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The distraction effects of phone use during a crucial driving maneuver

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Abstract

Forty-two licensed drivers were tested in an experiment that required them to respond to an in-vehicle phone at the same time that they were faced with making a crucial stopping decision. Using test track facilities, we also examined the influence of driver gender and driver age on these dual-task response capacities. Each driver was given task practice and then performed a first block of 24 trials, where one trial represented one circuit of the test track. Half of the trials were control conditions in which neither the stop-light was activated nor was the in-vehicle phone triggered. Four trials required only stop-light response and a further four, phone response only. The remaining four trials required the driver to complete each task simultaneously. The order of presentation of specific trials was randomized and the whole sequence was repeated in a second block giving 48 trials per driver. In-vehicle phone response also contained an embedded memory task that was evaluated at the end of each trial circuit. Results confirmed our previous observation that in the dual-task condition there was a slower response to the light change. To compensate for this slowed response, drivers subsequently brake more intensely. Most importantly, we recorded a critical 15% increase in non-response to the stop-light in the presence of the phone distraction task which equates with increased stop-light violations on the open road. These response patterns varied by driver age and driver gender. In particular, age had a large effect on task components that required speed of response to multiple, simultaneous demands. Since driving represents a highly complex and interactive environment, it is not possible to specify a simplistic relationship between these distraction effects and outcome crash patterns. However, we can conclude that such in-vehicle technologies erode performance safety margin and distract drivers from their critical primary task of vehicle control. As such it can be anticipated that a causal relation exists to collision events. This is a crucial concern for all in-vehicle device designers and for the many safety researchers and professionals seeking to reduce the adverse impacts of vehicle collisions.

Keywords: In-vehicle distraction; Driver performance; Braking response

1. Introduction

Perhaps the most critical question in contemporary driving research concerns the influence of in-vehicle devices on a driver's response capability. The most visible current form of technology to penetrate the driver's world is the in-vehicle telephone. Given the exponential growth in mobile phone sales since its commercial introduction to the US in 1983 and also the propensity for their use in all contexts, the number of times drivers use mobile phones while in motion is clearly growing at a phenomenal rate (Edwards, 2001). What we don't know in sufficient detail is how this use affects driver response capacity and more specifically what the change in collision risk there is given this usage. Given the vast investment in all burgeoning forms of in-vehicle technology and the perennial costs of collision, injury, and fatality this is clearly a critical question and given acceptance of such basic premises, the importance of the present experimental procedure is clearly established.

While new technologies often appeal purely on the basis of novelty, there is a tendency, even in science, to assume that what has gone before does not necessarily apply to newer circumstances since there appear to be so many differences from previous situations. In the present case, this tendency is unfortunate since there have been in-vehicle distractions ever since there have been vehicles. Further, contemporary research has identified the importance of certain distraction demands (e.g. conversation) that are themselves as old as vehicles (see Goodman et al., 1997; Irwin et al., 2000; Manser and Jenkins, 2001; Strayer et al., 2001). One of the earliest controlled empirical studies of in-vehicle communication distraction was conducted by Brown et al. (1969). Constrained to employ hand-held walkie-talkie systems, they used a safe airfield location to evaluate the effect of secondary task performance such as grammatical reasoning (Baddeley, 1968), on driving efficiency. Most importantly, they evaluated communication response during a stressed

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driving maneuver, one of the few existing tests that evaluated performance at a critical decision point. They concluded that some degree of mutual interference was inevitable given that the concurrent demands that were imposed on the driver. This was one of the first experimental demonstrations that the context of driving task demand exerts a critical influence on overall performance outcome. The most comprehensive evaluation of the influence of in-vehicle phone use on driver performance was conducted by the National Highway Traffic Safety Administration (Goodman et al., 1997) and this work has been summarized in an open literature publication (see Goodman et al., 1999). This evaluation concluded that when compared to driving alone, manually dialing a cellular phone can have a deleterious effect on vehicle control, including such activities as lane keeping and speed maintenance (and see also Alm and Nilsson, 1994, 1995; Lamble et al., 1999; McKnight and McKnight, 1993; Serafin et al., 1993; Stein et al., 1987; Zwahlen et al., 1988).

There are many questions yet to be resolved regarding the influence of cell phones on driving performance (see Hove et al., 2000; Violanti, 1997, 1998). These include epidemiological concerns about the exact relationship between phone use and crash occurrence (MacClure and Mittleman, 1997; Redelmeier and Tibshirani, 1997; Violanti and Marshall, 1996) as well as a number of issues in respect of the physical configuration of the phone itself in conjunction with the nature of the vehicle used. We have to be careful in distinguishing between different forms of mobile phone since some are vehicle attached and some are free-standing and different types can be voice activated while others require mandatory manual response. Do hand-activated devices used in manual transmission vehicles cause more interference than hands-free phone in automatic-transmission vehicles (and see Fairclough et al., 1991; Redelmeier and Tibshirani, 1997; Tokunaga et al., 2000; Tokunaga et al., 2001)? There are now technologies specifically designed to alter functional type, i.e. from manual to voice activation. Sales of these devices are founded upon an appeal to drivers of increasing driving safety but is this true? Many of these methodological concerns have been considered in Haigney and Westerman (2001) informative paper (and see Briem and Hedman, 1995; Brookhuis et al., 1991). Yet the degree to which in-vehicle phone use is 'safe' is still unresolved and is the subject of continuing debate which centers around the nature of the driving task itself (Hancock and Ranney, 1999; Hancock and Scallen, 1999; Tijerina, 1999). While the level of adverse influence continues to be debated, most authorities acknowledge at least the potential for erosion in the margin of safety (Kantowitz, 2001). It is possible such influences are contingent upon the specific combination of sensory and effector systems the driver uses for response. Thus a hands-free phone that uses auditory input and vocal output is conceived as being less disruptive to driving which is primarily a visual-manual task. The linkage between attention and dual-task performance disruption has been formalized by Wickens (1980, 1984, 1987) whose heuristic suggests design recommendations concerning the distribution of task load across different processing resources (and see Boer, 2001). From these premises, a number of empirical studies have been directed toward an understanding of what design configurations might minimize interference.

