Transport Canada Transports Canada

Canada

The Impact of Cognitive Distraction on Driver Visual Behaviour and Vehicle Control

FEBRUARY 2002

TP# 13889 E

Aussi disponible en français

Joanne L. Harbluk
Y. Ian Noy
Ergonomics Division
Road Safety Directorate and Motor Vehicle Regulation Directorate

Moshe Eizenman, **EL-MAR Inc.**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Driver distraction and inattention are important driving safety issues. As the use of in-vehicle technologies becomes more popular, there is concern about a concomitant increase in driver distraction arising from their use. While the introduction of hands-free operation for telematics devices is intended to reduce or eliminate the distraction due to manual operation of these units, a significant proportion of the distraction associated with their use may arise not from the manual manipulation of these devices, but rather the cognitive consequences of their use.

In the present study, the impact of cognitive distraction on drivers' behavior was investigated in an on-road experiment. Twenty-one drivers drove an 8 km city route while carrying out tasks varying in cognitive complexity. Each driver drove the route under three task conditions: while performing difficult addition problems (e.g., 47+38), while performing easy addition problems (e.g., 6+9), and with no additional task. The addition questions and the participants' responses were communicated via a fully hands-free cell phone so that the participants did not have to look away from the road to manually operate the phone. Visual scanning patterns were recorded using eye tracking equipment, measures of vehicle control (braking/longitudinal deceleration) were obtained using the MicroDAS system, and drivers' subjective evaluations of workload (NASA TLX), safety and distraction were obtained through questionnaires.

An examination of drivers' visual behavior revealed that, under conditions of increased cognitive load, they made fewer saccades, spent more time looking centrally and spent less time looking to the right periphery. Less time was spent checking instruments and the rear view mirror. Many drivers changed their inspection patterns of the forward view when performing the most demanding tasks. Marked individual differences were observed in these patterns of change. Performing the additional tasks while driving resulted in more incidents of hard braking while driving. The increase in cognitive load induced by the addition questions was reflected in drivers' increased ratings of workload and distraction as well as reduced ratings of driving safety.

The results of this study indicate that even when in-vehicle devices are hands-free, significant changes in driver behaviour may result due to the cognitive distraction associated with their use. A better understanding of the ways in which drivers interact with these devices should result in improved designs that minimize the amount of distraction.

The study recommends public education, as well as continuing research to determine the need for regulating original equipment.

1. INTRODUCTION

Driver distraction has been implicated as a contributing factor to over 20 percent of motor vehicle crashes in reviews of accident causation (Wang, Knipling, & Goodman, 1996; see also Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansifer, & Castellan, 1979; Zaidel, Paarlberg, & Shinar, 1978). Concerns about driver distraction and inattention are not new, nor are concerns that new technologies may contribute to driver distraction. What is new is the proliferation of information-based technologies available to drivers and the range of in-vehicle activities these on-board devices offer. Drivers today are concerned with not only getting from point A to point B but also with talking on cell phones, reading e-mail, receiving faxes and accessing the Internet. Some systems, which provide automatic accident notification or road condition warnings, may provide a safety benefit to the driver and other road users. Other systems, however, are available in the vehicle primarily for driver convenience or to improve the productivity of the driver while driving. While drivers may enjoy the convenience and increased productivity these technologies offer, the safety implications of their use must be considered.

Many in-vehicle devices require visual attention to the device interface either to input information manually or to read visual output. As a result, when these devices are in use, the driver's attention is diverted from the road to the device. Speech recognition technology has been introduced for in-vehicle interfaces in an attempt to overcome this problem. The primary advantage of this technology is that it allows drivers to interact with in-vehicle devices using spoken commands while viewing the road and keeping their hands on the steering wheel. The implicit assumption underlying the introduction of these interfaces is that there will be no appreciable changes in driver behaviour when hands-free devices are used.

Voice-based interactions, however, are not effortless and road safety researchers (e.g., Goodman, Tijerina, Bents, & Wierwille, 1999; Lee, Caven, Haake, & Brown, 2000) have raised concerns that they also have the potential to distract drivers and degrade safety. What has been changed is the *mode of interaction*, which is now voice-based, allowing drivers to maintain visual contact with the driving environment. The *nature of the interactions* that are carried out using this mode of interface may still have a significant cognitive component that results in increased driver workload. This increase in workload may in turn contribute to driver distraction and consequently produce a significant impact on driver behavior. The increase in cognitive demand experienced by drivers using these voice-based systems can arise from two sources. First, 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. Second, and perhaps more important, is the workload component due to the requirements of the transaction that is being carried out using the device. An intense business conversation, for example, would be expected to increase workload and result in more distraction than a casual conversation. Cell phones are a popular way to conduct business while driving. In a survey of cell phone users, McKnight & McKnight (1991) reported that 72% of cell phone conversations are for business purposes. To the degree that the content of these calls is important or complex, and their nature urgent, driver distraction might be expected to increase.

Driving is a complex behavior that requires the extraction and integration of information from multiple sources in an effort to produce safe and efficient vehicle control. How are these processes affected by the use of voice interactive devices while driving? Much of the information relevant to driving is taken in visually; consequently any change in drivers' visual behavior could be significant for driving safety. Past research (e.g., Miura, 1990) has demonstrated that patterns of visual search may be influenced by environmental complexity, such as the road scene. There is, however, additional evidence that visual search behavior may also be influenced by factors intrinsic to the person. Some researchers have focused on the detrimental effects that could result from the experience of strong emotions. Early work by Easterbrook (1959) described the phenomenon where emotional arousal acts to reduce the range of cues that are used. For some tasks the reduction in the range of cue utilization improves performance since irrelevant cues are excluded. In other tasks, however, where good performance requires the use of a wide range of cues, this reduction in cue utilization is detrimental to performance.

Janelle, Singer and Williams (1999) recently investigated these ideas in an auto-racing simulation study. Their results indicated that at higher levels of anxiety the identification of lights in the periphery became slower and less accurate. These findings are consistent with the idea that an internally experienced emotion (anxiety) reduced perception of cues in the environment. Other researchers have examined the effects that result from demanding cognitive tasks carried out in the context of driving. In a driving simulator study, Parkes and Hooijmeiher (2000) reported that drivers reacted significantly more slowly to an unexpected event during a telephone conversation. They attribute their findings to a reduction in situation awareness that is due to the level of concentration demanded by the phone conversation while they drove. In an on-road study Recarte and Nunes (2000) examined the effects of performing concurrent cognitive tasks on drivers' eye fixations. An experimenter in the vehicle interacted with the driver asking them to perform verbal and spatial-imagery tasks. They reported that drivers' visual functional-field was reduced vertically and horizontally (especially for the spatial-imagery task). In addition, fixations were longer during the spatial-imagery task and glance frequency at mirrors and the speedometer decreased.

Taken together these studies provide support for the idea that the nature of a cognitive task that is being carried out while driving could have a significant impact on drivers' behavior. Although a hands-free device frees the driver from having to manually operate and look at a device while using it, the cognitive demand associated with its use could still be considerable. These effects could arise from the cognitive demand of performing the task and/or the emotional content of the transaction.

