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Final Report

Driving Performance During Cell Phone Conversations and Common In-Vehicle Tasks While Sober and Drunk

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16. Abstract (Limit: 200 words)

The crash risk associated with cell phone use while driving is a contentious issue. Many states are introducing Advanced Traveler Information Systems (ATIS) that may be accessed with cell phones while driving (e.g. 511 Traveler Information Services). In these contexts, there is a need for relevant research to determine the risk of cell phone use. This study compared driver performance while conversing on a hands-free cell phone to conditions of operating common in-vehicle controls (e.g., radio, fan, air conditioning) and alcohol intoxication (BAC 0.08). In addition, the study examined the combined effects of being distracted and being intoxicated given that there may be a higher risk of a crash if the driver engages in a combination of risk factors. During simulated traffic scenarios, resource allocation was assessed through behavioral measures and an event-related potential (ERP) novelty oddball paradigm.

The results indicated that during a car following scenario, drivers engaged in the conversations or completing in-vehicle tasks were more impaired than drivers that were not involved in any distraction task. Indeed, both the cell phone and in-vehicle sources of distraction were generally more impairing than intoxication at the legal limit. These results will be used in a follow up study in order to compare the effects on attention of driving and using 511 to distraction from these tested distractions.

Driving Performance During Cell Phone Conversations and Common In-Vehicle Tasks While Sober and Drunk

Final Report

Prepared by:

Michael Rakauskas
Nicholas Ward

HumanFIRST Program
Institute of Technology
University of Minnesota

Edward Bernat
Meredith Cadwallader
Department of Psychology
University of Minnesota

Dick De Waard
University of Groningen
The Netherlands

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- Minnesota Public Radio, April 27, 2005
- *Pioneer Press*, April 27, 2005
- *USA Today*, June 2, 2005

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EXECUTIVE SUMMARY

The crash risk associated with cell phone use while driving is a contentious issue. In response, some states are imposing restrictions on the use of hand-held phones. However, there is ample evidence that a risk remains for hands-free phones due to the mental distraction associated with cell phone conversations. Moreover, many states are introducing Advanced Traveler Information Systems (ATIS) that may be accessed with cell phones while driving (e.g. 511 Traveler Information Services).

In these contexts, there is a need for relevant research to determine the risk of cell phone use. One method to determine this risk is to compare the driver impairment resulting from cell phone use relative to other identified risks in the driving environment. This study compared driver performance while conversing on a cell phone to conditions of operating common in-vehicle controls (e.g. radio, fan, air conditioning) and alcohol intoxication (Blood Alcohol Content of 0.08 [BAC 0.08]). In addition, the study examined the combined effects of being distracted and being intoxicated given that there may be a higher risk of a crash if the driver engages in a combination of risk factors.

Participants experienced simulated traffic scenarios in the Virtual Environment for Surface Transportation Research (VESTR) at the HumanFIRST Program, University of Minnesota. During each scenario, participants drove normally along a rural route and were exposed to a variety of traffic interactions. These interactions included a prescribed period of continuous car-following in which the participant driver had to adjust their speed in order to maintain a constant headway with a lead vehicle that randomly varied its own speed.

Participants drove the simulated route while (1) engaged in hands-free cell phone conversations, (2) interacting with common in-vehicle controls, and (3) not completing any secondary-tasks. In addition, half of the participants were impaired by having their BAC raised to 0.08. Driver impairment was measured in terms of driving performance, including:

- Car-following performance – distance and speed maintenance
- Episodic driving task performance – reactions to unexpected events, as well as curve, speed, and lane keeping
- Environmental awareness – sign-detection reaction time and performance
- BAC – breathalyzer reading of intoxication
- Physiological differences – heart rate and brain activity (Evoked Response Potential, [ERP])
- Subjective measures - mental workload, past trends, and opinions

With this experimental design, the main effect of distraction type (cell phone vs. in-vehicle tasks), the main effect of alcohol impairment (sober vs. intoxicated), and the interaction effect of combining distraction while impaired were analyzed.

The results suggest that distracted drivers who were engaged in the cell phone conversations or completing in-vehicle tasks were more impaired than drivers that were not involved in any distraction task. Indeed, both the in-vehicle and cell phone sources of distraction were sometimes more impairing than intoxication at the legal limit (BAC 0.08). Distraction from operating in-vehicle controls, such as changing stereo settings, tended to produce the largest impairment.

For example, as summarized in the following two Tables, drivers completing either secondary-task during the continuous driving task showed worse car-following performance than driving without a task in terms of time headway, less-consistent speed profile with respect to the lead vehicle, and increased randomness in steering input. Unlike impairment symbols for the secondary-tasks in the table represent significantly different levels of task impairment.

Table 0-1 – Synopsis of results from continuous behavioral tasks

Continuous Behavioral Task		Task Condition Performance		
		Baseline	Cell Phone	In-Vehicle
Car Following	Time headway	√	●	●
	Headway variability	√	○	●
	Coherence	√	○	●
	Modulus	√	√	●
	Phase shift (delay)	√	○	●
	Steering reversals	√	●	●
	Steering entropy	√	○	●
	Safety margin	√	√	●

Key to Performance Comparisons
√ = No Impairment (baseline)
○ = Significantly Impaired
● = More Significantly Impaired

This study was also one of the first to include psychophysiological measures of driver mental workload and distraction in conjunction with the driving task and secondary-tasks. In terms of driver awareness and mental processing, drivers completing the secondary-tasks had impaired reaction time and identification of target tones associated with the ERP measurement task. This suggests that distracted drivers had fewer resources available to interpret information from the driving environment or to process tertiary tasks while driving. Measurements of brain activity also showed that drivers engaged in secondary-tasks were less attentive and mindful of unexpected (sound) events. This methodology may also prove to be a useful measure of driver impairment in future studies.

Drivers conversing on the cell phone task while sober had lower accuracy and more false positives during the target tone task than intoxicated drivers not completing any secondary-task. Drivers completing the in-vehicle task while sober had worse performance during the novel ERP tones than intoxicated drivers not completing any secondary-task.

Table 0-2 – Synopsis of results from performance measures

Performance Measures		Task Condition Performance		
		Baseline	Cell Phone	In-Vehicle
Subjective Rating Scale of Mental Effort		√	●	●
Physiological	Heart Rate IBI	√	●	√
	Target RT	√	●	●
	Target accuracy	√	●	√
	Total Errors	√	●	√
	ERP target	√	√	√
	ERP novel	√	●	○
Environmental Awareness	Reaction time	√	√	○
	% correct responses	√	●	●
	Detection errors	√	●	●

Key to Performance Comparisons
√ = No Impairment (baseline)
○ = Significantly Impaired
● = More Significantly Impaired

The results of this study remind us that the seemingly simple act of interacting with the controls and displays in our dashboards can be a very real source of distraction that increases the chances of a fatal crash. This study also demonstrates that the mental component of cell phone conversations does significantly impair driver performance, thereby increasing crash risk. Laws that only restrict hand-held phones may not be sufficient to reduce crash risk. Furthermore ATIS that are accessible by cell phones should be designed to minimize the risk of interacting with these systems while driving.

CHAPTER 1: INTRODUCTION

There is considerable debate without sufficient research regarding cell phones as a risk factor in traffic crashes. Specifically, there is insufficient knowledge about the relative risk of cell phone use while driving compared to other existing secondary-tasks drivers may perform in the vehicle. Now that that there are many states intending to introduce traveler information systems (e.g. 511 Traveler Information Services) and companies offering services and directions (e.g. Yahoo! Driving Directions) that may be accessed with cell phones while driving, there is an even greater need for relevant research to determine the risk of secondary-task distractions including cell phone use while driving.

In a review of vehicle crash causes (Najm, Mironer, Koziol, Wang, and Knipling, 1995), inattention was cited for 56 percent of rear-end crashes, as well as 36.4 percent of signalized intersection crossing path crashes. A similar type of inattention, looking but not seeing, was the cause of 61.2 percent of lane change crashes, 60.8 percent of backing crashes, as well as 36.7 percent of unsignalized intersection crossing path crashes. Both of these types of inattention could be described as driving recognition errors, which as a group account for 43.6 percent of all crash types. It is suggested from the literature (for reviews, see Goodman, et al., 1999; Haigney and Westerman, 2001; RoSPA, 2002; Horrey and Wickens, 2004) that driving while accepting the consensual risk of conversing on a cell phone causes the driver to be in a state of inattention, and thus more prone to a variety of accident types such as these.

A risk can be assumed for any secondary-task that demands driver attention such that there are fewer mental resources remaining to allocate toward the primary task of driving safely (Figure 1). Given that performance impairment may not be observed until task demands exceed the mental resource capacity of the driver to manage the demand, it is necessary to consider the interaction of both primary and secondary-task demands. The cognitive demand of a secondary-task may depend on the complexity of interaction required to engage the task. Whereas a driver may have the capacity to generate enough mental effort to manage this task while driving without apparent detriment to performance, the amount of spare capacity may not be adequate to cope with gradual or unexpected increases in the primary driving task demand. Once this spare capacity is exceeded, driving performance will be at risk. Similarly, whereas a driver may be able to cope during a normal operating state, the driver may be less able to manage resources for primary and secondary-task demands while impaired by such factors as fatigue or alcohol.

Thus, the key question is not if cell phone use imposes a risk, but rather if the amount of risk is unacceptable. An acceptable risk threshold can be assessed in relative terms by comparing cell phone use to other common risk factors.

First, there is a range of common in-vehicle tasks that are routinely engaged by the driving population. The risk imposed by this common task set may be considered a baseline that is based on the notion of consensual risk in the sense that there is a general consensus among drivers that such risk is acceptable by virtue of its normative acceptance (as determined by each state).