For example, Vollrath and Totzke (1999), confirmed that as driving demand increased with a change from straight to curved roadways, auditory communications proved less disruptive than visual displays. The conception of load distribution can thus be used to disperse demand and it is possible for this to be accomplished in a dynamic manner. The conception of adaptive human–machine systems has now been in existence for over two decades (see Hancock et al., 1985; Hancock and Chignell, 1987; Rouse, 1976). The extension of this idea into the driving realm was embodied in the GIDS Project (Michon, 1993) and has been explored with respect to different driver states beyond task-mediated cognitive workload to issues such as driver fatigue (Hancock and Verwey, 1997). It may well be possible to use this capability to enhance safety (Kantowitz, 2001), rather than the blanket banning of in-vehicle phone use, as has been enacted in law by a number of countries and states within the US (see Jerome et al., 2001; MacClure and Mittleman, 1997).

The central problem with test and evaluation of in-vehicle phone use is that examining performance in non-critical situations is unlikely to reveal the most important facets of performance change. This is because driving is an over-learned task with which individuals often have extensive experience (Groeger, 1999; Groeger and Clegg, 1997). A comparison with beginning driving may be helpful here. Early in the learning process novices are awkward, inept, and often inhibited by their own extraneous actions. Presenting such individuals with any additional information, sometimes even instructions, can induce immediate overload and even panic. As the trainee driver progresses, they 'automate' those skills which provide a high degree of stimulus-response consistency (see Schneider, 1985). After what seems a short period, the learner has evolved into a fully competent driver and passes into the general driving population. The apparent simplicity of normal 'everyday' driving hides two crucial facts. First, normal driving is an interplay of over-learned responses underpinning more cognitively demanding processes. The learner progresses from a tactical, momentary control mode to a longer-term, strategic form of task management. Following such a transition, the driver appears to be able to deal with added or embedded secondary tasks, e.g. radio tuning, talking to passengers, etc. In reality, the driver manages those tasks, shedding load or re-initiating secondary tasks as the primary demands of the driving task fluctuate. In non-critical conditions, it therefore appears that drivers can perform secondary tasks and indeed, as is evident on the roadway, they can and do conduct such activities. However, when emergency situations arise, two hidden problems quickly emerge. First, 'normal' driving skills provide little practice at near-term emergency avoidance maneuvers and even supposedly over-learned capacities are not useful when the stimulus-response mapping is broken by the novel situation presented. Second, as an interleaved sequence of open and closed-loop control, where and when distractions strike the driver in the interplay of control is fundamentally unpredictable. Thus drivers are able to adapt their own control actions when events are directly perceivable, e.g. paying more attention at intersection. However, even experienced drivers may well be taken by surprise when distractions are added to emergency situations.

As such, in normal driving, we see long periods of sub-critical demand interspersed with moments of crucial response, or hours of boredom and moments of terror as it has been termed (Hancock, 1997a). On most journeys, drivers have a number of occasions upon which their full attention must be directed to the driving task in order to be successful. Some of these circumstances may be anticipated before the journey. These include encounters with complex intersections, heavy traffic, etc. Other events such as children running into the road or a tire blow out for example, are by their very nature unpredictable. We hypothesize that the distractive effects of cell phone use on safe driving are thus contingent upon the momentary context of driving. Phone use during undemanding driving periods is accomplished with apparent and seductive ease. However, it is the combined situation of maximum driving demand together with phone usage that represents the most dangerous combinations. We cannot help but note the prevalence of phone use among young inexperienced drivers and indeed driver characteristics, such as skill will themselves play into the over all context. Of course, even the most adverse of circumstances need not necessarily lead to collision. Given the adaptive capacities of most drivers, we expect that even such coincident high demand will only occasionally lead to an adverse outcome. These observations mean that the critical evaluation of the safety effects of in-vehicle phone use must examine driver response at these crucial decision points and it is this we have sought to accomplish as the goal of the present study.

2. Experimental method

2.1. Experimental participants

A total of 42 licensed Massachusetts drivers successfully completed the present experimental procedure. Of these, two participants' data were not included due to evidence that the tasks were not performed correctly and four were not included due to equipment problems resulting in an incomplete data set for each of these individuals. The remaining 36 participants comprised 19 younger (ages 25–36 years) and 17 older (ages 55–65 years) drivers whose details are presented in Table 1. On average, the older participants had just over 40 years of driving experience, while the younger participants had 13 years of driving experience. Gender did not interact with experience level. In terms of experience with mobile phones, there were no overall ownership differences between the age groups, however, within age groups younger males and younger females reported an equivalent level of ownership but older women reported much higher levels of ownership than their male, age peers.

Table 1
Age and gender details of the experimental participants

	Younger		Older	
	Male	Female	Male	Female
Frequency	10	9	9	8
Mean age	31.0 (3.4)	29.1 (3.6)	61.4 (3.5)	58.8 (2.5)
Mean age	30.1 (3.6)		60.2 (3.3)	

2.2. Experimental apparatus

The driving tasks were implemented on a 0.5 mile closed-looped test track, configured to allow continuous driving (see Hancock et al., 1999, Fig. 1). A simulated intersection, located at the end of one straight a-way, was equipped with a traffic signal (Fig. 1). Four pairs of inductive loops, buried in the pavement, monitored vehicle position as it progressed down the straight toward the signal. All participants completed the driving tasks in an instrumented 1991 Ford Crown Victoria with automatic-transmission. The vehicle was equipped with a DATRON optical sensor, used to collect continuous speed data, a brake activation sensor, and a 10 in. flat-panel LCD touch-screen mounted adjacent to the steering-wheel which used to display the image of a cellular telephone which is shown in Fig. 2. A two-way radio allowed communication between the participant driver and the experimenter who monitored performance from the data collection site in the blockhouse facility adjacent to the intersection, as shown in Fig. 1. Computational systems in the blockhouse controlled the activation of the traffic signals and the presentation of stimuli on the simulated cellular phone, while simultaneously collecting all of the performance data.

2.3. Experimental design

During the experiment, participants drove the instrumented vehicle repeatedly around the test track facility. They began at the designated start/stop location that was at the opposite end of the test track from the data collection blockhouse. Each individual drove down the straight section of road toward the intersection, then via the return loop, they retraced their path to the start/stop location. They were instructed to maintain a speed of 25 mph on the approach to the intersection and to use the two-way radio only when the vehicle was stationary. The experiment consisted of four tasks. Instruction and training was provided for each task and participants completed 12 practice trials before beginning the experimental sequence. Performance data

Fig. 1. View of the test vehicle on the track approaching the stop-light. Directly below the light stanchion is the controlling blockhouse with other test vehicles behind.

were collected during the experiment, but no feedback was provided to participants until they had completed the whole experiment consisting of two, 24 trial blocks. The tasks in the present experiment were as follows.

