due to the cognitive demands of the task.

3.1.2. Drivers' inspection of instruments and mirrors

These data did not meet the normality assumption for ANOVA and were analyzed using Friedman's nonparametric analysis of variance (ANOVA). (Percentages do not sum to 100 since not all areas are included.)

As task difficulty increased, there was a significant reduction in the percentage of time that drivers spent monitoring the instruments ($\chi^2_{(2)} = 16.38$, $p < .001$). Post hoc Wilcoxon tests revealed significant differences between the No Task (mean 1.48, S.E. = ±.30) and Difficult Task (mean .63, S.E. = ±.25) conditions ($p < .001$) but not between the No Task and Easy Task (mean 1.18, S.E. = ±.33; $p > .05$) conditions.

The mean percentage of time that drivers spent viewing the mirrors (including rear view, left and right mirrors) while driving decreased from 1.94 (S.E. = ±.37), to 1.75 (S.E. = ±.36), to 1.19 (S.E. = ±.27) for the No Task, Easy Task and Difficult Task, respectively ($\chi^2_{(2)} = 7.25$, $p < .05$). The reduction from the No Task to the Difficult Task was significant at $p < .05$.

Fig. 2 provides a summary of the above analyses in terms of changes in drivers' visual behavior. The data represent the change in the percentage of time spent looking at each of the areas as a function of the difference between the cognitive task conditions (Easy or Difficult cognitive task) and the No Task baseline. The pattern of data indicates, that when engaged in a

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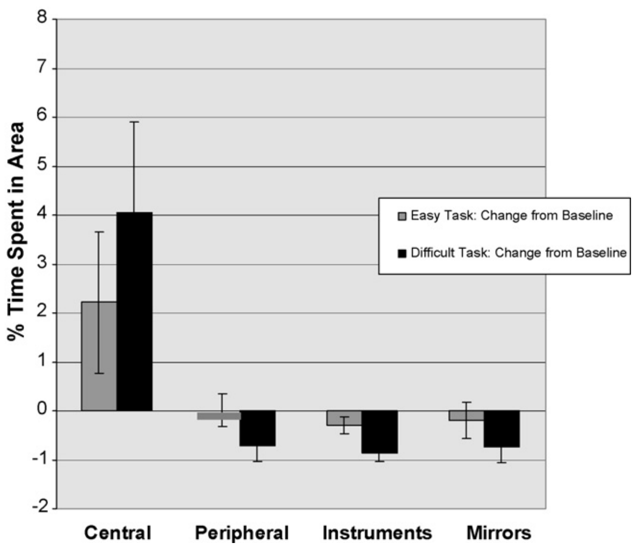

Fig. 2. Percentage change for viewing time in specific areas (±S.E.).

demanding cognitive task while driving, drivers increased their focus in the central forward view, while decreasing their inspection of the periphery, instruments and mirrors.

When data for individual drivers were examined, it was found that some drivers completely neglected to monitor areas under certain conditions. As can be seen in Table 1, all drivers looked at the instruments and rear view mirror when driving in the No Task condition, but two of the drivers shed the tasks of viewing the instruments and mirrors when the cognitive load was increased during the Difficult Task condition. In the case of the left and right mirrors, the number of drivers who did not look to these areas increased with increasing task difficulty. Of the 21 drivers, 7 did not check the left mirror and 13 did not check the right mirror when performing the Difficult Task.

3.1.3. Analysis of glance patterns at intersections

In order to make the connection between drivers' visual behavior and their driving environment outside the vehicle, detailed analyses were made of the drivers' eye glances as they drove through intersections on the route. Specifically, the mean number of glances to the traffic lights, the mean percentage of times drivers completely shed the task of looking at the traffic lights, and the mean number of glances to the right and to the left were examined. These analyses were carried out for the No Task and Difficult Task conditions (which demonstrated the greatest differences in the previous analyses) for the outbound direction of the route. Data were not available for one driver due to a recording failure.