Second, demonstrable limits have been set for other impairment factors such as alcohol (i.e. BAC 0.08) since it is already widely regulated (NCADD, 2000). The risk imposed by these legislated limits can also be considered as a baseline that is based on the notion of sanctioned risk in the sense that there are legislated limits to the amount of risk that is permitted.

Research on cell phone conversation risk has seldom, if at all, made comparisons to the consensual risk of common in-vehicle tasks (Greenberg, Tijerina, Curry, Artz, Cathey, Kochhar, et al., 2002) and has rarely made comparisons to the sanctioned risk of alcohol (Burns, et al., 2002; Strayer, Drews, and Crouch, 2003). Indeed, no research has considered the risk of cell phone use as a product of combining distraction with alcohol intoxication. Such interactions are important to consider given that most crashes are the results of combined risk factors (Evans, 1991; Stutts, Reinfurt, Staplin, and Rodgman, 2001; Brick, 2004). For example, in a recent Minnesota incident, an intoxicated driver using a cell phone caused a head-on crash while attempting to pass another vehicle, killing three brothers in the other vehicle (Adams and Smith, 2004). In this anecdotal evidence, it is apparent that the driver created a dangerous situation for himself and others by exceeding these acceptable risk thresholds for both sanctioned (drinking) and consensual (talking on the phone) risk levels.

CELL PHONE DISTRACTION

Worldwide use of cell phones is growing with more than 175 million U.S. subscribers at the beginning of 2005 (CTIA, 2005). It has been reported that 90 percent of surveyed cell phone owners use their phones at least infrequently while driving (cited in Goodman, Tijerina, Bents, and Wierwille, 1999). This potentially equates to more than 156 million drivers in the U.S. who may concurrently converse on a cell phone while driving. In the United Kingdom, hand-held phone usage rates while driving are closer to 31 percent (Direct Line Motor Insurance, 2002). Even so, this is the equivalent of over 10 million people conversing on phones while driving of which 60 percent of these users are high-mileage drivers. Thus, understanding these driving performance decrements due to conversing on a phone could benefit a large number of drivers worldwide.

Recently a number of reviews (e.g. Goodman, et al., 1999; Haigney and Westerman, 2001; RoSPA, 2002; Horrey and Wickens, 2004) and commentaries (e.g. Hancock and Scallen, 1999; Tijerina et al., 1999) have reported on the literature regarding the effects of cell phone use, design, and safety. From these reviews it has been found that cell phones lead to impairment in the maintenance of lateral lane position; maintenance of appropriate and predictable speed; maintenance of appropriate following distances; reaction time to detect and respond to ambient events; judgment and acceptance of gaps; and general awarenes of other traffic.

Hand-held vs. Hands-free

Some believe banning the hand-held mode of phone operation will help relieve some of these problems. This has been done in the entirety of the UK (UK Department for Transport, 2003) and numerous municipalities (Science Daily, 2005), most notably New York state (IP Online, 2004).

The presumption behind hand-held phone bans is that by removing the need to physically manipulate the device, the phone will not be distracting. However, this presumption appears to be false given that a safety hazard has been demonstrated with hands-free phones in comparison to hand-held phones (Drucker and Lundegaard, 2004, Brookhuis, de Vries, and de Waard, 1991). Hands-free adaptors to phones may also add time to the call or be more difficult to use (Mazzae, Ranney, Watson, and Wightman, 2004), and associated with higher mental workload (Matthews, Legg, Charlton, 2003). Thus these types of applications may create a situation where it takes more effort and resources away from the primary task of driving instead of aiding the driver. Further research from the Texas Transportation Institute (TTI; Crawford, Manser, Jenknis, Court, and Sepulveda, 2001) found the hand-held and hands-free phones to be equally detrimental to performance, showing that drivers displayed larger variations in steering performance during both types of conversation as compared to not conversing at all.

In fact, a survey conducted by the AEI-Brookings Institute (Hahn and Prieger, 2004) found that using hands-free devices did not lead to significant reductions in crashes and that such analyses can be confounded by other factors. For example, other factors such as phone usage and gender are more powerful predictors of crashes; specifically, there was an interaction showing that higher phone usage led to higher risk for females. They also claim that drivers who purchase and use hands-free adaptors are already safer drivers to begin with. Indeed, a survey of Finnish drivers (Poysti, Rajalin, and Summala, 2004) has shown that phone-using drivers in general are riskier drivers, especially since the highest risk demographic group (18 to 24 years old) reported using cell phones most often. They also found that phone-related hazards were dependent upon exposure to the risk, through increased mileage and time on the phone. They suggested that driving skill level did not determine on-road safety while using a cell phone, but instead it affects whether the driver uses the phone or not.

The impairment effect of hands-free phones is presumed to be the engagement of mental resources to process the phone conversation. This is assumed to be exacerbated by the change in conversation dynamics during phone-based communication. It is presumed that the driver shares the same environment with a passenger during a conversation. Both the driver and passenger may be dynamically regulating the pace and level of conversation in relation to the mutually recognized demands of the driving task. In contrast, the person a driver is communicating with on a cell phone while driving does not have access to the same environment, and therefore, can not dynamically regulate the conversation. As a result, the driver is presented with a conversation pace and level that may conflict with attentional demands required for hazards imposed by the driving environment.

Contrary to this assumption, Laberge, Scialfa, White, and Caird (2004) found that passengers did not regulate their conversations based on the driving scene any more than those talking remotely on a phone. They saw that drivers engaging in a conversation (passenger or remotely) showed more severe decrements in reaction to unexpected hazardous events (intersection light change, pedestrian incursion) than those not conversing at all. Gugerty, Rakauskas, and Brooks (2004) also found no evidence that passengers modulated their conversation rate on a verbal task while sharing the same environment as the driver (i.e. acting as a passenger watching the driving scene). Conversing drivers had similar performance on situation awareness measures regardless of whether the passenger was present and witnessing the driving scene or remotely conversing with the driver. In addition, their results suggest that people engaged in both remote and in-vehicle (passenger) verbal interactions adjust to each others' verbalization rate or rhythm in an unavoidable manner. Therefore, as it was shown that passengers did not change their verbalization rhythm due to the driving scene, this suggests that any conversation (whether it be on a hand-held phone, hands-free phone, or otherwise) could add to the attentional demands of the driver.

Whereas some evidence suggests that cell phone use does impose a risk, the specific stage(s) of operating a cell phone and underlying psychological processes have not been clearly delineated. Simply put, conversing on a cell phone would demand auditory attention to the phone, verbal and spatial processing, and an auditory response. A recent simulator study conducted at the University of Illinois (Kubose, Bock, Dell, Garnsey, Kramer, and Mayhugh, 2005) attempted to assess whether driving performance was hindered more by speech production (processing stage) or by speech comprehension. Overall, they found that the consequences from producing or comprehending speech were relatively similar yet both detrimental to driving performance. Because it is unclear whether conversation regulation, comprehension, or production is the primary source of conflict, there is a need for further research specific to what other psychological processes or stage of (hands-free) conversation processing/production may cause the distraction witnessed in past research.

Cell Phone Risk Relative to Common Tasks

It has been hypothesized that cell phone use is no more distracting than a range of other in-vehicle tasks or driving conditions that are already accepted by the driving population and policy makers. It is apparent that this hypothesis needs additional attention. Research from the American Automobile Association (AAA; Stutts et al., 2001) suggests that distraction from cell phone use is less prevalent than other common activities such as using the radio. However, this is inferred from epidemiological evidence based on police reports that may be unreliable, and does not directly compare the relative impairment of driving performance during these task activities.

Ford Motor Company (Greenberg, et al., 2002) conducted a study whereby radio tuning and HVAC (heating, ventilation, and air conditioning) adjustments were compared to hand-held and hands-free cell phone tasks. The experimenters found that dialing or answering either type of phone led to more misses in detection of ambient dangerous driving events as well as more difficulty in maintaining consistent lane keeping performance. They also found that the in-vehicle tasks caused errors in heading maintenance and (rear) dangerous event detection similar to the errors seen when dialing or answering the phone.

Lamble, Kauranen, Laakso, and Summala (1999) looked at drivers' reaction to a rapidly decelerating lead vehicle and compared drivers' performance while dialing a phone (akin to an in-vehicle task) to performing a verbal cognitive task (akin to conversing). They found that while performing either task, drivers were slower to detect the lead vehicle's deceleration as compared to a control condition. Using a response task on a hand-held phone has also been shown to slow brake response time, increase braking intensity (shorter stopping time), decrease stopping distance (from a hazard), and lower compliance to stop-light activation (Hancock, Lesch, and Simmons, 2003).

These findings would lead us to believe that driving while completing in-vehicle tasks or while conversing on a cell phone could be dangerous. However, what these studies do not tell us is just how much additional mental effort a driver is exposed to while engaging in these consensual risks (e.g. cell phone conversations or in-vehicle tasks) in comparison to a legally sanctioned risk (e.g. alcohol intoxication). To help quantify an answer to this, it is necessary to compare the risk of driving while conversing to driving while engaging in risks for which we can quantify the level of cognitive load involved, such as driving while intoxicated.

ALCOHOL IMPAIRMENT

The level of task demand that can be managed may be reduced when the driver is impaired by factors such fatigue, intoxication, drugs, or inexperience. Indeed, many crashes result from a combination of risk factors (Brick, 2004). This suggests that secondary-task demand should not be examined in isolation from other factors, such as alcohol.