1. *The number memorization and recall task*: At the beginning of each trial, while the vehicle was stationary at the starting location, a seven-digit phone number was presented on the simulated cellular phone display as a preliminary loading task. Participants were instructed to memorize the phone number and then press a button to indicate they were ready to begin driving toward the intersection. At the end of each (trial) lap, when the vehicle had stopped at the same location, participants were asked to enter the memorized number into the simulated cellular phone using the keypad on the touch-screen. For this task, the dependent variable was recall accuracy (RA).
2. *The distraction (cell phone) task*: On one-third of the trials, as the vehicle approached the intersection, a tone sounded and a digit appeared on the simulated cellular phone display. For these trials, participants were instructed to press a key on the simulated phone pad to indicate whether the digit was the same or different from the first digit of the phone number presented as the memory set at the start of the trial. Analysis was subsequently performed on both response time and response accuracy for this task.
3. *The stopping task*: On one-third of the trials, as the vehicle approached the intersection the traffic signal changed from green to red. For these trials, participants were instructed to stop the vehicle as quickly and as safely as possible before reaching the stop line in front of the intersection. The primary dependent measure for the stopping task was stopping distance (SD) which represented the distance from the front of the driver's vehicle to the stopping line at the intersection after the vehicle had reached a complete halt. We also assessed brake response time (BRT) and stopping time (ST) as measures of driver reaction.

Fig. 2. Schematic representation of the in-vehicle phone display. Shown in the upper portion is the initially presented seven-digit memory.

The experiment consisted of two blocks of 24 trials. For each block, there were four conditions, based on the presence or absence of the distracter and stopping tasks during the approach to the intersection. The order of conditions was randomized within each block. The memorization and recall task was performed on every trial. The four conditions were described as follows.

(a) *Control condition*: Neither the distracter nor stopping task was presented (12 trials).

(b) *Distracter only condition*: Only the distracter task was presented (four trials).
(c) *Stopping only condition*: Only the stopping task was presented (four trials).
(d) *Distracter and stopping condition*: Both the distracter and stopping tasks were presented (four trials).

In the latter condition, the stop-light was activated after a randomized delay ranging between 0.5 and 1.0 s following the onset of the distracter task. Specification of this range of onset times was derived from the results of previous experimentation (Hancock et al., 1999). Calculation of all response times took account of this differential onset and recorded response from the beginning of each respective stimulus presentation.

In order to encourage accurate and efficient response on behalf of each participant, we instituted a reward/penalty structure that followed our previous experimental procedure (see Hancock et al., 1999). Briefly, drivers were rewarded with a 10 cent bonus for each correct response on the memory recall task and 10 cent for each correct response to the distracter presentation. Further, they were given a US$ 1 bonus for correctly stopping before the line in the stopping condition. Penalties were comparable such that drivers lost 10 cent for incorrect responses on the memory recall task and the distracter task and lost US$ 1 for passing over the line in the stopping condition. Further, individuals were penalized 50 cent for brake activation in the absence of red light activation, essentially a false alarm. Participants could not lose money overall and almost all drivers ended up with a positive balance at the end of testing.

3. Experimental results

In the present experiment, there were seven principal dependent measures. Four of these measures, BRT, ST, SD and stopping accuracy (SA) had to do with the longitudinal control of the vehicle, a further two, distracter response time (DRT) and distracter response accuracy (DRA) reflected performance on the distraction task, while the final measure, RA reflected on-going, short-term memory capacity. The following results are partitioned according to these sequential dependent measures. Analysis was performed across the independent variables of driver age, driver gender, and repeated blocks of driving trials. Analyses of variance (ANOVAs) were computed individually for each of the performance measures using SPSS (version 10.1).

Participants were instructed to maintain a speed of 25 mph. Approach speed was defined as the mean speed traveled during a 2 s interval approximately 3 s after the participant reached the beginning of the straight section of roadway that was the approach to the stop-light location (see Fig. 1). This time period corresponded to the interval just prior to the earliest possible distracter presentation time. This measurement was automatic and drivers were oblivious to its presence. An analysis of variance of approach speed as a function of age and gender indicated that younger participants approached the intersection at a faster speed ($M = 26.7$) than did older participants ($M = 25.4$); $t(33) = 2.21$, $P < 0.05$. However, approach speed was not significantly different for males ($M = 26.5$) and females ($M = 25.6$); $P = 0.12$. As approach speed might vary as a function of participant and experimental condition, mean approach speed was calculated as described earlier for each participant-experimental condition combination and was included as a covariate in all analyses. By including approach speed as a covariate, it is possible to partial out any potential contribution to the differences that were observed amongst experimental conditions. For the purpose of discussion, the means and standard error of the mean (S.E.M.) used in the following results represent the observed means and S.E.M.

3.1. Brake response time (BRT)

Of primary interest in the BRT results was the main effect for the presence of the distracter. Direct comparison showed that drivers exhibited a significantly slower BRT, $F(1, 30) = 41.6$, $P < 0.01$, in the presence of the distracter versus its absence (0.71 s versus 0.52 s). This confirmed the general proposition concerning the deleterious effects of distraction on primary driving response. A second main effect was evident as a result of age in which older drivers gave significantly longer BRT's, $F(1, 30) = 9.82$, $P < 0.01$, than younger drivers by over 100 ms on average (0.68 s versus 0.56 s). Such results confirm the often observed slowing effect of aging on speeded performance (see Fozard et al., 1994; Birren and Schaie, 1990). These main effects were modified by a number of interactive effects of which the principal one was a first-order interaction between age and distraction $F(1, 30) = 8.91$, $P < 0.01$. As is evident from Fig. 3, the presence of the distracter had relatively little effect on the younger drivers compared to the substantive slowing caused in older drivers (older 0.53 s versus 0.82 s, younger 0.50 s versus 0.61 s), where again this result is consistent with the significant disadvantage to older individuals in the presence of tasks of great complexity (Fozard et al., 1994).

In addition to age interacting with the distracter presence, gender also interacted with this factor to give a marginally significant effect $F(1, 30) = 3.89$, $P = 0.06$, which is illustrated in Fig. 4. This shows that the presence of the distracter had a greater influence on female as compared to male drivers (male 0.54 s versus 0.68 s, females 0.50 s versus 0.75 s). It should also be noted that females started from a slightly faster BRT in the non-distracter condition. Finally, there was a significant second-order interaction involving all three factors, age, gender, and distraction, $F(1, 30) = 4.19$, $P < 0.05$. This pattern, illustrated in Fig. 5, shows that the presence of distraction had a relatively comparable effect on younger males and females. However, the obvious difference occurred between older males versus older females (males 0.56 s versus 0.72 s, females 0.51 s versus 0.91 s).