Clear differences in the drivers' glance patterns were observed as shown in Table 2. Specifically, when drivers performed the Difficult Task, they made significantly fewer glances (mean 1.75; S.E. = ±.18) to the traffic lights than when they drove without a task (mean 2.68; S.E. = ±.29; $F_{(1,19)} = 21.34$, $p < .001$). In some cases, drivers did not inspect the signal lights at all. The percentage of time drivers completely shed the task of looking at the traffic light was significantly greater during the Difficult Task (mean 21.9%, S.E. = ±4.53) than during the No Task condition (mean 7.8%, S.E. = ±2.56; $\chi^2_{(1)} = 8.07, p < .01$).

Differences were also found in drivers' visual inspection of the area around the intersections as indicated by the significant interaction between task type and glance direction ($F_{(1,19)} = 4.65$, $p < .05$). Specifically, drivers reduced the frequency with which they looked to the right under the Difficult Task condition (mean 1.34, S.E. = ±.15) compared to the No Task condition (mean 1.70, S.E. = ±.18; $p < .05$) but there was no difference in the frequency with which they looked to the left (Difficult Task mean 1.48, S.E. = ±.20; No Task mean 1.34, S.E. = ±.14, $p > .05$).

3.2. Vehicle control measure: braking performance

The drivers' continuous driving data for the 8 km drive were coded for discrete braking events that represented hard breaking. The longitudinal deceleration rates were sampled at a frequency of 30 Hz. Occurrences of hard braking were defined as longitudinal decelerations exceeding .25 g (Mortimer et al., 1970). Braking data were not available for 5 of the 21 participants due to recording failures. The vast majority of the hard braking events (85%) took place at signalized intersections.

Fig. 3 displays the mean number of braking events exceeding .25 g that occurred in each of the three task conditions (a total of 291 braking events). Their occurrence increased across the

Table 1
Number of drivers who did not look at specific areas

	Instruments	Rear view mirror	Left mirror	Right mirror
No Task	All drivers look	All drivers look	2	6
Easy Task	1	All drivers look	5	9
Difficult Task	2	2	7	13

Table 2
Summary of drivers' glance behavior at intersections

	Mean number of glances to traffic lights	% of times drivers did not glance at traffic lights	Mean number of glances to the left	Mean number of glances to the right
No Task	2.68	7.8	1.34	1.70
Difficult Task	1.75	21.9	1.48	1.34

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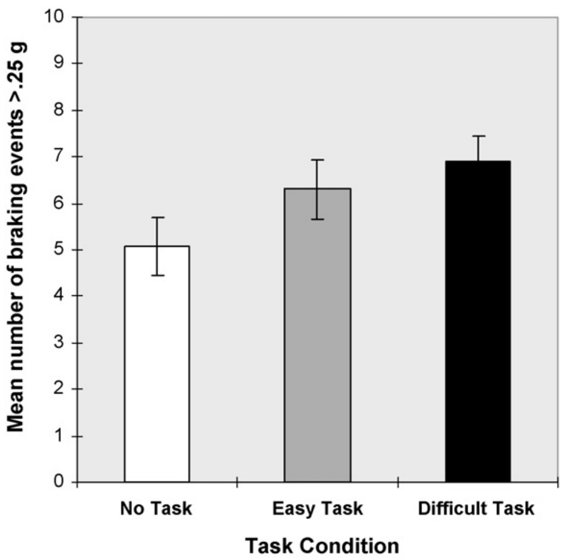

Fig. 3. Mean number of braking events exceeding .25 g (±S.E.).

task conditions with a mean occurrence of 5.06 (S.E. = ±.62) in the No Task condition, 6.31 (S.E. = ±.73) in the Easy Task Condition and 6.88 (S.E. = ±.58) in the Difficult Task Condition ($F_{(2,30)} = 3.21$, $p = .05$). A significantly greater number of these braking events occurred in the Difficult Task Condition compared with the No Task condition ($p < .05$).