One of the most important activities a driver must perform in the constantly changing driving environment is the determination of when and how hard to brake. Braking decisions are based on drivers' assessments of speed, distances and angles, as well as other factors relating to driving (Newcomb, 1981). Vision provides essential input for braking decisions (Lee, 1976). In order to make appropriate braking decisions, drivers must be actively engaged in the monitoring, gathering, and synthesis of appropriate information from the environment. When a driver is distracted by an in-vehicle task, the resulting inattention to driving may reduce or delay the driver's ability to estimate these parameters and consequently delay the decision of when braking should begin. In a test track study, Hancock, Simmons, Hashemi, Howarth, and Ranney (1999) had drivers drive while performing an in-vehicle task that required drivers to respond using a touch screen. When the distracting in-vehicle task was present, slower brake response times to a change in a traffic light were observed. An additional finding was that once having realized the light had changed, drivers braked more intensely in an attempt to compensate for delayed detection. Irwin, Fitzgerald, and Berg (2000) also reported a delay in reaction times in a mockup of braking behaviour when participants were engaged in a wireless telephone conversation.

2. PURPOSE AND SCOPE OF THE STUDY

Driver distraction is recognized as one of the most common causes of traffic crashes. The goal of the present study was to directly investigate the impact of cognitive distraction, the sort that might arise in the course of using hands-free in-vehicle communication devices, on driving behavior in a real world setting, on-road and in city traffic. The tasks required of the drivers were relayed entirely using the technology, not by interaction with a person in the vehicle. Interactions using the in-vehicle device (cell phone) were completely hands-free; drivers did not have to look at the display or manually adjust it. The level of cognitive distraction was manipulated by having the drivers perform tasks at three levels of cognitive complexity.

Measures of three types of driver behavior were collected: visual behavior, vehicle control (as indicated by braking behavior), and drivers' subjective assessments of workload, safety, and distraction. Drivers' eye movements were recorded while they drove to assess any changes in visual behavior that might arise as a consequence of performing the cognitive tasks. Drivers' braking behavior was recorded reflecting its importance in vehicle control. Previous research by Hancock et al. (1999) suggested that drivers would demonstrate more incidents of hard braking when they were distracted than when they were not. Finally, in an effort to assess how well drivers monitor the effects of using these devices on their driving performance, subjective evaluations for workload, safety and distraction were collected for the various task conditions. Concerns have been raised that drivers may not realize when in-vehicle tasks are distracting and as a result, they may not compensate by modifying the task or their driving behavior (e.g., Boase, Hannigan, & Porter, 1988). A description of the research plan for the present study (Harbluk, Noy, & Eizenman, 2000) appeared as part of the NHTSA Driver Distraction Internet Forum held during the summer of 2000.

3. METHOD

3.1 Participants

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

3.2 Equipment

3.2.1 Vehicle & Cell Phone

Participants drove a 1999 Toyota Camry (owned and maintained by Transport Canada) equipped with an additional safety brake on the front passenger side where the experimenter was seated. The driver side airbag was deactivated for the duration of the study. The vehicle was equipped with a Micro-DAS data collection system which is capable of recording a number of driving performance parameters including lateral and longitudinal acceleration, steering wheel angle, brake activation, and lane position (Barickman & Goodman, 1999).

A Nokia model 5160 cell phone was used complete with microphone (attached to upper left A-pillar) and a speaker (mounted under the dash). It remained in the cradle (Nokia car kit) mounted to the right of the console, which is the typical location, for the duration of the study.

3.2.2 Eye Tracking System

While driving, participants wore a portable eye tracking system (VISION 2000; EL-MAR Inc) as shown in Figure 1. The unit is lightweight (300 gms) and is fitted with a visor (70 gms) to filter IR, the visual effect of which is comparable to wearing sunglasses. The unit does not restrict head movement and does not interfere with vision to the front or periphery (Eizenman, Jares, & Smiley, 1999).

The portable eye-tracking system includes a head-mounted eye-tracking unit with a scene-camera, a main-processing unit and a video recorder. The head-mounted portion of the eye-tracking system includes two IR light sources that illuminate the eye, a shatterproof plastic beam-splitter that is located below the line of sight and redirects the reflected IR light to a CCD camera that is located above the eye. The eye-tracking system uses the difference between the pupil-center and two corneal-reflections (the virtual images of the two light sources) to measure horizontal and vertical eye-position. The system can measure eye-movements up to +/- 45 degrees horizontal (H) and up to +/- 35 degrees vertical (V). The system estimates eye-position 120 times/sec and has resolution of better than 0.2 degrees. The accuracy of the system is better than +/- 0.5 degree for the central visual field (+/- 15 H and V) and decreases to +/- 1 degree at the limits (Wetzel, Poprik, & Bascom, 1996).

FIGURE 1. PARTICIPANT WEARING EYE TRACKING SYSTEM

In the main-processing unit the horizontal and vertical coordinates of eye position are converted to the movements of a cursor that is electronically combined with imagery from a miniature color scene camera. The combined imagery and the cursor position are recorded to videotape. The miniature scene-camera (Elmo, Nagoya, Japan, Model CC421E) has a large field-of-view (92.1^{o} (H) * 69.1^{o} (V) degrees) and is mounted level with the eyes 2 cm to the right of the right eye.

3.3 Design & Procedure

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

After a brief description of the procedures and what to expect, the consent form was completed. Driver information was collected consisting of driving history (year license obtained, annual km driven, insurance information) as well as name, age and address. The participant, the experimenter and research assistant then drove to the start of the route. Prior to the actual recorded drive, the participant received instructions concerning the specific procedure, the tasks, and the eye tracker. The participant wore the eye tracker (uncalibrated) and drove a practice route for approximately 15 minutes in order to become acquainted with the vehicle, eye tracker, and the tasks required. There was a brief break during which the participant removed the eye tracking system.

After the break, the eye tracker was calibrated on the participant. During the calibration procedure the subject was instructed to look at 10 points on a chart that was positioned 60 centimeters in front of the subject. At the end of the eye tracker calibration routine, the subject was instructed to look at three points outside the vehicle (approximately 5 meters from the subject's eye) for a scene-camera alignment routine. During the alignment routine the eye-position cursor was adjusted to coincide with the position of the fixated point on the imagery from the scene-camera.

The test route was a 4 km stretch of a busy 4-lane city road on which the driver drove north and south for a total of 8 km per condition. The posted speed limit was 50 km/h. Each participant completed three runs, each under one of following task conditions: easy addition (e.g., 6+9), difficult addition (e.g., 47+38) or no additional task. A research assistant at a remote location conversed with the driver using the cell phone, asked the addition questions and recorded the answers. After each run, there was a brief break (5-10 minutes) during which the eye tracking unit was removed. During this time the participant had a rest break and completed a modified version of the NASA-TLX (Hart & Staveland, 1988) to assess workload and answered additional questions about driving safety and distraction with respect to the session they just completed. This procedure was repeated for the three drives that each participant drove.

At the conclusion of the test trials, each participant was interviewed to solicit their opinions about perceived safety, whether they felt their driving behavior was influenced by the tasks and what behaviors, if any, they intentionally altered as a result of the task conditions.

3.3.1 Data Reduction Procedure for Eyetracking Data

Data from the videotape were analyzed by an automated fixation analysis software package (FAST, EL-MAR Inc.). The automated analysis system provides two streams of statistical data. The first is associated with eye movements and pupil dynamics (i.e., saccades, pupil-diameters, blinks) while the second is associated with the fixation behaviour on objects in the participant's field of view. For each participant the data for the drive in each condition were segmented so that periods where the car was stationary were not included in the analysis. Each of these time intervals began 5 seconds after the car started to move and ended 5 seconds before the car stopped.