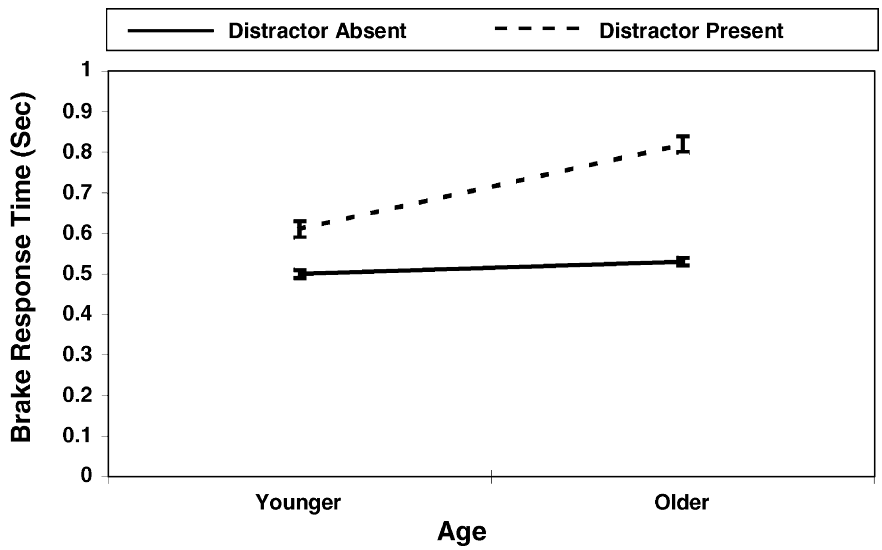

Fig. 3. BRT as a function of distracter presence and age.

Again, the disproportionate disadvantage to older females is consistent with previous findings concerning age and gender difference in tasks requiring fast response (Fozard et al., 1994) and points to the importance of considering different groups in the driving public as future in-vehicle technologies are considered for implementation (see Jerome et al., 2001).

3.2. Stopping time (ST)

ST was defined as the period between the drivers' first activation of the brake after the red light came on and the time at which the vehicle sustained 0 velocity. Analysis of these data showed that there was a significant effect for the presence of the distracter $F(1, 30) = 15.74$, $P < 0.01$, in which ST was faster in the presence of the distracter (2.23 s versus 2.57 s). Initially, this might appear counter-intuitive, however, as will be discussed, these results are consistent with our previous findings which also demonstrated significantly faster STs (Hancock et al., 1999) and represents evidence of drivers' greater braking intensity once the source of distraction has been identified. In addition to distraction effects, there was a block effect such that drivers were faster on the second block as compared with the first, $F(1, 30) = 5.48$, $P < 0.05$. This effect illustrates some degree of learning on behalf of our drivers and is to be reasonably expected in the present experimental procedure. Of particular interest was

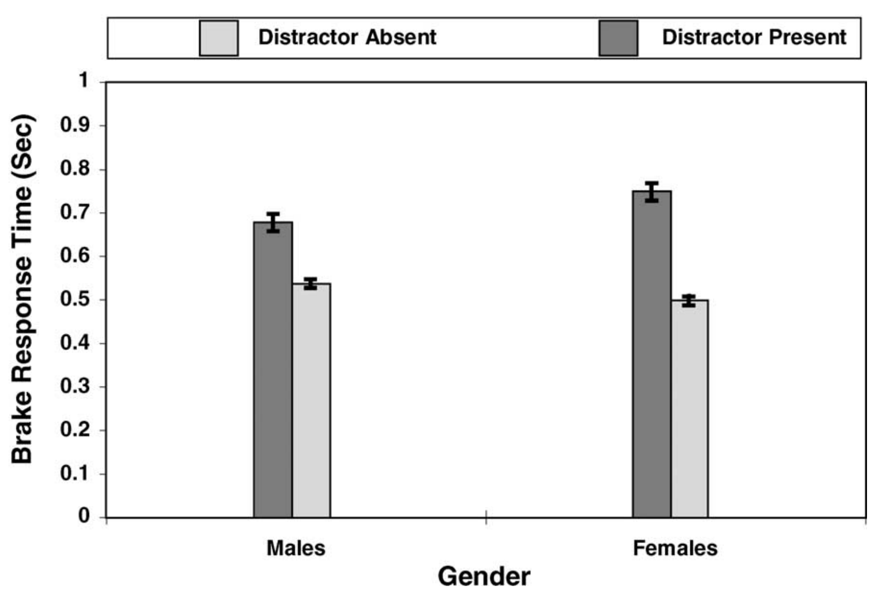

Fig. 4. BRT as a function of distracter presence and gender.

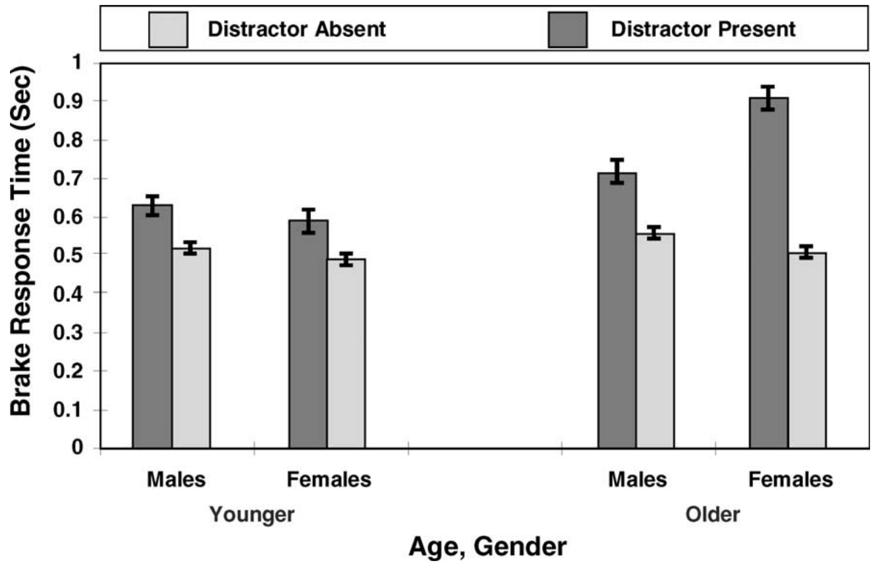

Fig. 5. BRT as a function of distracter presence, age, and gender.

the first-order interaction between age and distraction on ST, $F(1, 30) = 4.45$, $P < 0.05$. As is evident from Fig. 6, younger drivers slightly decreased their ST but older drivers had a much more substantial decrease in ST. Consistent with our earlier findings (Hancock et al., 1999) and the results from BRT here, the present results indicate that while our drivers reacted more slowly, they sought to compensate for this by increased braking intensity.