3.3. Ratings of workload, safety reduction and distraction

Drivers' subjective ratings for workload, safety reduction and distraction are displayed in Fig. 4. The impact of increased task difficulty was clearly reflected in each type of rating. The rating data were analyzed using Friedman's ANOVA and Wilcoxon tests were used for the post hoc tests of means.

Ratings for the six scales of the NASA TLX were combined using equal weighting to produce a composite NASA

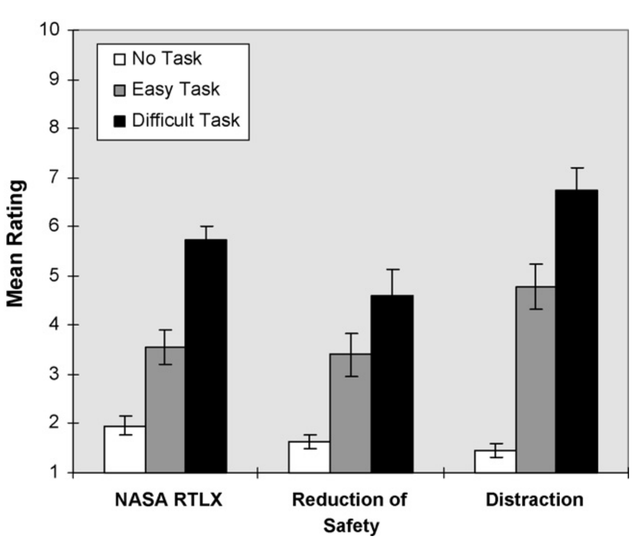

Fig. 4. Mean ratings of workload (NASA RTLX), safety reduction and distraction (±S.E.).

RTLX score where higher ratings indicated greater workload (Byers et al., 1989). As the complexity of the cognitive task increased, so did the perception of workload (No Task = 1.94, S.E. = ±.19; Easy Task = 3.55, S.E. = ±.35; Difficult Task = 5.73, S.E. = ±.29; $\chi^2_{(2)} = 32.67$, $p < .0001$). The NASA RTLX means for both the Easy and Difficult Tasks were significantly greater than the No Task condition ($ps < .001$).

Drivers also rated their driving as less safe (higher numbers mean less safe) with increased task difficulty ($\chi^2_{(2)} = 27.07$, $p < .0001$). Ratings were 1.64 (S.E. = ±.15) for No Task, 3.40 (S.E. = ±.45) for Easy Task and 4.60 (S.E. = ±.52) for Difficult Task Conditions. Comparisons of the ratings for both the Easy Task and Difficult Task indicated that drivers felt less safe in either of these conditions compared with the no Task Condition ($ps < .001$).

As the task difficulty increased across conditions, drivers reported higher ratings reflecting increased distraction ($\chi^2_{(2)} = 34.05$, $p < .0001$). Mean distraction ratings increased from 1.45 (S.E. = ±.29) for the No Task, to 4.79 (S.E. = ±.52) for the Easy Task and 6.74 (S.E. = ±.44) for the Difficult Task Conditions. The ratings for each of the Task conditions were significantly greater than those for the No Task Condition ($ps < .0001$).

4. Discussion

Hands-free and voice-based technologies are often proposed as solutions to the problem of distraction from in-vehicle devices. In this study, drivers drove on-road, in city traffic to assess the impact that the cognitive demand associated with using these types of systems might have on driver behavior and performance.

The drivers' visual behavior changed in a number of important ways. Drivers changed their allocation of looking time in the forward view, spending more time looking directly ahead of their vehicle and less time looking to the periphery. Their inspection of specific objects and areas inside the vehicle was also affected. Drivers spent less time checking instruments and their mirrors. Some drivers shed these tasks completely, not checking these areas at all. Similar reductions in drivers' functional field of view and inspections of the rear view mirror have been reported when experimenters in the vehicle posed questions to drivers (Recarte and Nunes, 2000). In the present study, we found that these changes occurred when drivers were engaged in interactions using a hands-free in-vehicle device while driving in city traffic.