Alcohol-impaired drivers suffer from slower information-processing abilities, exaggerated states of emotion, recollection difficulty, and decrements in fine movement and balance (Laberge and Ward, 2004). Alcohol dissolves in water and is distributed evenly throughout the body, making detection easier since positive test results from blood have a near perfect relationship with levels of alcohol in the brain (Moskowitz, 2002). Because of this, the relationship between BAC, recent consumption, impairment, and crash risk has been quantified in past research. Reviews by the National Highway Traffic Safety Administration (NHTSA; 2003) encompassing 289 studies found that even at a

BAC of 0.08, most drivers are impaired at critical driving tasks such as divided attention, complex relation time, steering, lane changing, and judgment. Previous research has also found that a BAC of 0.50 is the level at which deterioration of driving skills begins (Council on Scientific Affairs, 1986).

Alcohol is a crucial safety concern for researchers and policy makers, as Stewart (2001) reported that 38.6 percent of fatal U.S. crashes in 1998 were alcohol-related. Unfortunately, this problem has not improved, as 39.9 percent of traffic fatalities in 2003 were still alcohol-related, averaging one alcohol-related fatality every 31 minutes (NHTSA, 2004). In the vast majority of these fatalities (86 percent) the drivers had a BAC greater than 0.08. The U.S. is not alone, as heightened values are also seen in other countries including Canada (38.6 percent), Australia (28 percent), UK (19 percent), Sweden (18 percent) and Germany (17 percent). In most of these countries, legal BAC limits for alcohol are the primary way transport policy has evolved to manage alcohol use by drivers.

According to Taylor, Miller, and Cox (2002), alcohol-related crashes in the United States cost an estimated $114.3 billion in 2000 and accounted for approximately $103 billion of U.S. auto insurance payments. Alcohol offenders are not the only ones punished, as people other than drinking drivers paid a disproportionate 63 percent ($71.6 billion) of the total alcohol-related crash cost. In addition, the average alcohol-related fatality in the United States cost $3.5 million while the estimated cost per injured survivor was $99,000.

The Minnesota Department of Public Safety's Office of Traffic Safety (OTS, 2004) reported that there were 32,193 Driving While Intoxicated (DWI) citations given in 2003; 41 percent of these were repeat offenders with alcohol-related crashes totaling $350 million. This is notable since Minnesota did not join the other 48 states that already enforce a legally impaired driving *per se* limit of 0.08 until August 1st, 2005. In 2003, Minnesota also hosted 255 alcohol-related deaths at an estimated economic impact of nearly $280 million. This is a 4 percent increase from 2002 and shows room for improvement in light of the other 28 states that reduced their alcohol-related fatalities.

Thus, more definitive evidence is needed of the relative risk of cell phone use compared with other secondary-tasks, especially under conditions when this risk may be exacerbated, such as high primary task demand, combined secondary-tasks, or driver impairment.

Alcohol vs. Cell Phone Use

Until recently, there has been little research relating the known decrements of driving while intoxicated to driving while talking on a cellular phone, most probably because cell phones have only recently been recognized as a driving safety issue.

The Transport Research Laboratory (TRL) in England conducted a study comparing performance on a hands-free cell phone task to performance while intoxicated (Burns, Parkes, Burton, Smith, and Burch, 2002). The TRL used a motion-base simulator to measure performance during a car-following scenario, a sign discrimination task, curves, and traffic negotiation. Using a within-subjects design participants drove while using a hand-held phone, a hands-free phone, without conversing, and while intoxicated at BAC 0.08 (during a separate session from the phone conditions). Conversations consisted of answering a series of questions from the Rosenbaum Verbal Cognitive Test Battery (Waugh, Glumm, Kilduff, Tauson, Smyth, and Pillalamarri, 2000).

Drivers using a hand-held phone had a more-difficult time maintaining stable speed than those driving without a phone, conversing on a hands-free phone, or driving intoxicated. Intoxicated drivers also had more difficulty maintaining stable lane position than those conversing on either type of phone or driving without conversing. During the sign-detection task, sober participants conversing on both the hand-held and hands-free phones had slower Reaction Times (RTs) than those not conversing whether intoxicated or sober. In addition, intoxicated participants had slower RTs than sober participants. They also reported that there were more errors in their hands-free phone condition than while not conversing (whether intoxicated or sober).

Researchers at the University of Utah have conducted a number of studies on the effects of distraction on driving performance in a simulated vehicle (Strayer, Drews, and Johnston, 2003; Strayer and Drews, 2004). In particular, one study focused on comparing driving performance while intoxicated to driving while using a hand-held phone, a hands-free phone, or driving without conversing (Strayer, Drews, and Crouch, 2003). Only drivers in the alcohol condition received a beverage. They used a fixed-base simulator for a driving task consisting of car-following while driving on a multi-lane highway. Their cell phone task consisted of conversing with a research assistant on a topic of interest for both a hand-held phone and on a hands-free earpiece. There were no significant differences between hand-held and hands-free conversation, so these conditions were collapsed for the analyses.

Those engaged in the cell phone conversation were 8.4 percent more sluggish in reacting to the braking event. They also found that it took drivers conversing on the cell phone 14 percent longer to recover to normal speed as compared to the baseline condition, though the intoxicated participants had a similar recovery time to those sober and not conversing. Drivers in the cell phone condition drove on average 3.1 percent slower and at a 4.4 percent larger following distance than while in the baseline condition. The cell phone condition drivers also had 7.5 percent greater following distance and took 14.8 percent longer to recover the speed lost during braking than while intoxicated. During the cell phone condition there were also three rear-end collisions whereas the baseline and alcohol conditions produced no collisions.

Intoxicated participants applied 26.1 percent greater braking pressure than those conversing on the cell phone. The intoxicated drivers also had no differences with baseline for accident rates, RT, or recovery time. However, they describe the intoxicated drivers as having a more-aggressive driving style in that they had a 3 percent decreased following distance and braked with 23.4 percent more force than the baseline condition, which was speculated to be predictive of accidents

These two simulator studies explored how driving after having consumed alcohol compares to driving while using a cell phone, though neither study examined if both types of impairment would have additional detrimental effects if experienced at the same time.

DRIVER MODEL, DRIVING TYPE, AND TASK DEMAND

Driver Model

The following methodological approach was taken to define a driver model in the design of this experiment, presented in Figure 1-1. In this model, a task is seen as having a continuum of demand on the driver to apply resources (effort) to achieve operational goals. The driver will recognize increased task demand and apply greater effort. However, because humans have limited resources, there will be a point where no more effort can be generated. At this threshold, performance becomes more variable and may decline, with a probability of reduced safety and productivity.

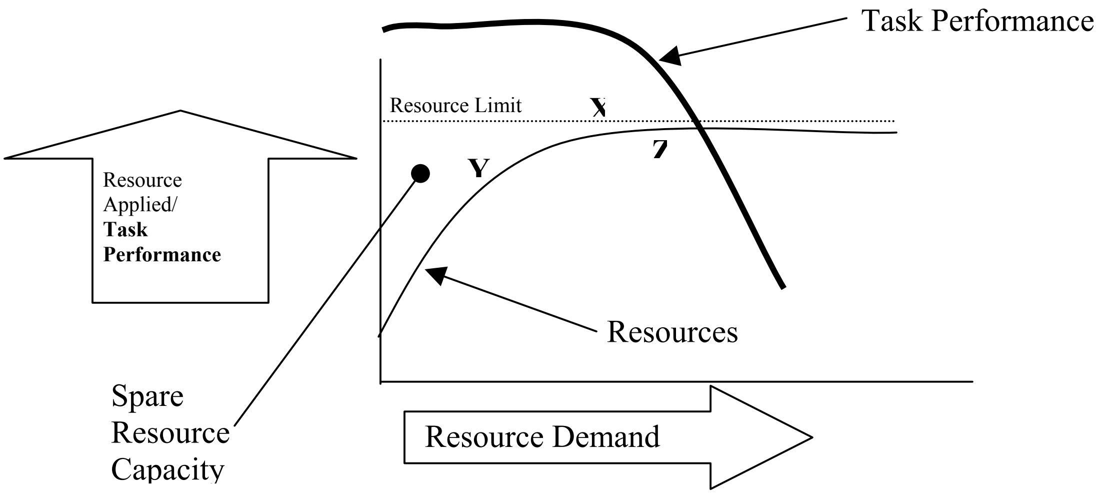


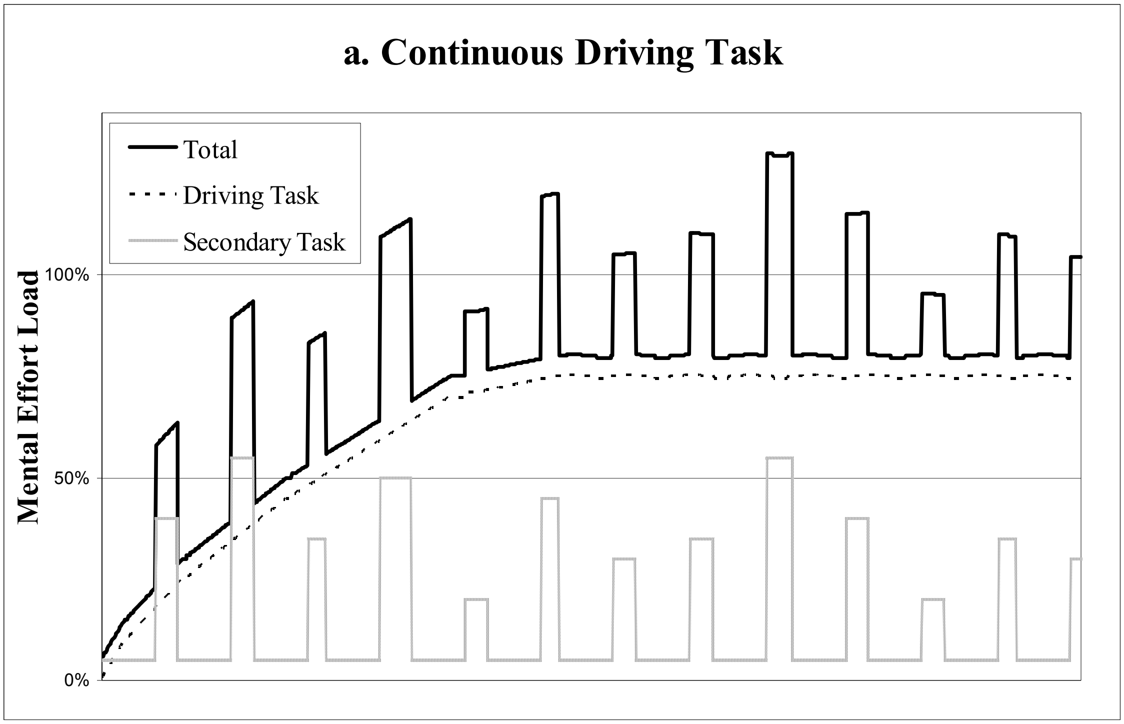
Figure 1-1 – Model task demand and threshold limits for task performance

The model can be used to examine the spare resource capacity (Y in Figure 1) that a driver has in reserve to apply to additional and unexpected demands during the driving task. This concept is critical to safety because it is the buffer that accommodates changing events in the operational context. This experiment was designed to load the participant with additional (secondary) task demands and measure the available increase in effort and amount of impairment in performance. Analyses were made in order to determine if secondary-tasks demanded a difficult but reasonable loading (Y to X) as opposed to loading that may otherwise be a risk factor (Y to Z).