3.3. Stopping distance (SD)

SD was measured as the distance from the front of the driver's vehicle to the stopping line at the intersection light, when the vehicle had reached a complete stop. Results for this measure showed a main effect for block such that drivers stopped further from the line in block 2 as compared to block 1. We interpret this result as a learning effect on behalf of drivers who became progressively more proficient at the task with repeated exposure. Such context contingent learning is not unexpected given the novel test track environment and unfamiliar vehicle. Results further indicated a significant main effect for gender in which females stopped closer to the line as compared to males, $F(1, 31) = 5.04$, $P < 0.05$, (5.48 ft versus 9.45 ft) although this might potentially be due to the differences between the sexes in the brake pressure that they can apply. There was also a significant main effect for distraction, $F(1, 31) = 27.36$, $P < 0.01$, in which drivers stopped closer to the line when the distracter was present as compared to stopping in its absence (5.13 ft versus 9.8 ft). Finally, as shown in Fig. 7, there was a significant

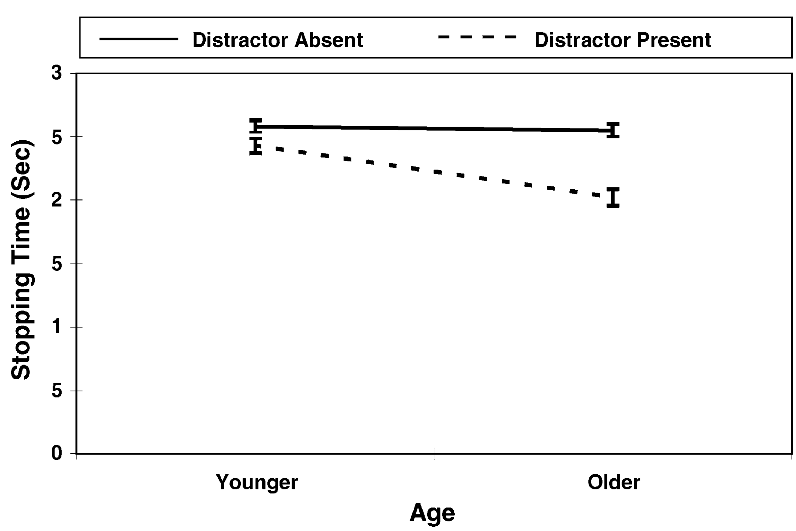

Fig. 6. ST as a function of distracter presence and age.

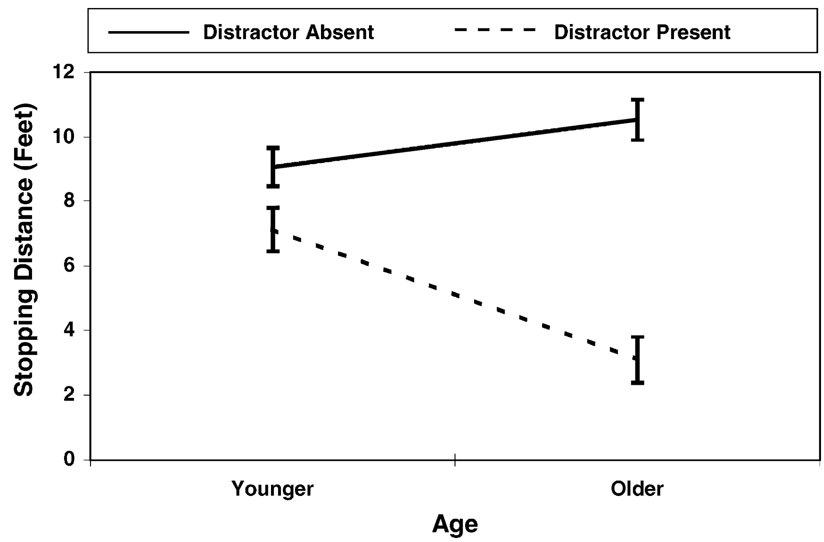

Fig. 7. SD as a function of distracter presence and age.

first-order interaction between age and the presence of distraction $F(1, 31) = 9.63$, $P < 0.01$, such that there was relatively little difference for younger drivers but a much greater difference for older drivers (young: absent, 9.07 ft versus present 7.14 ft; old: absent, 10.53 ft versus present 3.11 ft).

3.4. Stopping accuracy (SA)

The final category in terms of vehicle control was SA. This represents the percentage of occasions upon which the driver successfully complied with the change in light status in terms of stopping before the cross line on the roadway. For this measure, there was a significant and crucial effect of distraction on SA, $F(1, 25) = 18.35$, $P < 0.01$. Without distraction there was a 94.64% compliance rate with the stop-light upon its activation. However, in the presence of distraction, this level of compliance fell to only 80.35%, a dramatic 14.29% difference. This finding is of critical importance for safety concerns and is one we return to in discussion. Stopping compliance was also contingent upon two first-order interactive effects. The first significant effect, $F(1, 25) = 4.48$, $P < 0.05$, was a modification of the distraction effect due to age. While the compliance of younger drivers fell in the presence of distraction, this was much greater for the older drivers, an effect illustrated in Fig. 8. Interestingly, there was also a significant interactive effect between gender and distraction. As shown in Fig. 9, the rather small change in compliance for the males was dwarfed by the dramatic change for the female drivers. It should be noted that compliance rate was higher in females in the non-distractive condition, as compared to their male counterparts, again indicating the differential deleterious effect that distraction has