The number and amplitude of saccades made by drivers while they performed the different tasks were calculated. These data were calculated for 5-second intervals within the driving segments. Saccades were detected automatically by identifying eye-movement sequences with absolute peak-velocities that exceed 30 deg/sec. Use of this threshold guarantees that saccadic eye movements with an amplitude of 1 degree will be easily detected (mean peak velocity for 1 degree saccade is 50 deg/sec). For each such sequence the beginning and end of each saccade was determined by the two first zero-crossings to the left and right of the peak-velocity. If the duration of the detected sequence was less than 120 msec (larger than the duration of a 30 degrees saccade) the sequence was identified as a saccade and was included in the statistical analysis. Eye velocity estimates were obtained by differentiating the eye-position data with a 5-point FIR differentiator. The differentiator has a bandwidth exceeding 20 Hz.

In order to determine the elements in a visual scene that are fixated by the participant, the automated analysis system calculates the intersection of the line-of-sight vector with the observed scene. To facilitate this analysis three distinctive reference targets were placed along the car's dashboard in a way that maximizes the probability that for the expected head movements at least two reference targets will appear within the field-of-view of the scene camera in each video.

The analysis procedure starts by manually identifying the reference markers and the objects-of-interest (i.e., left mirror, central mirror, etc.) in a single video frame. The video frame is captured from the recorded videotape by a frame grabber that is part of the FAST system. Following this initial procedure the analysis software tracks automatically the coordinates of the reference targets in all subsequent video frames. Using the reference targets as point correspondences, the automated analysis software calculates the point-to-point mapping between any video frame and the initial one (i.e., the coordinates of the objects-of-interest in each video frame are calculated). Using the calculated boundaries of the objects-of-interest and the eye-position data from the eye-tracker, the system calculates fixation statistics on objects of interest. Fixation time on a specific object is defined as the total time spent within the boundaries of the object. In this study the amount of time spent on the central mirror, left-mirror, right-mirror, dashboard and cell-phone were computed. To study changes in the visual scanning patterns in areas of the forward view the fixation time on the central 15, 25, 35 and 50 degrees portions of the windshield as well as the fixation time in areas of the windshield to the left and to the right of the central 50 degrees were calculated. To study the visual scanning patterns of the roadway in more detail, the central $44^{o} * 20^{o}$ portion of windshield was segmented to a matrix of 55 cells (55 cells of 4*4 degrees) and the fixation-time in each cell of the matrix was calculated. To determine if cognitive load affected the preferred fixation distance or direction in the forward view, the mean eye-position on the windshield, for each of the cognitive tasks, was also calculated.

4. RESULTS

Demanding cognitive tasks may influence drivers' behavior in a variety of ways. In an attempt to capture the complexity of this impact, three categories of dependent measures were gathered: visual behavior, vehicle control (as indicated by braking behavior), and drivers' subjective assessments of workload, safety, and distraction.

4.1 Analyses of Driver Visual Behavior

Several types of analyses were made of drivers' visual behavior while driving under the three task conditions. First, comparisons of saccadic eye movements under the different task conditions were examined. Next, calculations were made of the percentage of time drivers spent looking at the area directly ahead (the Central 15 ° of the windscreen) and to the left and right peripheral areas, as well as the percentage of time drivers spent looking at specific locations (instruments, rear view mirror, left mirror, and right mirror). Finally, to provide a more detailed characterization of the changes in visual behavior that result from increased cognitive demand, density plots were constructed depicting the amount of time spent by drivers in areas of the forward view.

4.1.1 Analyses of Saccades

Saccades are high-speed ballistic eye movements that facilitate exploration of the visual field. Comparisons were made of the mean number of saccades per 5 second interval made by drivers in the different driving conditions.

As can be seen in Figure 2, drivers made significantly fewer saccadic eye movements as the cell phone task increased in cognitive demand ($F_{(2,40)} = 7.27$, $p < .002$). The mean number of saccades was significantly lower in the difficult addition condition (6.72) than either the easy addition (7.42) or the no task (7.53) condition ($ps < .003$). Although the participants made numerically fewer saccades in the easy addition condition compared with the no task condition, this difference was not reliable ($p > .05$).

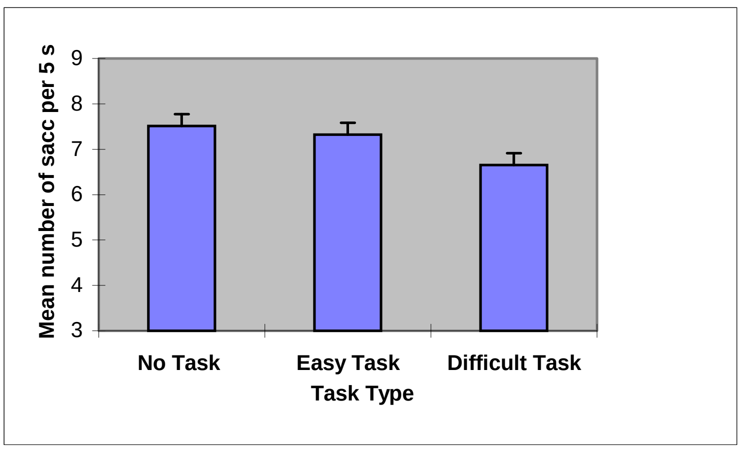

FIGURE 2: MEAN NUMBER OF SACCADES PER 5 S INTERVAL (+SE)

When the performance of individual subjects was examined, it was found that 15 of the 21 subjects showed the numerical decrease in the number of saccades for the difficult addition condition compared with the no task condition.

4.1.2 Percentage of Time Spent Looking at Central and Peripheral Area of Forward View

Previous research has suggested that as workload increases there is a tendency towards "attentional narrowing" or "perceptual tunneling" where there is an increase in time spent looking straight ahead and a concomitant reduction in detection of peripheral stimuli. Miura (1990) has reported this type of effect as a consequence of an increase in demands posed by the complexity of the driving environment in an on-road study. Janelle, Singer, and Williams (1999) reported a similar effect in a simulation study where they manipulated the anxiety levels of the participants. They found that participants who were highly anxious experienced an altered ability to acquire peripheral information at the perceptual level. They interpret their findings in terms of Easterbrook (1959) who posited that emotional arousal acts to reduce the range of environmental cues that are used.

FIGURE 3: PHOTO OF FORWARD DRIVING VIEW AND AREAS TO RIGHT AND LEFT

In the present study an examination was made of the changes that might occur when drivers are engaged in a cognitive source of distraction while driving. Figure 3 provides an example of a driver's forward view and depicts the areas of interest. The central area (Central 15°) represents the area directly in front of the vehicle in the same lane. The Left and Right Areas are those that extend to the left and right beyond the central 50°. Because drivers drove consistently in the leftmost of the two lanes, the area to the left represents oncoming traffic to a large degree. The right area represents the lane to the right of the one in which the participants drove.

Table 1 presents the mean percentages of driving time spent looking centrally ahead and to the more extreme left and right areas (as shown in Figure 3) while driving and performing the cognitive tasks. These percentages are based on the time spent looking in the area of interest divided by the total time for which there is eye tracking data available in the condition of interest. (Percentages do not sum to 100 since not all areas are included.)