City intersections are known high-risk areas where drivers must monitor the traffic closely for events such as pedestrians, passing vehicles and vehicles changing lanes. Performing the demanding cognitive tasks while driving changed the drivers' visual behavior at signalized intersections. Drivers made significantly fewer glances to traffic lights and fewer inspection glances to the right as they approached and drove through intersections. In an earlier simulator tracking study, Strayer and Johnston (2001) reported that participants were more likely to miss traffic signals and react more slowly to ones they did detect when they were involved in cell phone calls. In another simulator study, drivers engaged in hands-free phone conversations had slower reaction times for the detection of road signs (Smith et al., 2005). The results from the present study confirm that when on-road drivers are engaged in a demanding task, they are looking less often at the lights and informative intersection regions.

In 2004, the Insurance Institute for Highway Safety (IIHS) reported that 1.9 million urban crashes occurred at intersections. Of these 52% occurred at traffic signals and over 50% of these were personal injury crashes (IIHS, 2006). Even with the performance demands of driving in traffic during a research study, participants reduced their glances to traffic lights and the surrounding area. It is noteworthy that one driver in the present study shed the task of monitoring this area completely while performing the most demanding task; for others the reduction in viewing time was as great as 70%. It is often these "worst case" performers who are the causes of crashes (Wickens, 2001).

More incidents of hard braking occurred in the condition where the Difficult Task was performed while driving. In order to make appropriate braking decisions, drivers must be actively engaged in the monitoring, gathering and synthesis of appropriate information about speed, distances and angles, as well as other factors relating to driving (Newcomb, 1981). When a driver is distracted by an in-vehicle task, the resulting inattention to the constantly changing driving environment may reduce or delay the driver's ability to monitor these parameters and consequently delay the decision of when braking should begin. Drivers may have to brake harder to compensate for the delay in initiating braking. Although we were not able to directly relate the glance behavior of the drivers directly to their braking behavior, the reduction in drivers' visual scanning along with the increase in hard breaking incidents is consistent with this type of explanation.

This explanation is also consistent with results from previous simulator, track and laboratory testing. Strayer and Drews (2004) found an 18% increase in participants' brake reactions times when they talked on hands-free cell phones. Hancock et al. (2003) reported that drivers, distracted by a visual-manual task while driving on a test track, responded more slowly to the change of a light and subsequently demonstrated stronger vehicle braking in compensation. Treffner and Barrett (2004), in another test track study, interpreted their results in terms of drivers having to use a higher degree of late deceleration (resulting in harsher braking) when they were engaged in speech-based tasks. In a lab set up, Consiglio et al. (2003) reported a delay in reaction times in a mock up of braking behavior when participants were involved in conversations using hand-held or hands-free phones.

To summarize the main findings and address the questions which were posed at the outset:

(1) Drivers narrowed their inspection of the outward view and spent more time looking directly ahead and less time looking at areas to the periphery. They reduced their inspection of the instruments and mirrors.
(2) Having participants drive a vehicle on-road not only increased ecological validity but, perhaps more important with respect to real world driving, also provided the opportunity to assess drivers' glance behavior at intersections. These data indicated that participants reduced their glances to traffic signals and their monitoring of the area around the intersection.
(3) Increased incidents of hard braking were observed, consistent with reduced visual monitoring of the driving environment.
(4) The increased task demands were reflected in drivers' ratings of workload, reduction of safety and distraction. That drivers were sensitive to these changes is encouraging from the point of driver training and awareness.

While it is possible that hands-free and speech-based interfaces may be safer than visual-manual interfaces in some applications, the results of the present study add to the accumulation of research evidence across various experimental configurations indicating that voice-based interactions are not effortless and these interfaces also have the potential to distract drivers and degrade safety.