Measurements of this loading may be accomplished by using performance-based assessment techniques (both primary and secondary), subjective workload assessment techniques, and physiological workload assessment techniques. These measures can also optimize the global sensitivity of performance-based measures or optimize our ability to differentiate between variations in task load imposed on driver mental processing through subjective and physiological measures (as outlined in Eggemeier, Wilson, Kramer, and Damos, 1991).

Driving Type

The amount of effort a driver had to put forth at any time depended upon both the driving type and task condition they were asked to complete during that particular continuous and episodic driving segment. The continuous driving segment in this study consisted of following another vehicle and constantly maintaining a safe headway. This type of task requires almost constant attention as can be seen by the dashed line in Figure 1-2a. This type of driving is referred to as a continuous task. In contrast, a number of episodic driving events were also included that consisted of a series of simple driving tasks to be accomplished by the driver which only demand attention of the driver at discrete times, as can be seen by the dashed line in Figure 1-2b.



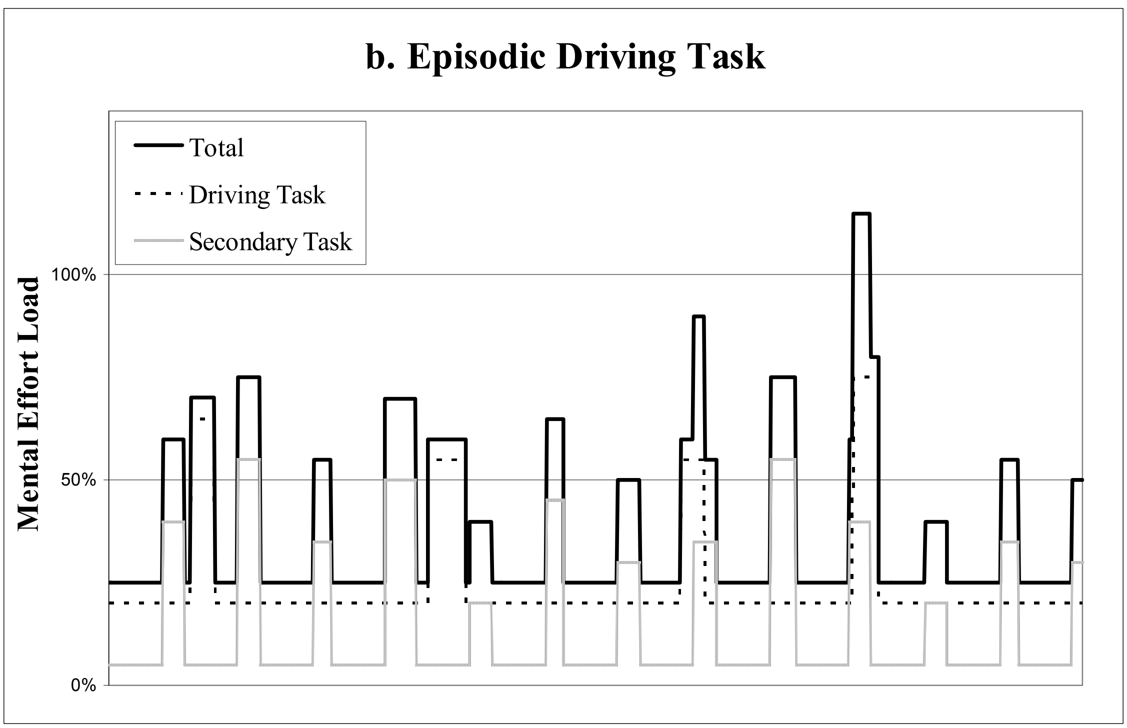


Figure 1-2 – Mental effort load during a) continuous, and b) episodic driving tasks

The demand imposed by the primary driving task is externally-paced. Figure 1-2 a) and b) also shows the amount of mental effort imposed by the same secondary-task (grey line). This secondary-task has various peaks in mental effort that are required to complete the task. These correspond to driver-paced interactions with the distracting device. Neither the primary driving task nor the secondary-task alone imposed an amount of effort greater than the driver's capacity (100 percent). However, engaging in the secondary-task while driving such that the demand of the secondary-task is added to the primary task (black line) will produce a combined effort that is greater than for either task alone, and which may exceed driver resource limits. In the case of the continuous task (Figure 1-2a) where effort demand is prolonged, the occasional demand of the secondary-task may more often exceed the capacity of the driver to safely perform resulting in driving impairment and an increase in crash risk. For the episodic task (Figure 1-2b), the additional demand can also increase risk by the same mechanism, but only at the coincidence of peaks in both primary and secondary-task demands. Thus, whereas the mechanisms of increased crash risk from distraction is the same for both continuous and episodic traffic scenarios, the increase in risk is more probable for continuous driving scenarios and coincidental for episodic driving events.

There are two related implications from the distinction between continuous and episodic traffic scenarios and the risk imposed by distracting tasks. First, increased crash risk from distraction is more probable during continuous tasks such as sustained car-following (Brookhuis, de Waard, and Mulder, 1994; Ward, Manser, de Waard, Kuge, and Boer, 2003). Second, research that examines distraction in the context of episodic traffic scenarios may find no evidence because chance did not produce a coincidence of primary and secondary-task demands that exceeded the capacity of the driver to cope (Rakauskas, Gugerty, Ward, 2004). A fair number of studies have found both continuous and episodic scenario measures to be sensitive to distraction. For these reasons, this study included both continuous and episodic traffic scenarios, but focused on the distraction impairment during the continuous task as the most relevant and sensitive scenario to examine the relative risk imposed by cell phone use.

Task Demand

Participants performed two sets of secondary-tasks: In-Vehicle tasks and Cell Phone conversation. These tasks were completed while sober and intoxicated (alcohol). Participants were told to do their best on the secondary-tasks, but that their main focus was to drive safely. The proportion of in-vehicle and cell phone tasks attempted and the proportion attempted during the car-following scenario were calculated as manipulation checks and potential performance variables.

In addition, half of the participants experienced a psychometric recording system consisting of a 40-channel Neuroscan NuAmp quick cap and arm leads. This allowed us to measure heart rate inter-beat interval (IBI), electrocardiogram (EKG), and electronic potential across the scalp, for which evoked response potentials (ERP) were recorded using an oddball task paradigm. For this task, participants were to press a pedal with their left foot when they heard the higher of two tones in order to measure accuracy and response time to the task.

Drivers were told that driving was their first priority. As shown in Table 0-2 during the different secondary-task conditions, resources were allocated differently depending on the task (Table 1-1).

Action	Dominant Source of Driver Input	Processing Modalities	Dominant Source of Driver Output
Driving	Visual	Spatial and Auditory	Manual (hands and right foot)
In-Vehicle Task	Visual	Spatial (and Auditory)	Manual (right hand)
Cell Phone Task	Auditory	Auditory and Spatial	Auditory

Table 1-1 – Resource allocation for driving and tasks

It is apparent that there are different mental effort resources dealing with input and output stages of processing as per Wickens' multiple resource model of time-sharing efficiency (1980, 1984, and 1991). Drivers are able to handle a limited amount of effort at each task stage and so if two tasks demand resources from the same modality a conflict may occur. For example, driving demands the driver to be attentive to visual input (verbal and spatial) of the driving scene, process this spatial and verbal information, and respond in a manual output through the wheel and pedals.

An in-vehicle task such as radio tuning also demands visual attention to the radio (input), spatial processing, and manual manipulation of radio controls (although auditory elements would normally play a part in radio tasks, the radio was silenced for our in-vehicle task). Since both the task and driving share the same modes of visual input, spatial processing, and manual output modalities, conflicts in processing may occur when the two actions are done concurrently. Conversing on a cell phone would demand auditory attention to the phone, verbal and spatial processing, and an auditory response. Since both conversing and driving share the same modes of verbal and potentially spatial processing, conflicts are also possible when the two actions are done concurrently. For both secondary-tasks, the conflicts were expected to result in degraded performance for both the driving and secondary-task. It also seems that driving while completing the in-vehicle task may be more impairing to driving performance than driving while conversing as on a cell phone.

OBJECTIVES

The aim of the study was to demonstrate the relative risk of hands-free cell phone use compared with other common secondary-tasks and alcohol:

1. How does the distraction of common in-vehicle tasks impact driving?
2. How does the distraction of cell phone conversations impact driving?
3. How does the impairment of alcohol impact driving and compound distraction effects?
4. Is the impact of cell phone conversations greater than performing common secondary-tasks or being intoxicated?