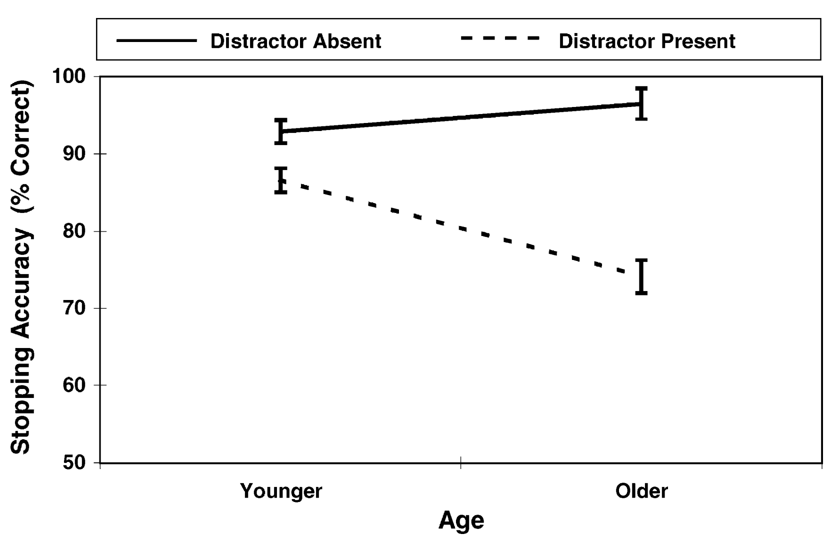

Fig. 8. SA as a function of distracter presence and age.

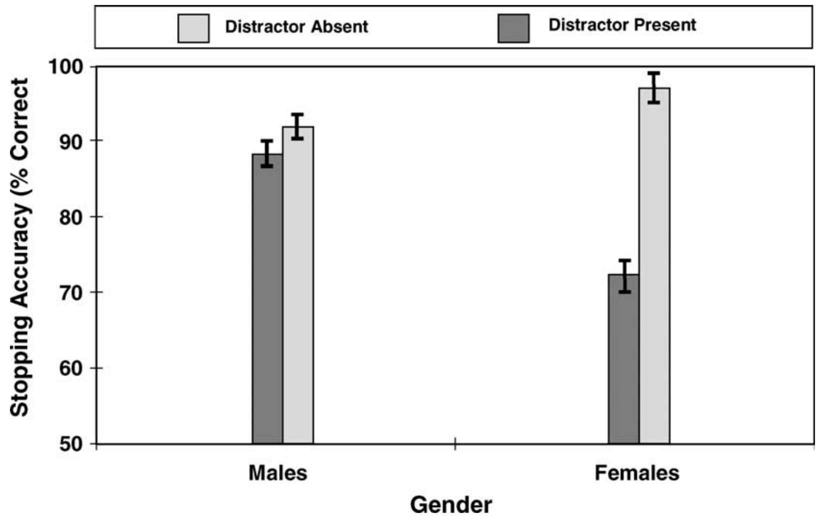

Fig. 9. SA as a function of distracter presence and gender.

on different driver populations. Given that the concurrent activation of the in-vehicle phone and the external traffic control device essentially demands a dual-task form of response, it is very important to consider the performance on the internal task (i.e. distraction response) as well as the external vehicle control as represented by the earlier measures. This is because the pattern of findings may well be influenced by a speed-accuracy trade-off between attention given respectively to internal and external demands. As a consequence, we now examine the results from the distracter task.

3.5. Distracter response time

The primary main effect on DRT was the presence of the stopping task. This significant effect $F(1, 30) = 6.75$, $P < 0.05$, showed that drivers respond more quickly in the presence of the stopping requirement as compared to its absence (1.49 s versus 1.56 s). This argues against the idea of a direct speed-accuracy trade-off between internal and external tasks. Like many of the vehicle control measures, DRT was modified by levels of independent variables. Thus, there was a significant first-order interaction between gender and stopping condition $F(1, 30) = 8.95$, $P < 0.01$, in which males responded faster to the distracter in the presence of a stop while there was very little difference for female drivers. This effect itself was further modified by the age of the driver $F(1, 30) = 6.94$, $P < 0.05$, and as shown in Fig. 10, younger males and females as well as older males were faster when the stop-light was activated in contrast to the older female drivers who were slower in this circumstance.

3.6. Distracter response accuracy

With respect to distracter accuracy there were some marginally significant effects that are worthy of mention. In particular, there was an interaction between age and sex, $F(1, 31) = 3.51$, $P = 0.07$, which indicated the comparable performance of younger males and females but the greater accuracy of older females over their male peers. There were also interactions between gender, block, and the presence or absence of the stop requirement, $F(1, 31) = 8.91$, $P < 0.01$. This effect, illustrated in Fig. 11, shows that both males and females exhibited fairly stable performance across the blocks when no stopping response was necessary. However, as soon as the need to respond to the traffic light was added, the pattern of response changed significantly. Males showed an obvious improvement that may be taken as evidence of learning or an ability to mobilize attentional resources in a dual-task situation. In contrast, the performance accuracy of the female drivers decreased across trial blocks. While this might be due to some form of fatigue effect, we cannot attribute this observation to a response strategy change since results from the primary vehicle control task do not support such an assumption.

In general, these results indicate that there was no substantive trade of speed for accuracy within the distracter task itself and further in respect of the overall results the outcome for vehicle control was not obviously contingent upon a trade between internal and external tasks. Finally, we examined the results for the memory-loading task that was imposed on the individual drivers throughout the experimental sequence. This represented memory set RA following each specific trial.

3.7. Memory task recall accuracy

The primary finding of the seven-digit memory recall task (Miller, 1956) was that recall was significantly worse in the presence of the distracter task, $F(1, 29) = 7.41$, $P < 0.05$, (85.63% versus 89.71%). This main effect was modified by a significant three-way interaction between age, gender, and the presence of distraction, $F(1, 29) = 4.23$, $P < 0.05$,