	Left Periphery	Central 15°	Right Periphery
No Task	.73	78.63	2.09
Easy Task	.65	80.84	2.19
Difficult Task	.55	82.68	1.56

TABLE 1. PERCENTAGE OF TIME SPENT LOOKING AT CENTRAL AND PERIPHERAL REGIONS

The data for the Central 15° area indicate that drivers spent more time looking directly ahead as the task demands increased ($F_{(2,40)} = 3.62$, $p=.03$), consistent with idea of attentional narrowing. Post hoc analyses revealed only the difference between the No Task and Difficult Task conditions to be significant. ($p<.04$). An examination of the individual performance of the drivers revealed that this increase ranged from 13% to 38% for 6 of the 21 drivers based on percent increase relative to the No Task Condition. What is clear from this analysis is that the shift from No Task to a Difficult Task resulted in an increase in time spent looking through the central area of the forward view.

Analyses of the time spent looking in the Left Peripheral Area revealed a numerical reduction in percentage of time spent in these areas as a consequence of increasing task difficulty but none of the pairwise comparisons approached significance (ps.>05).

In the Right Peripheral Area, drivers spent less time looking to the right as the cognitive task became more demanding ($F_{(2,40)}= 3.17$, $p=.05$). Post hoc comparisons revealed that drivers spent less time looking at the Right Peripheral Area in the Difficult Task compared with the Easy Task ($p<.02$) and the No Task Conditions ($p<.05$). When the individual performance of the drivers was examined, 14 of the 21 drivers showed a reduction in the amount of time spent looking in the right periphery. For eight of the drivers this difference represented a reduction of 70% or more (based on % decrease from No Task Condition) in time spent. For one of these drivers there was a 100% reduction, indicating that he did not look at all at this area when doing the Difficult Task and driving.

In sum, drivers spent more time looking straight ahead when performing demanding cognitive tasks while driving, consistent with the idea of a narrowing of the visual inspection area due to cognitive distraction. As a corollary, they spent less time looking to the periphery, but this effect was asymmetrical and observed only for the area to the right. The lack of difference for the area to the Left may be due to the relatively small percentage of time spent in that area even under the No Task condition. The area to the left represented a relatively less demanding driving environment (a median was present for some of the route) relative to the area to the right where drivers had to monitor the traffic more closely for events such as passing vehicles and vehicles changing lanes. It is worth noting for some individuals the change (increase/decrease) in viewing time was considerable.

4.1.3 Percentage of Time Spent Looking at Instruments and Mirrors

Analyses were made of the percentage of driving time that subjects spent looking at the instruments and mirrors. The data in Table 2 represent the mean percentage of time that drivers spent looking at those particular areas while driving in each of the three task conditions. (Percentages do not sum to 100 since not all areas are included.)

	Instruments	Rear View Mirror	Left Mirror	Right Mirror
No Task	1.48	1.56	.24	.13
Easy Task	1.18	1.36	.28	.11
Difficult Task	.63	.91	.18	.11

TABLE 2. PERCENTAGE OF TIME SPENT LOOKING AT INSTRUMENTS AND MIRRORS

There was a general tendency for drivers to spend less time looking at these areas as the task difficulty increased. Planned comparisons indicated a significant reduction in the percentage of time spent looking at the Instruments and the Rear View Mirror as task difficulty increased. These differences were significant in the comparisons between the No Task Condition and the Difficult Addition Condition for both the Instruments ($p < .001$) and Rear View Mirror ($p \leq .05$) areas. In the analysis for the Instruments, there was also a significant reduction in time spent viewing the instruments when the Difficult Addition condition was compared to the Easy addition condition ($p < .001$).

For both the Left and Right mirrors, there was a tendency for drivers to spend less time looking at these areas as task demands increased. None of these comparisons reached significance, however.

Table 3 provides data on the number of drivers who did not monitor specific areas while driving under the various task conditions. All drivers looked at the Instruments and Rear View Mirror when they were not required to do any additional tasks while driving. There was a tendency for some drivers to shed the tasks of viewing the Instruments and mirrors as the cognitive load increased. 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.

	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 3. NUMBER OF DRIVERS WHO DID NOT LOOK AT THESE AREAS

4.1.4 Percentage of Time Spent in Areas of Forward View

In order to provide a more detailed characterization of drivers' gaze behavior as a function of cognitive task, the forward driving view (44°) was segmented into a matrix of 55 cells (11 in the horizontal plane and 5 in the vertical). An example of the forward view with the superimposed matrix is provided in Figure 4.

FIGURE 4: FORWARD DRIVING VIEW WITH SUPERIMPOSED MATRIX

Summaries were made for each driver of the percentage of time spent in each cell of the matrix during the No Task and the Difficult Addition conditions. The decision was made to examine these two conditions because they represented the conditions of greatest change.

The patterns of change in visual behavior that occurred as a function of cognitive task were not homogeneous. It was noted that participants seemed to exhibit one of three types of change. As a result, drivers were categorized into groups based on the type of change they exhibited in their visual gaze behavior when their data from the Difficult Addition Condition was compared to their data from the No Task Condition (baseline). Three main groups of drivers emerged: those who looked down (n=5), those who looked up (or up and to the left; n=8) and those tended to look centrally or showed no particular pattern (n=8). Illustrative data for subjects who looked Down (Figure 5) and those who Looked Up (Figure 6) are presented below. Locations where the drivers spent more than 3% of their time are colour coded in the matrices.

Findings from previous research present a mixed picture on the question of where drivers look while driving and what the important influences are on this behavior. Early work by Mourant and Rockwell (1972) examining driver skill reported differences between experienced and novice drivers, specifically that novices concentrated their search in a smaller area, closer to the front of the vehicle than more experienced drivers did. Chapman and Underwood (1998) found the opposite, namely that older more experienced drivers generally looked lower down (closer to the front of their vehicle) and that novice drivers generally look further ahead. Recartes and Nunes (2000) recently reported that when drivers were required to perform a mental task of a visual-spatial nature during driving that gaze direction rose.

The inconsistency in the literature points up the need for a better understanding of the relevant environmental variables, secondary task demands and individual driver characteristics and how these might interact to influence driver visual behavior. A consideration of specific task requirements and an understanding of individual differences in the strategies used to perform tasks may prove to be helpful. For example, several drivers in the present study (group that looked up and to the left) reported that they attempted to solve the difficult addition problem by creating a visual-spatial representation of it. They reported looking up and to the left when attempting to solve these problems. These anecdotal reports are consistent with the distribution of gaze as a consequence of cerebral thought processes proposed by Kinsbourne (1974). He reasoned that subjects who were attempting to solve a spatial problem would shift their gaze up or up and to the left and that this would occur as a result of a contralateral shift of gaze from the right hemisphere which was occupied with (spatial) processing. Researchers have noted that there are individual differences in the strategies used to solve arithmetic problems (Geary & Wiley, 1991). Thus, the interaction of the chosen strategy to perform the addition task, skill at the task and driving and working memory ability (Baddeley, 1981) may all contribute to the observed individual differences in visual behaviour that are observed when people are occupied with cognitive tasks while driving.