CHAPTER 2: METHODOLOGY

PARTICIPANTS

Fifty-three male drivers participated in this study. Participants had to be at least 21 years old, live within a distance to the university (or on a bus route) that permitted them to walk to and from the on-campus experiment location, and report no evidence of alcoholism as assessed by the CAGE alcoholism screening instrument (Mayfield, McLeod, and Hall, 1974). Five participants from this initial sample were excluded from the analyses (two drivers in the control condition did not finish due to having symptoms of simulator-induced discomfort and three other participants experienced problems with particular scenarios during their experimental run).

The 48 remaining participants comprised the final test sample. Table 2-1 presents the mean value and range for the general demographic, driving history, and sensation seeking (SSS; Zuckerman, 1994) measures. There were no significant differences between the Alcohol (n = 24) and Control (Sober) groups (n = 24) for all measures. The complete set of results from the Driving History Questionnaire can be found in Appendix I.

Table 2-1 – Averages (and range when applicable) of sample characteristic measures (N = 48)

Measure	Alcohol	Control	All Drivers
Age [years]	22.3 (21-29)	22.2 (21-28)	22.3 (21-29)
Years with license	6.6 (4-13)	6.5 (5-13)	6.5 (4-13)
Sensation Seeking Scale [score from 1 – 13]	6.0 (0 – 12)	6.2 (0 – 11)	6.11 (0 – 12)
Weekly alcohol consumption [number of drinks]	9.1 (1 – 20)	8.3 (0 – 21)	8.5 (0 – 21)
Annual Mileage [multiple choice- mode is shown]	5k to 10k	5k to 10k	5k to 10k
Frequency of work commute [multiple choice- mode is shown]	Every Day	Most Days	Most Days
Convicted – Careless Driving in past 3 years [% of sample]	4.3%	0.0%	2.2%
Convicted – Speeding in past 3 years [% of sample]	47.8%	52.2%	50.0%

DRIVING SIMULATOR

The study used the Virtual Environment for Simulation in Transportation Research (VESTR). This immersive, motion-base driving simulator is linked to a full-sized Saturn vehicle with realistic operational controls and instrumentation. The visual scene is projected with a high-resolution (2.5 arc-minutes per pixel) five-channel, 210-degree forward field of view with 50-degree rear projected field of view and side mirrors comprised of color LCD panels. Auditory feedback and haptic feedback were provided by a 3D surround audio system, subwoofer, car body vibration, force feedback steering, and a three-axis electric motion system (roll, pitch, and z-axis). The vehicle was equipped with a Compaq iPAQ 3635 Pocket PC mounted on the dashboard near the driver to display the in-vehicle task instructions.

PRIMARY DRIVING TASK

The simulated driving environment was based on roads in northern Minnesota and comprised of a realistic rural highway with one 2-way-STOP intersection (see diagram in Figure 2-1). It was developed and configured to assess several types of driving performance on a range of driving scenarios.

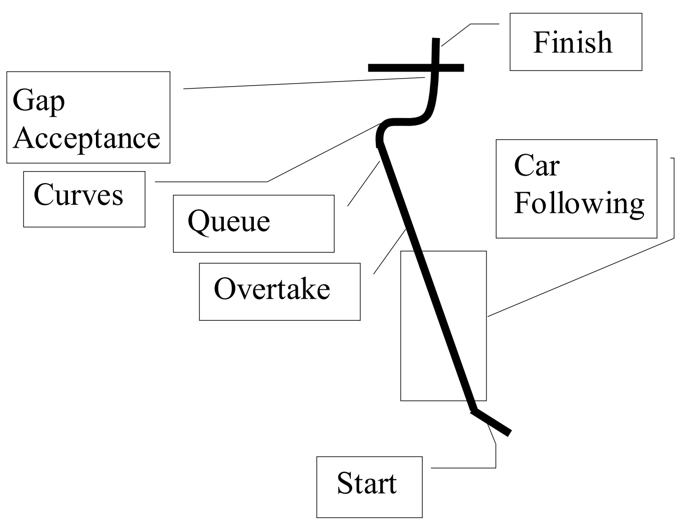


Figure 2-1 – Scenario path and approximate location of driving tasks

Audio instructions and cell phone conversations were conducted via recorded digital audio files triggered by the subject car's location in the virtual environment. These audio files were played through a representation of an after-market hands-free phone speaker system in the front of the car. In-vehicle task instructions were also triggered by similar means and displayed on the small IPAQ display on the dashboard.

Each trial consisted of driving the same simulated experimental route, with minor variations in each of the driving performance tasks. Driving scenarios were developed to represent either a continuous or an episodic level of primary task demand (see Figure 1-2).

Continuous Primary Task

The continuous primary task scenario required driver vigilance to maintain a constant safe headway while following another vehicle that randomly varied its speed (to potentially produce a fluctuation in headway if the driver did not compensate by adjusting speed; see Figure 1-2a). At the start of this scenario, the participant was told to begin driving in the right lane and to approach a car driving ahead of them in their lane (see Figure 2-1). This car would then begin to change its speed and the participant was to try and adjust their speed accordingly and maintain a constant safe following distance. To motivate driver awareness of primary task performance during this scenario, red text stating "please follow closer" was provided in the driver forward field of view if they failed to maintain a time headway of less than four seconds. The lead vehicle's taillights did not light during decelerations, as they would not typically light on a vehicle releasing the accelerator in order to slow down in higher-speed highway conditions.

The "coherence technique," established in Brookhuis, de Waard, and Mulder (1994; modified by Ward, Manser, de Waard, Kuge, and Boer 2003) was used to develop this scenario and quantify performance. This methodology has been found to be sensitive to both increased primary and secondary-task loading. In this application, the participant driver followed the lead vehicle as it changed speed with a varied cycle and fixed amplitude:

- Practice – 30 seconds of driving between 60 and 70 mph with a randomly varying cycle of .02 Hz to .04 Hz (i.e., cycles of 25 to 50 seconds).

- Low-frequency range – 2 minutes of driving between 55 and 75 mph with a randomly varying cycle of .02 Hz to .04 Hz (i.e., cycles of 25 to 50 seconds).

- High-frequency range – 2 minutes of driving between 55 and 75 mph with a randomly varying cycle of .06 Hz to .12 Hz (i.e., cycles of 8.33 to 16.66 seconds).

The switching amplitudes were continuously chosen at random within the given range, so as to make speed changes appear to be completely random to the participant.

Episodic Primary Tasks

The episodic primary tasks consisted of a series of driving events that only demanded peak attention from the driver for short episodes (see Figure 1-2b). The relative location of these tasks in the driving scenario can be found in Figure .

Overtake
After the car-following was completed, the lead car slowed and stayed at 55 mph. The subject was told to overtake the lead vehicle as quickly and safely as possible, then to return to the right lane.

Curve
The subject drove through a mild curve (Entrance to Exit Length = 683 m, Radius = 593 m, constant elevation) in the right lane.

Traffic queue
In this scenario, the participant encountered a slow moving traffic queue in the right lane. There were nine cars following a slow lead truck (35 mph) each with a time headway of two seconds. These vehicles were all identical in appearance, aside from the truck.

Participants were told to maintain the speed limit while overtaking the row of traffic and then return to the right lane after passing the lead truck. While passing, one of the cue vehicles was randomly chosen to pull out in front of the subject with a time-to-contact (TTC) of three seconds; this vehicle was always one of the four odd-numbered cars in the queue (either the third, fifth, seventh, or nineth car encountered by the participant). This car then passed the next vehicle in the queue and returned into the right lane.

Gap acceptance
While approaching the intersection, participants were told to stop at the Stop sign before proceeding through the first gap they perceived to be safe. To do this, they were to drive through crossing traffic by choosing a safe gap in a stream of cars coming from their right. All cars were identical, traveled at around the speed limit, and had dynamic motion capability. The first five cars in the approaching row had a 0.5 second time headway [TH] (to force the participants to wait at the stop sign for a minimum time period), and the gap between subsequent cars increased by 0.25 seconds. This was construed as a risk-taking situation represented by the size of the gap accepted.

SECONDARY-TASK CONDITIONS

Two types of consensual risk secondary-tasks were developed to represent different combinations of resource allocation to information input, processing, and output response in relation to primary driving task resources (see Table 1-1). The cell phone task was an audio input and verbal output task while the in-vehicle task was a visual input and manual output task. Thus, the two tasks required different modes of attention and response.

In-Vehicle Secondary-task Condition

A Compaq iPAQ mounted on the dashboard was used to display images of the radio and HVAC system. Note that visual instructions were used instead of audio instructions because (1) visual input is typical for use of in-vehicle controls, (2) pictorial representation may be most similar to mental intentions that initiate decisions to operate an in-vehicle control, and (3) using audio instructions would be too similar in form to the reproduction of a cell phone conversation in terms of input resources (see Table 1-1).

The screen showed an image of a system setting to signify that the participant was to copy the setting depicted on the actual vehicle controls; the four categories of settings can be seen in Figure 2-2. For example, if we wanted them to change the heat setting to maximum heat, we presented an image of that HVAC temperature knob (Figure 2-2c) turned all the way into the red. Each picture shown was preceded by one second of flashing to alert the driver to a new task instruction (250 ms white, 250 ms image, repeated).