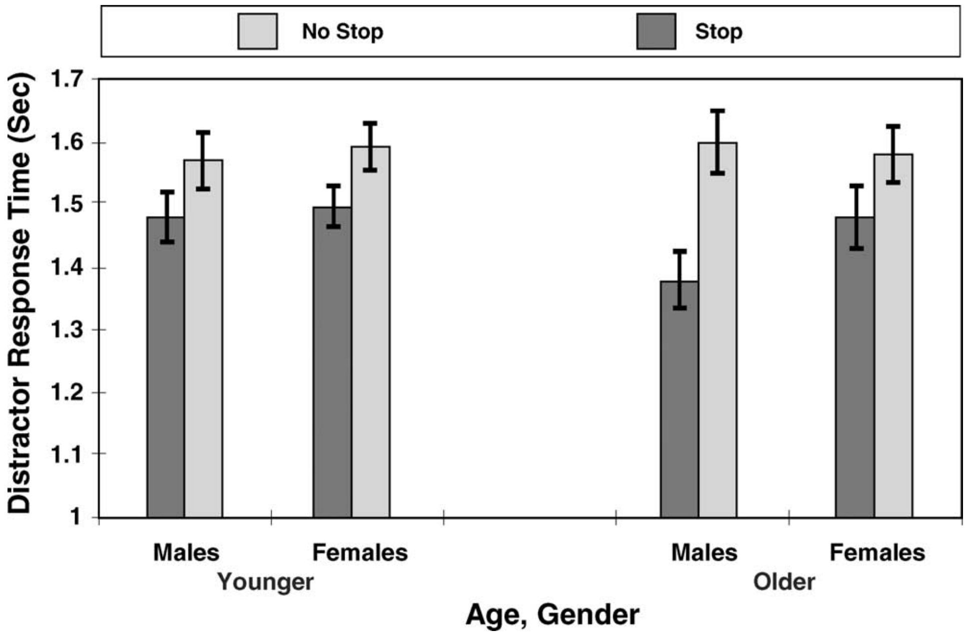

Fig. 10. DRT as a function of stopping task presence, age and gender.

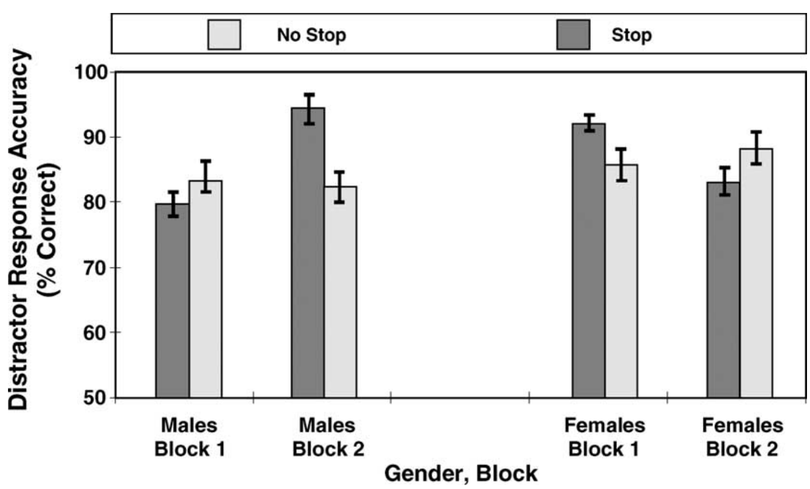

Fig. 11. DRA as a function of stopping task presence, gender and trial block.

as illustrated in Fig. 12. As is evident, the scores of the younger males and the older females did not change appreciably while the accuracy of the older males and younger females each declined by a similar percentage value. Finally, there was a significant two-way interaction between block and stop, $F(1, 29) = 5.48$, $P < 0.05$, in which the decline of accuracy in block 1 in the presence of the stop-light activation was matched by a comparable increase in accuracy in block 2.

4. Discussion

The most crucial finding in the present experiment was the variation in SA in the presence of the phone distraction task. As evident from the results, without the distraction, the overall compliance rate to stop-light activation was very close to 95%. However, when the phone distraction task was added, compliance rate dropped to 80%, a highly significant 15% reduction in stopping response. Since we have emphasized the context of events as so critical to the eventual outcome, we cannot draw a direct and simple link between this 15% decrease in compliance and subsequent collision frequency. For, it is clearly crucial exactly when and where such diminution in performance occurs. Thus, in the case of drivers 'running' red lights, one other obvious crucial component in such intersection collisions is the presence of another, unresponsive driver on the appropriate cross street. We can, however, conclude that the presence of the distraction erodes the inherent safety margin provided by a fully aware and

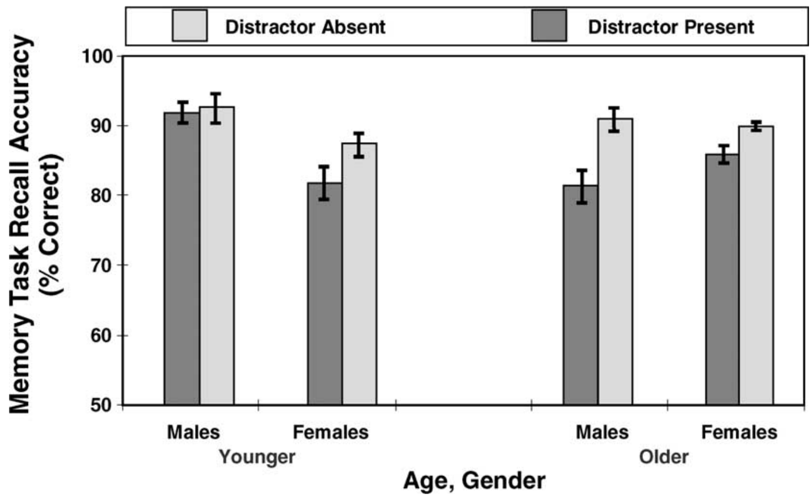

Fig. 12. Memory task RA as a function of distracter presence, age and gender.

responsive driver. It is also evident that the compliance effect is contingent upon the age of the individual. As is recognized in the gerontological literature (e.g. Birren and Schaie, 1990; Fozard et al., 1994), tasks with increasing complexity disadvantage older individuals disproportionately compared to their younger peers. Thus designs and systems created to simplify in-vehicle device operation are liable to be most effective for older drivers. In respect of red light compliance, there was also an interesting and significant modification of the effect, contingent upon the gender of the driver. Initially, female drivers are more compliant than their male peers in the normal, non-distracted situation. This finding accords with the existing evidence on greater risk-taking by male as compared to female drivers (see Evans, 1991; Howarth, 1985). However, when the distractive phone task was introduced, female drivers were disadvantaged to a greater extent than their male peers. To our knowledge, this is the first report of such an effect, since the dominant finding in cognitive sex differences concerns spatio-temporal orientation (see Baker, 1987; Block et al., 2000; Maccoby and Jacklin, 1974) and the present task is largely one of dual-task performance, upon which information concerning sex differences is sparse (but see Elliott et al., 1986). Collectively, the findings from measures of SA argue that driver characteristics are as crucial in considering the influence of in-vehicle phone use as are any of the other methodological concerns that have already been expressed (Haigney and Westerman, 2001).