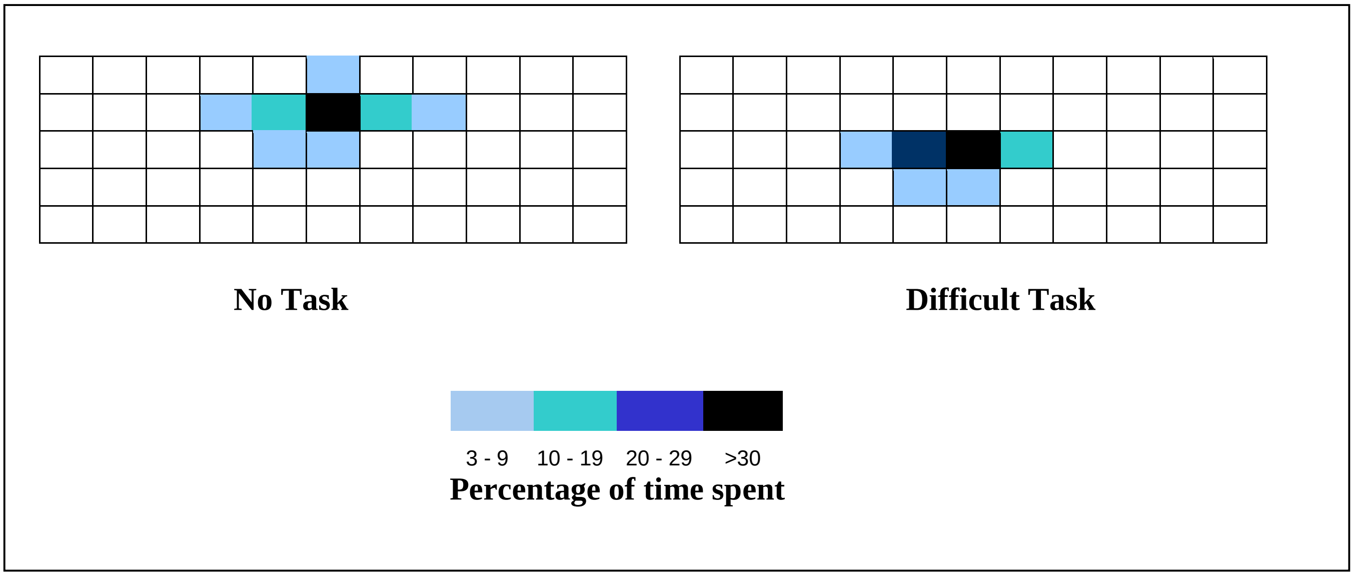

Figure 5. An example of a participant from the Look Down Group, No Task and Difficult Task Conditions

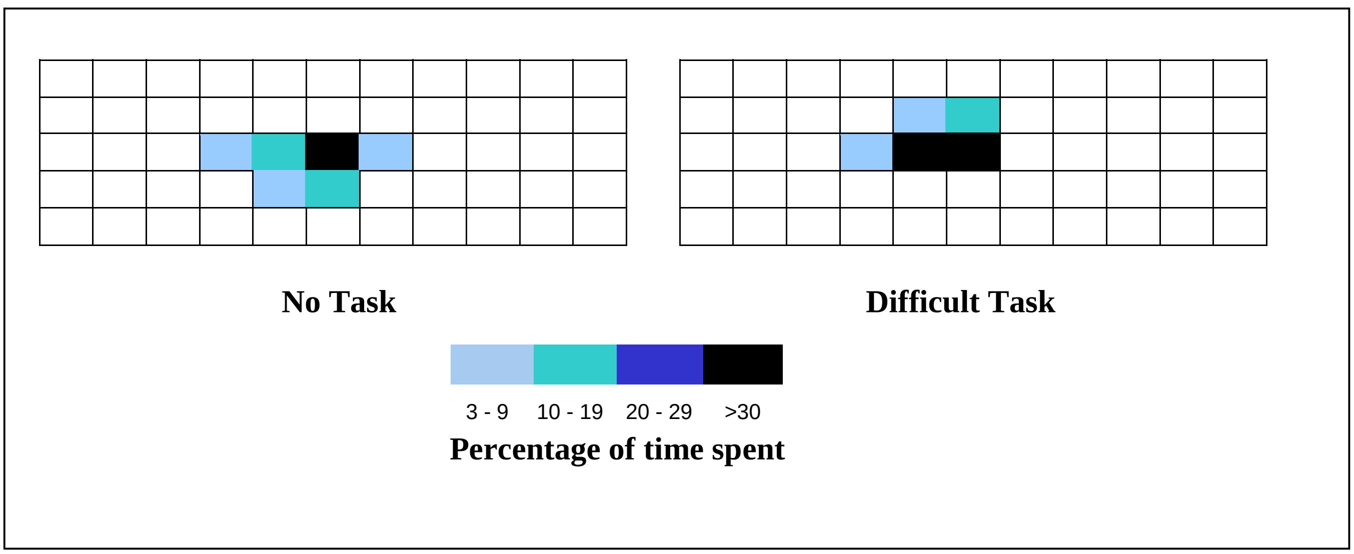

Figure 6. An example of a participant from the Look Up Group, No Task and Difficult Task Conditions

In sum, two things are apparent from the current data. The first is that drivers do change their patterns of visual behavior as a result of performing demanding cognitive tasks while driving. The second is that there are clearly individual differences in the patterns of visual change exhibited by drivers which may be a result of strategy used to perform the tasks.

4.1.5 Mean Vertical Gaze

An examination of the mean vertical gaze data was performed based on the groupings of subjects described in the previous section. This analysis, looking specifically at the difference in mean Y location between the No Task condition and Difficult Addition condition (which provides the best comparison) revealed, that for some drivers, there were appreciable differences in visual behavior across the task conditions. For the group of drivers who tended to shift their gaze downward during the difficult task, the mean shift in vertical gaze was 2.30 degrees. For some drivers the shift downward in gaze was as great as 4.41 degrees. For the group who tended to shift their gaze upward the mean shift was 1.28 degrees (as great as 2.13 degrees). A mean shift of .27 degrees was observed for the group who demonstrated no particular pattern or shift. These data provide numerical support for the groupings presented in the previous section based on the examination of the forward field of view. A comparison of mean vertical gaze location for these groups indicated that all pairwise comparisons among the groups were significantly different (all $ts>3.24$, $ps<.05$).

4.2 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. Braking data were available for only 16 of the 21 participants due to MicroDas equipment failures. The longitudinal deceleration rates were sampled at a frequency of 30Hz.

Two separate criterion levels were used to define occurrences of hard braking. The first analysis considered longitudinal decelerations exceeding 0.25g. The second analysis used a more stringent criterion, decelerations exceeding 0.30g. The categorization schemes were based on previous work indicating that under normal driving conditions only about 10% of all decelerations exceed 0.25g and less than 3% exceed 0.30g (Mortimer, Segel, & Dugoff, 1970), indicating that these are relatively rare events. The vast majority of the hard braking events (85%) took place at signalized intersections.

Figure 7 displays the mean number of braking events exceeding 0.25g that occurred in each of the three task conditions. There was a total of 291 braking events in this category. Their occurrence increased across the task conditions with a mean occurrence of 5.06 in the No Task condition, 6.31 in the Easy Task Condition and 6.88 in the Difficult Task Condition. Planned comparisons revealed that a significantly greater number of these braking events occurred in the Difficult Task Condition compared with the No Task condition ($t_{(15)} = 2.40$, $p<.05$). Although the number of braking events in the Easy Task Condition (6.31) exceeded those in the No Task Condition (5.06), this difference only approached significance ($t_{(15)} = 1.66$, $p=.06$). Twelve out of the 16 participants showed an increase in the number of hard braking events when driving and performing an additional task (easy or difficult addition) compared to driving with no additional task.