- Buttons with indicator light:
    - A/C (pictured in Figure 2-2a.)
    - Rear defrost
    - Internal circulation
- Air flow settings; knob settings
    - Dash (pictured in Figure 2-2b.)
    - Dash/feet
    - Feet
    - Defrost/feet
    - Defrost
- Temperature settings; knob at approximately:
    - 210^{o}
    - 135^{o}
    - 90^{o}
    - 45^{o} (pictured in Figure 2-2c.)
    - -30^{o}
- CD track; FF, RW buttons to change to track:
    - 1
    - 5
    - 7
    - 10 (pictured in Figure 2-2d.)
    - 12

Figure 2-2 – In-Vehicle secondary-task categories, a. Buttons with indicator light, b. Air flow, c. Temperature setting, and, d. CD track

Pictures were selected randomly so that no group was picked sequentially and that selections from the same category were not repeated.

Cell Phone (Hands-Free) Secondary-task Condition

The conversation tasks were based on questions from the Rosenbaum Verbal Cognitive Test Battery (Waugh et al., 2000) and used in the TRL study (Burns et al., 2002). These verbal tasks were in the form of "conversations" intended to represent different levels of mental demand by measuring judgment and flexible thinking in a limited response time. The questions were evenly taken from all five original levels of task difficulty, which were validated in the TRL study for driving performance measures of distraction. The selected conversations were recorded and automatically triggered by the simulator. The complete list of questions is presented in Appendix G, consisting of the following categories:

- Conversation Files - These consisted of Repeat Sentence (RS) and Verbal Puzzle (VP) categories of conversation file, and ranged in presentation time from 5 to 12 seconds. Conversation files were selected in alternating order from the RS and VP categories.

- Monologue Files - These consist of Monologue (M) conversation files and ranged in presentation time from three to five seconds, thus allowing more time to respond to the task than during the Conversation Files. These files were played during times where we wanted the driver to be continuously engaged in conversation. If the participant stopped responding for a few seconds, the experimenter asked relevant follow-up questions to maintain a naturalistic conversation.

The messages were sent through the front interior speakers of the car to represent an after-market hands-free cell phone speaker system. The experimenter monitored the conversations to make sure the participant was completing the conversation in order to motivate the participant to respond. Specifically, the experimenter would interact with the participant by engaging in naturalistic conversation as appropriate to prompt the participant to continue with the monologue.

Secondary-task Validation

The cell phone conversation and in-vehicle task sets were intended to represent different resource requirements (see Table 1-1), but represent a comparable level of task demand. These assumptions were validated with a series of subjective questions and an analysis of secondary-task performance.

A full evaluation of measures that validate the In-Vehicle and Cell Phone tasks can be found in Appendix F. In summary, the In-Vehicle and Cell Phone Tasks were found to be equally effortful. Thus, if differential effects between them are obtained in subsequent analyses, then these effects should not be attributed to differences in the amount of task difficulty but rather the specific type of processing resources required (and any competition with resources required for the primary driving task).

However, there were some interaction effects of Alcohol group for secondary-task performance. Control group drivers attempted a significantly smaller percentage of Cell Phone tasks than In-Vehicle tasks, indicating that these sober drivers may have been actively regulating their responses (i.e., not performing the Cell Phone task) so as to focus their attention on the car-following task and on maintaining safe driving performance. In addition, intoxicated drivers had missed or ignored more of the In-Vehicle tasks than the Cell Phone tasks, suggesting that drinking impaired the drivers' ability to attend to and manually respond to visual information presented in the vehicle.

INDEPENDENT MEASURES

Participants drove the same experimental route three times, once under each of the following conditions (in counter-balanced order):

1. No distraction (*Baseline*)
2. Common *in-vehicle* tasks
3. *Cell phone* conversations

Design

BAC group was a between-subjects factor. Participants were evenly distributed to either the Control (placebo beverage) or Alcohol (intoxicating beverage) groups.

ERP group was also a between-subjects factor. Participants were evenly distributed to either the ERP (experienced the ERP tone task and physiological recording methodology) or Non-ERP (did not experience the ERP tone task or physiological recording methodology) groups.

This experiment had a 3 (Task Condition: Baseline, Cell Phone, In-Vehicle) x 2 (BAC Group: Alcohol, Control) x 2 (ERP Group: ERP, Non-ERP) mixed model design, as outlined in Table 2-2.

Table 2-2 – Participant numbers by condition

	ERP	Non-ERP
Control	01 – 12	13 – 24
Alcohol	25 – 36	37 – 48

DEPENDENT MEASURES

A comprehensive set of subjective, behavioral, and physiological measures were used to analyze participant characteristics and ability to perform the primary driving tasks in terms of driving performance, mental resource allocation, and environment awareness.

Demographics

Each of the demographic questionnaire types below were only given once over the course of the study. All questionnaires can be found in Appendix E.

Driving History Questionnaire
This questionnaire has a number of questions relating to each participant's driving history and trends. It is mostly multiple choice questions (between two to six options) with a few short open-ended responses. These questions were used to establish a description of the drivers sampled by comparing them in terms of driving experience, road violations, and demographics. Results are presented above in Table 2-1 of the Participants section.

Sensation Seeking Scale (SSS)
This survey is the shortened form of the full SSS and is used to determine if participants have a tendency to seek out or avoid risky situations and actions (Zuckerman, Eysenck, and Eysenck, 1978; Zuckerman, 1994). Participants are presented 13 pairs of statements and instructed to indicate, "… the choice that best describes your likes or dislikes, or the way you feel." Participants then receive an overall score by the number of times they agreed with the more-sensation-seeking statement of the pair. A high score on the SSS indicates that the participant has a propensity to be a risk-taker and to put themselves in more dangerous situations. A low score indicates that the participant tends to avoid risky situations. Results are presented above in Table 2-1 under the Participants description section.

Cell Phone Survey
This survey consists of a number of questions relating to each participant's cellular phone opinions and usage tendencies. It is mostly multiple choice questions (between two to eight options) with a few short open-ended responses and opportunities to comment. These questions were used to establish a description of the participant's cell phone usage as well as their feelings towards cell phone legislation limitations.

Distraction Survey
This survey instructs participants to rate a number of tasks that are often encountered while driving by indicating on a scale from 1 (not at all distracting) to 10 (very distracting). The tasks include cell phone conversations, text messages, tuning the radio, and reading a map (among others). There is a large section allowing participants to comment or suggest further on cell phone use. These questions were used to establish a

description of the drivers' understanding of how the driving setting is affected by distractions.

Driving Capability Questionnaire
The Driving Capability questionnaire shows the five questions asked after each condition as well as the additional question asking participants to approximate the number of drinks they had consumed (only asked during recovery). The questions related to how capable or willing the participants would be to drive at that moment. They were instructed to answer by striking a continuum between "not at all" to "extremely".

During the recovery period, the questionnaire was modified to have participants approximate how many alcoholic drinks they had consumed. These questionnaires were used to establish driver's subjective feeling of being drunk, including any placebo effect for the sober condition. Results from this questionnaire are presented in the BAC Manipulation Validation section.

Driving Performance Measures

These measures were recorded from simulator driving performance data.

Continuous Primary Task (Car-Following) Performance
Specific to the coherence technique, the following measures were taken:

- Coherence – a measure of correlation between the speed signals from the lead vehicle and the participant's vehicle.
- Modulus – a measure representing the amplification of the participant's speed signal with respect to the load vehicle.
- Phase shift (delay) – a measure of the lag between the speed signals of the lead vehicle and the participant's vehicle.

Good performance on these measures would be indicated by larger (positive) coherence values as well as smaller delays and modulus values. Impaired performance would be indicated by smaller coherence as well as larger delays and modulus values.

Driving performance was also quantified by the following measures:

- Median time headway [seconds].
- Time headway variability (standard deviation) [seconds].
- Steering reversals – Mean number of steering reversals computed with a two-degree filter (Verwey and Veltman, 1996) [count]. For further explanation, see Appendix H.

- Steering entropy – a measure of the predictability of the driver's steering responses, as defined in Nakayama et al. (1999; also see Boer, 2000). For further explanation, see Appendix H.

- Lane Position Variability (safety margin) – variation (standard deviation) in inverse time to line crossing (TLC^{-1}) [seconds]. Data was analyzed as the reciprocal of TLC (TLC^{-1}) to eliminate large values (infinity) when the vehicle vector is parallel to the lane boundary.

Good performance on these measures would be indicated by larger safety margins and time headways as well as smaller variation in headway, number of steering reversals, and steering entropy. Impaired performance would be indicated by smaller safety margins and time headways as well as larger variation in headway, number of steering reversals, and steering entropy.

These measures will be presented in the following order: median time headway, time headway variability, coherence, modulus, phase shift (delay), steering reversals, steering entropy, and lane position variability (TLC^{-1}). Median time headway shows compensation strategy. Time headway variability shows overall performance on primary task goal of maintaining a constant headway. Coherence, modulus, and phase shift will explain the nature of any impairment. Steering and lane position variables are other measures showing the workload imposed from impairment on driving performance. In this sense, these variables will show that distraction may not only impair primary task performance (i.e., longitudinal control) but also may spill over to non-primary driving, in this case, lateral control.

Overtake

The Overtake scenario started when the midline of the vehicle crossed the midline of the road, as it moved to the left. It ended when the midline of the vehicle crossed the midline of the road, as it moved to the right (once the lead vehicle has been passed). During this period, driving performance was quantified by the following measures:

- TTC at the start of the overtake maneuver; expressed as the inverse TTC (TTC^{-1}) [1/seconds]

- TTC at the end of the overtake maneuver; expressed as the inverse TTC (TTC^{-1}) [1/seconds]

- Duration of the overtake maneuver [seconds]

- Maximum lateral acceleration [miles per hour/seconds]

Good performance on these measures would be indicated by low TTC^{-1} values, shorter overtake durations, and slower maximum lateral accelerations. Impaired performance would be indicated by high TTC^{-1} values, longer overtake durations, and slower accelerations.