In addition to the significant change in red light compliance rate, there were significant influences on performance for the three dependent variables that measure longitudinal vehicle control on those trials where individuals responded successfully. The first of these measures was the BRT that represented the time from the onset of the red light until the first activation of the braking system. The primary main effect confirmed that BRT was slower in the presence of the distraction as compared to its absence. Quite clearly, there is a dual-task decrement associated with the presence of the phone task. However, like the measure of compliance, this response varied according to the age of the individual. Consistent with the compliance findings for SA, older drivers were at a greater disadvantage in the presence of the distractive phone task compared to their younger counterparts who were little affected by such distraction. This confirms that not all individuals are affected to the same degree by the presence of distraction and therefore, we may well expect that the erosion in the margin of safety differs significantly across individuals. Further, in direct agreement with the findings on compliance, female drivers were affected more by the distraction than their male counterparts but they also started from an initially advantageous situation in terms of speeded BRT in the normal driving condition. Thus the initial compliance rate, and initial braking activation time show very consistent patterns of response in which distraction exerted significant influences, where such influences were mediated by the age and gender of the driver.

Having examined compliance and initial response time (essentially a direct correlate of reaction time as used by the transportation community), it is now important to evaluate how drivers actually brought the vehicle to a halt in terms of ST and SD. Results showed that drivers stopped faster in the presence of the distraction as compared to its absence. Initially, this might appear to be a counter-intuitive finding, since the presence of the distracter to this point has retarded performance and this shows performance improvement. However, consideration of the situation renders this a reasonable outcome since it shows that drivers brake harder with the distraction than without it. Such a result confirms our previous findings (Hancock et al., 1999) and represents, we suggest, an adaptive response on behalf of drivers who have recognized their limitation in initial response and have sought to make up for this by greater braking intensity. Also, we noted in the findings that drivers improved across blocks of trials such that they were faster. This learning effect is important for a number of reasons. If drivers are able to improve significantly at dual or multiple task performance, then the introduction of in-vehicle devices may not be as problematic as is sometimes currently painted. After all, we see radical improvement in-vehicle control from novice to expert and so we might see similar gains in dual-task performance as drivers become more familiar with these nascent ITS technologies. However, there is a counter argument to this learning effect that is embedded in our design. Even though we were careful to randomize the order of condition administration, drivers underwent a much more intense experience in the test track evaluation than they would do normally on the road. Thus, we suspect drivers began to prepare themselves for the activation of the respective devices, even though such activation was relatively rare in the experimental sequence. Thus the learning observed may well have resulted from the greater frequency of critical events and thus we cannot be sure how much such learning would transfer to the normal driving world. Certainly, the facet of driver learning with ITS devices is a critical area and one to which experimental attention is desperately needed at present. Again, consistent with all earlier results, we found the effects for ST contingent upon the age of the driver, which in this case showed that older drivers brake even more intensely than their younger peers, perhaps an indication of even more dramatic need to compensate for the preceding slowed reaction responses. That such intense braking activity might well cause problems for following drivers is itself a fundamental safety concern as risk is not totally eliminated but rather transferred between involved drivers.

Despite the adaptive response of more intense braking, the distance from which the vehicle stopped from the line of the red light was still shorter in the presence of the distracter compared to its absence. While this difference measured only approximately five feet in total, such a value needs to be viewed in light of the overall situation. We found that in the presence of the distracter, drivers stopped on average only 5.13 ft from the line. Thus, viewed in these terms, the 5 ft difference for the presence of the distracter makes almost a 100% safety margin difference. This pattern persists even with the pay-off matrix that we gave to the drivers. Again, driver age had a radical influence on this effect. While the SD for younger drivers barely varied in the presence of the distracter, it had a profound effect on the SD of older drivers. SD was also mediated by driver gender where female drivers stopped closer to the line than their male counterparts. Overall then, the findings in respect of vehicle control from the presence of the phone distraction are clear. First, distraction causes drivers to miss significantly more red light activations. When they do react to the red light, distraction causes them to react later. To compensate, drivers brake more intensely. Unfortunately, even this adaptive response is insufficient and they end up closer to the line than they normally would. It is important to note however, that on average in these successful trials, they do not cross the line even in the presence of the distracter.

From the present results, it is also clear that these response patterns are contingent upon the age and the gender of the driver. Female drivers suffer a greater disadvantage in respect of the presence of the distracter and whether this reflects a basic difference in dual-task performance capacity or results from the fact that driving presents a spatio-motor task upon which males perform better has yet to be adequately determined. Of perhaps greater importance is that older drivers are distinctly disadvantaged by the distraction effect. On virtually every measure of vehicle control, older drivers suffer a greater proportionate disadvantage compared to their younger counterparts. This consistency implies that technologies to assist the driver to cope with in-vehicle devices would be well advised to focus on issues related to the older, rather than younger driver. For, as has been noted several times, technologies which help the older individual serve to help all. Evaluation of the results for responses to the distracter task and the embedded memory task showed that the present findings were not a simple trade of speed for accuracy in a dual-task dyad. This is important to establish since, without this assurance, our collective findings might well have represented a strategic change on behalf of the drivers that might have been construed as misinterpretation of our original instructions. However, as is evident from the outcome of distracter response speed and accuracy as well as short-term memory capability, the results for vehicle control are pristine and not contingent upon such a speed-accuracy trade-off.

5. Summary and conclusions

In the present experiment, we have confirmed and extended our previous observations on the detrimental impact of a coincident in-vehicle phone task on a critical driving maneuver (see Hancock et al., 1999). We have demonstrated that the inherent driver characteristics such of age and gender have a substantial influence on patterns of response to in-vehicle phone distraction. Clearly, such distraction erodes the safety margin in driving when we compare against the performance of a fully responsive and undistracted driver (Boer, 2001). However, since context dictates whether such performance diminution is propagated into the adverse outcome of a collision, there is no simple, linear linkage between phone use and crash frequency. If, as we have postulated, crashes result from a concatenation of circumstances in which the confluence of sub-optimal task performances interact (see Caird and Hancock, 2002; Hancock, 1997b), then distraction effects are clearly one of these major precursor and thus a critical component in the causal sequence. In terms of system error (see Reason, 1990), distraction then becomes one critical local trigger which defeats the intrinsic defenses-in-depth of the overtaxed driver. It may be possible that through design and learning that we can reduce the impact of such distraction (and see Gale, 1997; Peters and Peters, 2000). However, whether we will wish to restrict or ban the use of in-vehicle devices on the grounds of safety is predominantly a social and legal decision. Hopefully, experimental results can act to impact such decisions by providing quantitative information to inform such legislative deliberations.

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