The use of the 0.30g criterion resulted in a total of 143 hard braking events across all participants. These data are also displayed in Figure 7. As in the previous analysis, an increase in the number of these events occurred as task demands increased. There was a mean occurrence of 2.38 events in the No Task condition, 3.25 in the Easy Task Condition and 3.38 in the Difficult Task Condition. Planned comparisons indicated that the number of braking events increased significantly from no task to easy addition and from no task to difficult addition (all $ts_{(15)} >1.77$, $p<.05$). In this analysis, 11 of the 16 participants showed an increase in hard braking events when performing additional tasks (easy or difficult addition) while driving compared to driving with no additional task.

Regardless of the criterion used to determine the braking events, the incidence of the braking events increased when drivers performed demanding cognitive tasks while driving. Additional analyses are planned to investigate the incidence of braking in general and the patterns of braking as a function of Task at signalized intersections and following other vehicles.

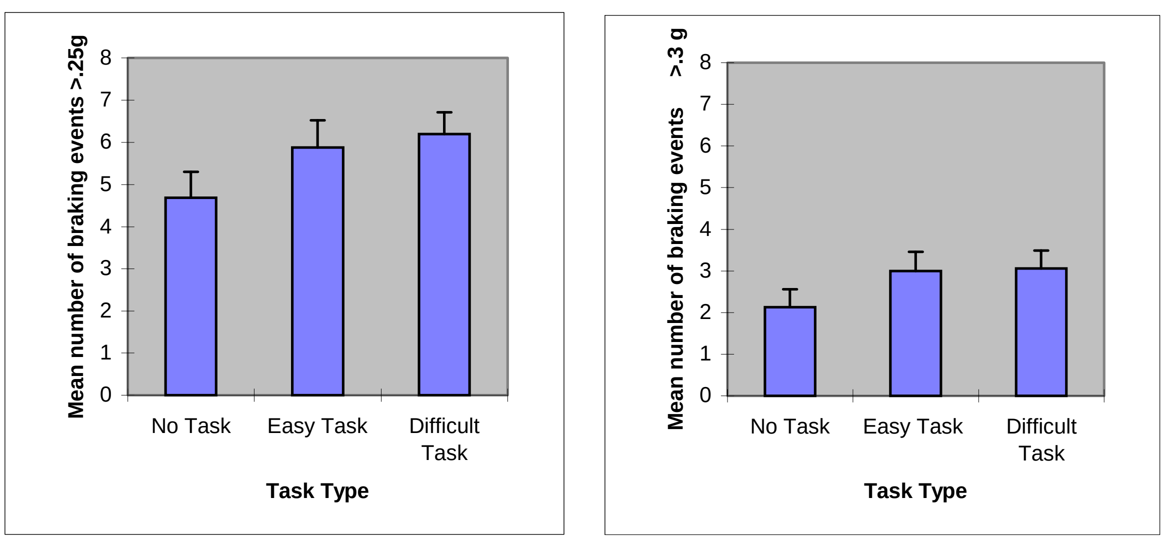

FIGURE 7: MEAN NUMBER OF BRAKING EVENTS EXCEEDING 0.25G AND 0.30G (+SE)

4.2.1 Relation Between Visual Behavior & Braking Performance

Visual information is considered to be an important determinant in the decision of when and how hard to brake (Lee, 1976). An effort was made with the present data to explore the relation between the changes that occur in visual behavior when performing demanding cognitive tasks while driving and the occurrence of hard braking events.

Data were examined for the 16 subjects for whom both eye tracking and braking data were available. More hard braking events (M=2.75) were observed for those participants who looked down (n= 4) and those who looked up (M=1.00, n=6) during the Difficult Task compared with those who showed less change in visual behavior (M= -.17, n=6). Nonparametric tests (Mann-Whitney U Test) revealed the difference between the downward looking group and the group that showed little change to be significant ($p < .03$). Taken together these data suggest that drivers who show the greatest change in visual behavior as a result of performing the additional task tend to brake harder more often.

4.3 Workload Ratings and Ratings of Safety Reduction and Distraction

Figure 8 displays the effects of cognitive task complexity on ratings of workload, perceived reduction of safety and distraction. Ratings for the six scales of the NASA TLX were combined using equal weighting to produce a composite NASA TLX score. Higher rating numbers indicate higher levels of workload. The NASA TLX data indicated that as the complexity of the cognitive task increased, so did the perception of workload. Mean ratings of workload were 1.94 (SD=.87) for No Task, 3.55 (SD=1.62) for Easy Task and 5.73 (SD=1.33) for Difficult Task Conditions ($F_{(2,40)} = 74.15$, Mse = 1.02, $p < 0.0001$). Significant differences in workload were found for all comparisons among the three conditions $ps < .01$).

Ratings of safety were also affected by the nature of the cognitive task. Here higher ratings on the safety scale indicated that drivers felt less safe. As cognitive task complexity increased, drivers rated their driving as less safe. The mean safety ratings were 1.64 (SD=.67) for No Task, 3.40 (SD=2.04) for Easy Task and 4.60 (SD=2.40) for Difficult Task Conditions ($F_{(2,40)} = 16.43$, Mse = 2.82, $p < 0.0001$). All comparisons of means for the safety ratings were significantly different ($ps < .01$).

Finally, drivers reported increasing distraction as the cognitive task complexity increased across conditions. Higher ratings indicate more distraction on this scale. Mean ratings of distraction were 1.45 (SD=.59) for the No Task, 4.79 (SD=2.12) for the Easy Task and 6.74 (SD=2.03) for the Difficult Task Conditions ($F_{(2,40)} = 67.20$, Mse = 2.23, $p < 0.0001$). All pairwise comparisons of means were significantly different ($ps < .01$).

In sum, the impact of increased task complexity was clearly reflected in the drivers' ratings for the three types of measurements: workload, safety and distraction.

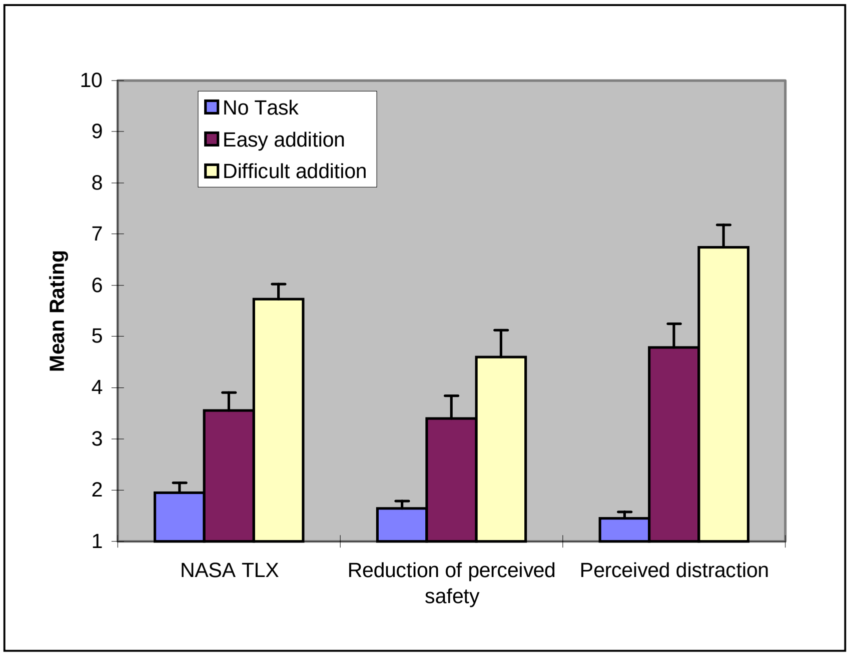

FIGURE 8. THE EFFECT OF COGNITIVE TASK COMPLEXITY ON RATINGS OF WORKLOAD (NASA TLX), SAFETY REDUCTION AND DISTRACTION (+SE)