Curve

The curve performance measures are related to the start, apex, and end of the curve. Driving performance was quantified by the following measures:

- Speed at curve apex [miles per hour]
- 85^{th} percentile deceleration rate between entrance and exit [miles per hour]
- Variability (standard deviation) in lane position [meters]

Good performance on these measures would be indicated by lower speed, deceleration rates, and lane position variability. Impaired performance would be indicated by higher speed, deceleration, and variability.

Traffic queue pullout event

The vehicle pullout event starts when the command is sent for the vehicle to start pulling out. Driving performance for the pullout event was quantified by the following measures:

- Reaction Time- elapsed time from start of pullout event to acceleration release (accelerator input = 0) [seconds]
- Movement Time- elapsed time between acceleration release (accelerator input = 0) and brake press (brake input > 0) for pullout event [seconds]
- Response Time- elapsed time from start of pullout event to brake press (brake input > 0) [seconds]

Good performance on these measures would be indicated by faster (smaller) reaction, movement, and response times. Impaired performance would be indicated by slower (larger) reaction, movement, and response times.

The position of the car that pulled out was checked to make sure the event car was evenly distributed across Task conditions and BAC groups. Results from Wilcoxon signed ranks tests showed no significant differences between specific Task conditions or between BAC groups within each Task condition. This indicates that the car chosen to pull out was sufficiently random and allows us to analyze the pullout data assuming that drivers did not come to expect a particular vehicle to pull out.

Gap acceptance

The start of the gap scenario was defined as when the first vehicle in the traffic stream crossed the intersection and when the participant's vehicle speed was less than 3 mph. After stopping at the intersection, participants were considered to have begun crossing when they hit the accelerator pedal. They were considered to have finished crossing when their car reached the opposite side of the intersection. Driving performance was quantified by the following measures:

- Time Headway of accepted gap [seconds]
- Movement time – Elapsed time from moment subject accelerates (acceleration rate > 0 and accelerator pedal input > 0) to end of gap scenario [seconds]
- Safety margin (TTC - Time to Contact) between subject vehicle (when midline of subject vehicle is in midline of lane where the gap is) and next nearest car that defines the gap; expressed as the inverse TTC (TTC^{-1}) [seconds]
- Number of Collisions [count]

Good performance on these measures would be indicated by larger gap headways, movement times, and safety margins as well as fewer collisions. Impaired performance would be indicated by smaller headways, movement times, and safety margins as well as more collisions.

Resource Allocation

In addition to measuring driving and secondary-task performance as a metric of mental workload and the driver's ability to handle multiple tasks effectively, we were interested in other ways to unobtrusively measure resource allocation. Wierwille (1981) recognized that assessing workload is difficult to do in that many commonly used measures implicitly require averaging quantified effort over time. Though useful in reporting an overall stable level of workload, instantaneous metrics taken alone mask the moment-to-moment fluctuations in workload level or task demand. This may potentially lead to the conclusion of low workload during a task when in fact there are several intense demands over short intervals hidden amongst the longer intervals of lower load.

Instantaneous measures that monitor the drivers resource allocation moment-by-moment throughout the drive will be able to discern what particular portions of the drive were most taxing or too demanding for the driver. Antin and Wierwille (1984) attempted to measure instantaneous mental workload (IMWL) by evaluating measures on visual search and number averaging tasks. They found that the most effective and non-intrusive means of measuring mental effort were by RT on a visual search task and verbal online subjective opinion. In addition, a subjective opinion via continuous control method was also found to be useful. Our ERP protocol is similar to this method and is more robust in that multiple psychophysiological measures were also taken simultaneously.

In addition, subjective measures of mental effort have been found to be sensitive to processing load that can be clearly represented in working memory (Hart and Staveland, 1988; Liu and Wickens, 1994; Verwey and Veltman, 1996; Zijlstra, 1993) while also being easily quantifiable by research participants.

For these reasons, it is recommended to gather both averaged and instantaneous workload measures. We have accomplished this by collecting averaged subjective mental effort ratings (RSME scale) and heart rate (IBI) as well as instantaneous psychophysical (ERP) and behavioral performance measures. This will allow us to compare and validate numerous mental load metrics.

Subjective Effort

The Rating Scale of Mental Effort, or RSME, is a univariate scale for rating mental effort or workload and has been shown as a good measure of mental effort in cases where a secondary-task is presented (Zijlstra, 1993). It was administered in order to subjectively assess and compare the amount of driving effort the participant had experienced during that driving trial. An additional RSME was administered in order to assess and compare the amount of effort it took to complete the cell phone and in-vehicle secondary-tasks while driving. All versions of the RSME can be found in Appendix E. Participants marked the place on the continuum that best described the level of workload they just put forth.

Physiological Effort (IBI)

An additional between-subjects factor was physiological response in the form of inter-beat interval (IBI), measured during in the ERP paradigm (ERP group only). Electrocardiogram (ECG) readings were recorded from the left and right forearms just below the elbows with two 1 cm Med Associates Ag-AgCl electrodes filled with electrolyte paste to record heart rate IBI. This ECG reading was taken in order to psychophysiologically assess drivers' levels of resource allocation during the three experimental conditions.

From the ECG, R-peaks were detected with one millisecond accuracy and these were time-stamped written to file. After artifact correction, power spectral analyses were computed with aid of the CARSPAN (CARdiovascular SPectral ANalysis) programme. To reduce inter-individual differences, a natural logarithmic (Ln) transformation was performed on the power spectra data (Van Roon, 1998). In general, a lower IBI indicates that a driver has an increase in heart rate and is indicative for increased controlled information processing and increased mental effort.

Psychophysiological Measures (Mental Processes)
Participants that were monitored for IBI were also asked to complete an evoked response potential (ERP) oddball paradigm. ERP readings were taken in order to psychophysiologically assess drivers' levels of resource allocation during the three experimental conditions by having them complete a tertiary task. Such recordings of mental processes have been found to be a useful physiological measure for road safety research (Michalski and Blaszczyk, 2004).

The oddball task includes a series of tones presented in succession at variable or uniform intervals. Two types of tones are heard: a standard tone (presented frequently, anywhere from 70 to 90 percent of the time), and a target tone of a different pitch (the "oddball") is presented infrequently. The task is to overtly respond to the target tone. Sometimes a task-irrelevant, unexpected or novel sound (e.g. dog bark, alarm clock) is presented at a similar frequency as the target.

In the current experiment the oddball task serves as a tertiary task; it is preformed concurrently with the primary driving and secondary-tasks. As task demand increases in the driving task, less processing resources are allocated to the oddball task, which is reflected in the physiological and behavioral response. For example, when driving conditions become more challenging, cognitive processing of the target tone will attenuate and successful responses to the target tone will also diminish. By measuring cortical responses to the oddball task, workload levels during various driving conditions can be inferred and subsequently contrasted. This technique is effective in assessing workload because the subject's normal ability to establish a pattern or expectancy based on past experience is disrupted with the imposition of additional central-processing loads, such as with our secondary-tasks (O'Donnell and Eggemeier, 1985). This is the case, as long as the task is kept relevant in a consistent way to the participant; we have done this by requiring a manual (foot) identification response for the oddball tones.

Physiological measurements to the oddball task employ electroencephalogram (EEG) recordings. Surface electrodes placed on the scalp directly gauge the brain's activity during a task. Within the overall recording, cortical-evoked ERPs are time-locked to the novel and target sound stimuli. ERPs are averaged over time and contain a series of negative and positive signal elements (see Figure 2-3). Particularly relevant is the amplitude of a positive signal, peaking around 250 to 500 ms after the onset of the stimulus of interest, known as the P300. Many studies have shown P300 amplitude to be inversely related to stimulus probability (Duncan-Johnson and Donchin, 1977; Squires, Wickens, Squires and Donchin, 1976), and therefore, target tones and novel sounds maintain the largest P300 amplitudes in the oddball task.

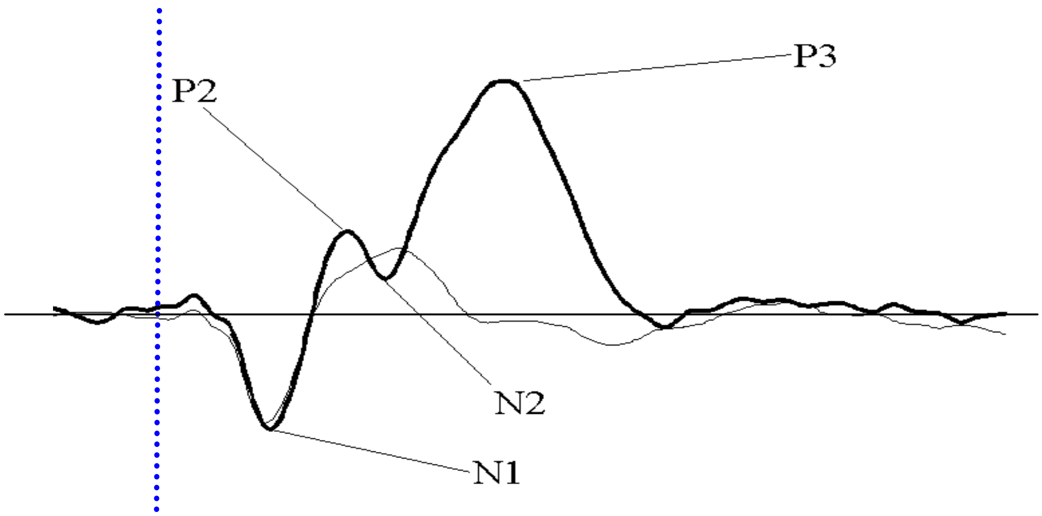


Figure 2-3 – Typical EEG response to oddball (thick line) and standard (thin line) tones during an oddball task (triggered at vertical dashed line) [Note: "P300" is abbreviated as "P3" in this figure]

P300 amplitude has proven an effective measure of workload when employed as a secondary-task. As an increasing amount of processing resources are dedicated to the primary task, the ability to formulate a pattern of expectancy to the target and novel sounds is proportionately interrupted, and consequently, the P300 amplitude to these sounds is proportionately attenuated (Wickens et al, 1977; Isreal et al, 1979).