There are many variables that could be investigated, but only a limited range of materials, participants and driving conditions were examined in the present study. As in other research (e.g., Treffner and Barrett, 2004), the decision to use math problems as materials was motivated by the need for an engaging task that offers a degree of experimental control as well as cognitive effort. This study did not address, for example, the impact that other manipulations of cognitive demand might have had or the changes in driver behavior that might take place with learning over time (e.g., Shinar et al., 2005). An older group of participants might be expected to show even greater negative effects due to the secondary task performance (e.g., McKnight and McKnight, 1993). Participants drove in a single environment (city traffic); however, the choice to use a more demanding driving environment would have to be balanced with safety concerns. Finally, drivers were obviously aware that they were being studied. Even given these strong performance demands and the demands of driving in city traffic, however, they still exhibited considerable safety-relevant changes in their behavior.

Late detection of relevant stimuli (Rumar, 1990) and driver inattention (Treat et al., 1979) are cited as the most common driver errors. When visual-manual tasks inside the vehicle compete for the driver's attention, it is easy to conceptualize the problem as one of looking away from the road. Although drivers can maintain a heads-up position while using hands-free devices, the competition for the driver's attentional resources can result in significant reductions in scanning and glance patterns as shown in the present results. Horrey and Wickens (2002) have reported that drivers may sacrifice event detection (when performing visual-manual or auditory-based tasks during driving) yet maintain basic vehicle control such as lane keeping. From a safety perspective, the detection of events in the environment may be even more important than maintaining an ideal lane position. This is important information for those concerned with the assessment of distraction from in-vehicle technologies. While vehicle control measures may be

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the most obvious measures to examine, they will not tell the whole story and measures assessing drivers' visual behavior must be included in a testing regime (see also Victor et al., 2005).

Goodman et al. (1999) have cautioned that the perceived safety associated with using hands-free units over those requiring manual manipulation may result in an overall increase of device use while driving. This perception may increase the use of cell phones (number of calls, duration of calls) for former hand-held users and convince previous non-users to use cell phones while driving. Increases in the frequency and/or duration of performing distracting activities while driving would result in increased risk exposure.

What are the sources of cognitive demand associated with using voice-based in-vehicle systems? Drivers must maintain a cognitive model of the device they are using. Depending on the nature of the device, this may be quite difficult for voice-based technologies where there is no manual feedback and little or no visual or auditory feedback. Applications may have complex menu structures that require considerable mental resources to maintain. Cell phones, for example, are being used to deliver traffic and navigation information to drivers although they have not been designed for this purpose. The quality of the speech output of the system (Kawano et al., 2005) as well as system reliability will also influence the workload associate with using these systems. Finally, the requirements of the transaction that is being carried out using the device also contribute to the workload. More complex, demanding tasks would be expected to produce greater workload.

Although work on guidelines and methodologies to assess the safely of in-vehicle devices has been ongoing for some time (e.g., AAM, 2003; EEC, 1999), the proposed methods to date address distraction arising from primarily visual/manual interfaces not speech-based interfaces. Research addressing the behavioral impacts of distraction arising from speech-based interfaces provides practical guidance as to the appropriate measures to use when assessing the safety of these technologies. While more traditional measures of vehicle control (e.g., lane keeping) may not be sensitive to this type of distraction, measures of driver visual behavior may be.

Driver distraction due to the use of on-board interactive technologies represents a potentially serious threat to road safety. When a driver's attention is drawn away from the road and the surrounding environment, the result could be a delayed reaction to a hazard, or possibly, a failure to detect it at all. The results of this study are consistent with an explanation that distracting cognitive tasks compete for drivers' attentional resources. To the extent that attention is directed toward the processing of distracting information (the additional task), the resources allocated to processing driving-relevant information both inside and outside the vehicle are reduced and performance decrements are observed. Recent research reviews have not supported the presumption that hands-free systems are safer (e.g., Horrey and Wickens, 2006; McCartt et al., 2006). Although these technologies are intended to reduce distraction and improve safety, the potential for negative consequences arising from their use must also be considered.

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