5. DISCUSSION & CONCLUSIONS

The purpose of this study was to examine the impact of cognitive distraction on drivers' visual behavior and vehicle control. Previous studies have looked at the impact of external demands due to environmental complexity (e.g., Miura, 1990) and distractions created by manual manipulation of devices in the vehicle (e.g., Hancock et al, 1999). Our interest was in the type of distraction created by the performance of demanding cognitive activities, the sort that might result when drivers interact with in-vehicle devices using speech control or converse using hands-free in-vehicle devices. The arithmetic problems were presented to the drivers over the cell phone and drivers responded by cell phone, all in hands-free mode. Drivers drove in city traffic responding to the questions while their eye movements and vehicle control were monitored.

The performance of a demanding cognitive task while driving produced changes in the drivers' visual behavior, vehicle control (as indicated by braking behavior), and subjective assessments of workload, safety, and distraction. Drivers' visual behavior changed in several important ways. Drivers made fewer saccades per unit time, consistent with a reduction in glance frequency and less exploration of the driving environment (see also Recartes & Nunes, 2000). They spent more time looking centrally and less time looking to the right periphery. Less time was spent checking instruments and mirrors, and in some cases drivers shed these tasks completely and did not check these areas at all. With the increased cognitive demand, many drivers changed their inspection patterns of the forward view. Over half of the drivers showed an appreciable change in their forward view patterns compared with when they drove with no additional task. Importantly, it was observed that not all drivers changed their visual inspection patterns in the same way. Clearly, there are individual differences in the type of visual behaviour changes that arise as a result of performing cognitive tasks while driving. Further studies of specific task requirements and a better understanding of individual differences in the strategies used to perform such tasks would be useful in understanding these performance differences.

The relationship between driver visual behaviour and driving safety is an important one. Wierwille and Tijerina (1998) devised a model that relates eye glance behaviour to crash rates. Their work incorporates the visual requirement (glance length and number of glances) for the use of in-vehicle devices where driver attention is taken from the road to the interior of the vehicle. This information is incorporated with the frequency of in-vehicle device use to predict crash rates.

The current study, in contrast, focused on cognitive distraction, which although it does not require drivers redirect their visual attention to the interior of the vehicle, is distracting none the less. To the extent that a device or activity that is distracting is performed more often while driving a concurrent increase in risk would be expected. Indeed, Goodman et al. (1999) have made the argument that the perceived safety associated with using a hands-free unit over a hand-held phone may result in an overall increase of cell phone use while driving. The switch from hand-held to hands-free may increase the use of cell phones (number of calls, duration of calls) while driving for those drivers who already use cell phones due to the apparent increase in safety. This perceived improvement in safety may also convince previous non users to use cell phones while driving. The increase in use among the driving population could lead to an increase in crash risk.

Significant changes were observed in drivers' vehicle control as a consequence of performing the additional cognitive tasks while driving. There was an increased incidence of hard braking during the condition where the drivers performed the difficult task. As well, when the visual behavior of the drivers was related to their braking behavior, it was found that those drivers who demonstrated noticeable changes in their visual behavior had more episodes of hard braking. These findings are consistent with work by Hancock et al. (1999) who reported that drivers, distracted by a manually controlled in-vehicle task while driving on a test track, braked more intensely to compensate for later detection of events in the environment. In the present study, however, drivers were not distracted by the requirement of making a manual response; rather the distraction was created by the cognitive task they were performing.

Finally, drivers reported that they were aware of the increased demands placed on them when they performed the additional tasks while driving. This was reflected in their increased ratings of workload and distraction and a reduction in their ratings of driving safety.

The findings of this study are consistent with an explanation that the distracting cognitive task competes for attentional resources. To the extent that attention is directed toward the processing of distracting information (the additional task), the resources available for processing driving-relevant information are reduced and performance decrements are observed. Taken together the results of the present study indicate that performing demanding cognitive tasks while driving has a negative impact on driver visual behaviour and vehicle control. The data are consistent with an explanation that these extra demands on the driver contribute to late detection, reduced situation awareness (Matthews, Bryant, Webb, & Harbluk, 2001) and a reduced margin of safety.

The results of this research contribute to the growing literature documenting the impact of cognitive distraction on driver behavior. Perhaps what is most surprising about the results of the present study is that these changes occurred in a real-world driving context with its strong demands for drivers to pay attention to driving. Other recent on-road work has found that distraction caused by a cognitive task was associated with later detection of lead car deceleration (Lamble, Kauranen, Laakso, & Summala, 1999). In another study, listening and responding to messages was associated with riskier decision making; distracted drivers accepted shorter gaps when making left turns (Cooper, Zheng, Richard, Vavrik, Heinrichs, & Siegmund, 2002). These empirical studies provide data to support epidemiological studies indicating an increased risk of vehicle crashes for cell phone users (Laberge-Nadeau, Maag, Bellavance, Desjardins, Messier, & Saïdi, 2001; Redelmeier & Tibshirani, 1997).

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. Although voice-based technology allows drivers to interact with ITS devices, such as cell phones, while viewing the road and keeping their hands on the steering wheel, the nature of the ongoing interaction could still be a source of considerable distraction. During a casual conversation drivers can adapt by pausing during the conversation or ending the call should the demands of driving increase. Business is commonly conducted using cell phones (McKnight & McKnight, 1991) however, and an intense business conversation could divert a driver’s attention away from the task of driving. An interface may be hands-free, but the conversation itself could be a source of considerable distraction under certain conditions.

The explosive introduction of cell phones into the Canadian market in recent years makes their potentially adverse consequences on traffic safety a matter of urgent public policy. There is accumulating evidence that their use while driving presents considerable risk (e.g., Pachiaudi, 2001). Whereas the use of cell phones while driving comes under provincial jurisdiction, the design and installation of original equipment in the vehicle can be regulated through instruments such the Canadian Motor Vehicle Safety Standards (CMVSS). Regulatory intervention of original equipment will require continued research and public consultation to establish that such intervention is warranted and to determine the nature of regulatory requirements. Although certain provinces are considering legislation to prohibit the use of cell phones (notably hand-held devices) while driving, no jurisdiction has yet enacted such legislation.

A household telephone survey commissioned by Transport Canada in 1997 found that 26 per cent of drivers indicated that they use cell phones while driving (Kiar, 1998). Of these, the majority (78 per cent) use hand-held phones. Eighty-one percent of the respondents indicated they felt that cell phone use poses a safety risk. The results of the present study, consistent with the results of epidemiological and experimental research, point out the need to inform the public about the increased risks associated with the use of cell phones while driving.

It is recommended that a leaflet be developed to inform the public about the serious risks associated with the use of cell phones while driving, to advise the public that the Federal government recommends that cell phones not be used by drivers while driving, to inform the public that hands-free phones are not risk-free, and to provide important safety tips for drivers to consider if they intend to continue to use their phones while driving. It is also recommended that research continue to determine the need for regulating original equipment.

Public awareness of the safety consequences of using in-vehicle ITS devices should be increased to promote better driving habits. If individuals are going to continue to use ITS, then the devices should be designed to reduce the amount of inattention and distraction they cause. Research that improves our understanding of the effects of cognitive distraction on driver behavior should prove to be a useful tool. Such knowledge will contribute toward the improved design of on-board information and communication systems and support the development of government policy in the area.

6. REFERENCES

Baddeley, A.D. (1981). The concept of working memory: A review of its current state and probable future development. Cognition, 10, 17-23.

Barickman, F.S., & Goodman, M.J. (1999). MicroDAS: An in-vehicle portable data acquisition system. Transportation Research Record, 1689, 1-8.

Boase, M., Hannigan, S., & Porter, J.M. (1988). 'Sorry, can't talk…just overtaking a lorry'. In E.D. Megaw (Ed.), Contemporary Ergonomics (pp. 527-532). U.K.: Taylor & Francis.

Chapman, P.R., & Underwood, G. (1999) Looking for danger: Drivers' eye movements in hazardous situations. In A.G. Gale et al. (Eds.) Vision In Vehicles VII. (pp.225-232). Amsterdam: Elsevier.

Cooper, P.J., Zheng, Y., Richard, C., Vavrik, J., Heinrichs, B., & Siegmund, G. (2002). The impact of hands-free message reception/response on driving task performance. In press: Accident Analysis and Prevention.

Easterbrook, J.A. (1959). The effect of emotion on the utilization and organization of behavior. Psychological Review, 66, 183-201.

Eizenman, M., Jares, T., & Smiley, A. (1999). A new methodology for the analysis of eye-movements and visual scanning in drivers. Transport Canada Contract Report. March 1999.

Geary, D.C., & Wiley, J.G. (1991). Cognitive addition: Strategy choice and speed-of-processing differences in young and elderly adults. Psychology and Aging, 6, 474-483.

Goodman, M.J., Tijerina, L., Bents, F.D., & Wierwille, W.W. (1999). Using cellular phones in vehicle: Safe or unsafe? Transportation Human Factors, 1(1), 3-42.

Hancock, P.A., Simmons, L., Hasemi, L., Howarth, H., & Ranney, T. (1999). The effects of in-vehicle distraction on driver response during a crucial driving maneuver. Transportation Human Factors, 1(4), 295-309.

Harbluk, J.L., Noy, Y. I., & Eizenman, M. (2000). The impact of internal distraction on driver visual behavior. Internet Forum on Driver Distraction. Hosted by US DOT NHTSA. http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/1.PDF

Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of experimental and theoretical research. In P.A. Hancock & N. Meshkati (Eds.), Human Mental Workload (pp. 139-183). Amsterdam: North Holland.

Irwin, M., Fitzgerald, C., & Berg, W.P. (2000). Effect of the intensity of wireless telephone conversations on reaction time in a braking response. Perceptual & Motor Skills, 90, 1130-1134.

Janelle, C.M., Singer, R.N., & Williams, A.M. (1999). External distraction and attentional narrowing: Visual search evidence. Journal of Sport & Exercise Psychology, 21, 70-91.

Kiar, S. (1998). Public Perceptions of Road Safety in Canada. COMPAS Inc. Ottawa, Ontario. Transport Canada Contract Report TP 13240 (E), May 1998.

Kinsbourne, M. (1974). Direction of gaze and distribution of cerebral thought processes. Neuropsychologia, 12, 279-281.

Laberge-Nadeau, C., Maag, U., Bellavance, F., Desjardins, D., Messier, S., & Saïdi, A.(2001). Les téléphones mobiles/cellulaires et le risque d'accidents. Centre de recherche sur les transports (C.R.T.). Université de Montréal.

Lamble D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car following situations: Safety implications for using mobile (cellular) telephones while driving. Accident Analysis and Prevention, 31, 617-623.

Lee, D.N. (1976). A theory of visual control of braking based on information about time to collision. Perception, *5,* 437-459.

Lee, J.D., Caven, B., Haake, S., & Brown, T.L. (2000). Speech-based Interaction with In-vehicle Computers: The Effect of Speech-based E-mail on drivers' Attention to the Roadway. Internet Forum on Driver Distraction. Hosted by US DOT NHTSA. http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/27.PDF

Matthews, M.L., Bryant, D.J., Webb, R.D.G., & Harbluk, J.L. (2001). A Model for Situation Awareness and Driving: Application to Analysis and Research for Intelligent Transportation Systems. Transportation Research Record, 1779, 26-32.

McKnight, J. & McKnight. A.S. (1991). The effect of cellular phone use upon driver attention. National Public Services Research Institute.

Miura, T. (1990). Active function and useful field of view in a realistic setting In R. Groner, G. d'Ydewalle, & R. Parham, (Eds.) From eye to mind. Information acquisition in perception, search, and reading (pp.119-127). Amsterdam: North-Holland.

Mortimer, R.G., Segel, L., Dugoff, H., Campbell, J.D., Jorgeson, C.M., & Murphy, R. W.(1970). Brake force requirement study: Driver-vehicle braking performance as a function of brake system design variables. HSRI Report HuF-6, University of Michigan, NTIS Report: PB-193-258.

Mourant , R.R., & Rockwell, T.H. (1972). Strategies of visual search by novice and experienced drivers. Human Factors, 14, 325-335.

Newcomb, T. P. (1981). Driver Behaviour During Braking. SAE Technical Paper Series, 810832.

Pachiaudi, G. (2001). Les risqué de l'utilisation du téléphone mobile en conduisant. Institut National de Recherche sur les Transports et leur Sécurité (INRETS).

Parkes, A. & Hooijmeijer, V. (2000). The influence of the use of mobile phones on driver situation awareness. Internet Forum on Driver Distraction. Hosted by US DOT NHTSA. http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/2.PDF

Recarte, M.A., & Nunes, L.M. (2000). Effects of verbal and spatial-imagery tasks on eye fixations while driving. Journal of Experimental Psychology: Applied, 6 (1), 31-43.

Redelmeier, D.A. & Tibshirani, R. J.(1997). Association between cellular-telephone calls and motor vehicle collisions. The New England Journal of Medicine, 336, 453-458.

Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Stansifer, R. L., & Castellan, N.J. (1979). Tri-Level study on the causes of traffic accidents: Final Report, Volumes I and II. U.S. DOT HS-805-086, (NTIS PB 80-121064).

Wang, J.-S., Knipling, R.R., & Goodman, M.J. (1996). The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. 40th Annual Proceedings of the Association for the Advancement of Automotive Medicine, 377-392 .

Wetzel, P.A., Poprik, C., & Bascom, P. (1996). An Eye Tracking System for Analysis Pilot's Scan Paths, 18th Annual Interservice/Industry training systems, Florida, 534-539.

Wierwille, W.W., & Tijerina, L. (1998). Modelling the relationship between driver in-vehicle visual demands and accident occurrence. In A.G. Gale et al. (Eds.) Vision and Vehicles VI. (pp. 233-243). Amsterdam: Elsevier.

Zaidel, D.M., Paarlberg, W.T., & Shinar, D., (1978). Driver performance and individual differences in attention and information processing, Volume 1: Driver Inattention. Institute for Research in Public Safety, DOT-HS-803 793.

7. AUTHOR NOTES

We wish to thank Jennifer Ferguson for assistance with the experimental set up, Marty Lochner for testing subjects, and Patricia Trbovich and Lisa Massel for assistance with data analysis