This method of workload measurement has also successfully been employed within simulated environments. In 1987, Kramer et al., took ERPs to an oddball task while participants performed concurrent tasks during a flight simulation. They concluded that P300 amplitude to the target tones consistently indexed changes in flight difficulty. Similarly, Sirevaag et al. (1993) took ERPs to irrelevant probes during a helicopter simulation and they found smaller P300 amplitudes to the probes as workload increased in the flight task. During a car-driving task, Janssen and Gaillard (1984) were able to discriminate task load within three distinct road environments by measuring P300 amplitude during an oddball task.

Experimental Stimuli
A 1000Hz tone and a 2000Hz tone were used for the standard and target tone respectively. Two categories of novel sounds were employed:

- Traffic-related sounds (e.g. horns, screeches, crashes).
- Various non-traffic-related sounds (e.g. human screams, buzzers, animal sounds).

Novel stimuli were drawn from:

- The International Affective Digitized Sounds (IADS), a collection of 116 naturalistic sounds designed for the study of emotion (Bradley and Lang, 1999)
- A previously used collection of random digital noises (Kiehl et al., 2001)
- Multiple non commercial sound effect sources on the Internet.

All sounds were shortened to 200ms for use in the study. To assess the quality of the sounds, the full set (N=240) was rated for valence and arousal using the Self-Assessment Manikin (SAM; Lang, 1980). SAM ratings consist of a Likert scale ranging from 1 to 9 from "most calm" to "most excited" for arousal and "most pleasant" to "most unpleasant" for valence (*degree of attraction or aversion toward the sound*). Only sounds rated negative in valence were considered for selection.

Based on these ratings, traffic-related sounds (N=42) and non-traffic-related sounds (N=42) were selected to maximize the rated arousal (M= 6.37, SD=.71) and negative valence (M=6.50, SD=.67). Sounds were selected from the larger set such that there were no significant differences between valence ratings of the selected traffic-related novel sounds (negative valence: M=6.59, SD=.76) and the selected non-traffic-related novel sounds (negative valence: M=6.42, SD=.56; $t(82)=1.203$, $p < .20$). There was a trend for the arousal ratings of the selected traffic-related novel sounds (arousal: M=6.51, SD=.65) to be higher than the arousal ratings of the selected non-traffic-related novel sounds (arousal: M=6.23, SD=.74; $t(82)=1.79$, $p<.08$). For more in-depth analysis, a subset of these sounds were selected to represent medium (arousal: M=5.91, SD=.63; valence: M=6.04, SD=.37) and high (arousal: M=6.83, SD=.47; valence: M=6.99, SD=.53) intensity categories (increased arousal and valence) between which there were no significant differences ($t(58)<1.0$).

Stimulus Delivery and Physiological Response Measurement

During each Task condition, 280 stimuli were presented (224 standards, 80 percent; 28 targets, 10 percent; 28 novel sounds, 10 percent). Three stimulus orders were used for each subject to balance stimulus presentation across participants. Stimuli were pseudo-randomized within each order such that no more than one target or novel sound occurred in succession. No novel sound was heard more than once over the course of the experiment, and equal numbers of traffic and non-traffic sounds of high and low intensity were presented within each experimental condition.

All stimuli were presented at 22.05 kHz (16 bit, stereo) with a two-second fixed ITI. Sounds were heard through computer speakers placed on the car floor behind the driver's seat. The volume was adjusted to play at approximately 70 dB. An IBM-compatible computer running E-prime software (MEL software Inc.) controlled the stimulus delivery.

Another IBM-compatible computer was used to collect the electrophysiological data using the Neuroscan NuAmp software. EEG/ERP measurements were collected using the Neuroscan NuAmp 40-channel Quick-Cap (Figure 2-4), where conductance was recorded at these electrodes: FP1, FP2, F9, F7, F3, F2, F4, F8, F10, FT7, FC3, FCZ, FC4, FT8, T3, C3, CZ, C4, T4, TP7, CP3, CPZ, CP4, TP8, T5, P300, PZ, P4, T6, O1, OZ, O2. Electrodes were filled with electrolyte paste. ERP group participants were to complete a typical auditory oddball paradigm with a novelty component. Responses to the targets were collected with a MEL foot pedal attached to the interior of the car floor to the left of the brake pedal.

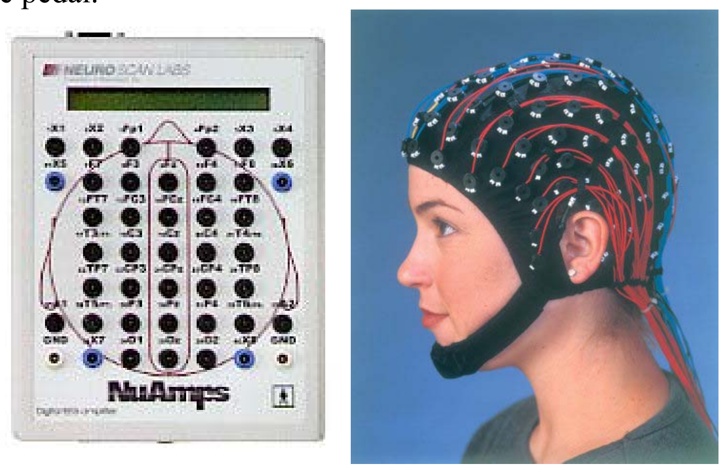


Figure 2-4 – Neuroscan NuAmp Amplifier and Quick Cap

For most participants, the ERP task ended just after they arrived at the STOP sign. For this reason, no ERP group effects were analyzed for the Gap Acceptance scenario. As this task was tertiary, completing (or not completing) this task was considered an additional measure of mental workload in that drivers were told their first priority was driving and they may regulate performing this and the secondary-tasks (cell phone and in-vehicle tasks) appropriately in order to safely drive their vehicle.

Effects of ERP Manipulation

In order to see if the ERP manipulation itself was having an effect on each participants' driving performance, analyses were performed on all measures to compare the 24 participants who completed the ERP paradigm to those who did not. There were only three measures that were affected by the ERP manipulation. More steering reversals [$F(1,44) = 9.27$, $p < .01$] and steering entropy [$F(1,44) = 9.85$, $p < .01$; were present during the car-following task for those completing the ERP paradigm than those who did not. Also, drivers' maximum speed during the overtake maneuver (episodic task) was slower than that of drivers not completing the ERP paradigm [$F(1,44) = 9.85$, $p < .01$]. In that these are the only measures where ERP had a significant difference in performance, this suggests that the ERP manipulation was relatively unobtrusive to normal driving performance.

Measures
Psychophysiological measures of mental processes were quantified through performance measures and metrics of attention resource allocation. The performance measures consisted of:

- Reaction Time (RT) to the target tones [milliseconds]
- Target Tone Accuracy, as the percentage of correct responses
- Total Errors, as a total of the number of false positive responses and the number of missed targets

There were no significant effects for P300 response to the target tones as expected at the Fz (frontal), Cz (central), and Pz (parietal, rear) electrodes. Therefore they are not described here in the methods or presented in the results. The remaining attention resource allocation measures consisted of:

- Novel Sounds P300 – P300 response to the novel sounds at the Fz (frontal) and Pz (parietal, rear) electrodes [μV, stated as mV in graphs]
- Novel Sounds Topographical P300 – comparison of P300 response waves from all electrodes (see example in Figure 2-5). To the left, the entire P300 waves for both conditions being compared are shown in comparison. To the right, the differences in particular electrodes are shown by color (red indicates the condition represented by the red line has a more positive μV, blue indicates the condition represented by the blue line has a more positive μV). The right-most head model shows significant differences ($p < .05$) in white

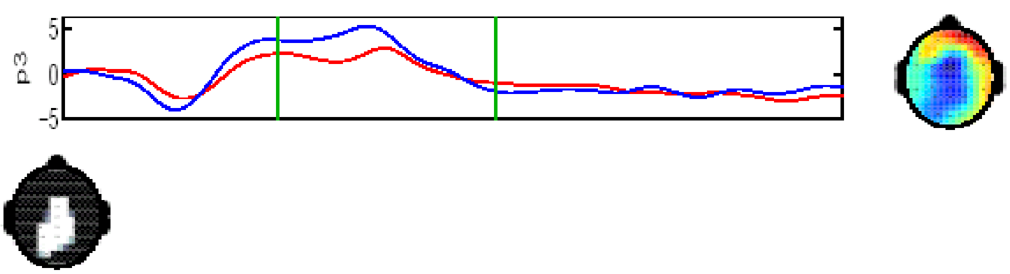


Figure 2-5 – Example ERP of P300 response (between vertical lines) for drivers' responses between two conditions (blue and red waveforms), and location and significance of differences (head models)

Data Reduction
ERP data was epoched from 500ms before stimulus delivery to 1000 ms post-stimulus. P300 measures were taken as the peak amplitude between 250 and 500 ms, relative to an equivalent 150 ms of baseline activity. A correction procedure was applied to adjust for vertical and horizontal ocular artifacts (Semlitsch, Anderer, Schuster, and Presslich,

1986). Trials on which amplitude in the 1000 ms post-stimulus window exceeded +/- 100 μV were excluded from further analysis. Analyzed data was taken from all electrodes, with emphasis on the frontal (Fz), central (Cz) and parietal sites (Pz) that are distributed along the anterior to posterior midline of the brain. Past research has localized the novel P300 (often referred to as P3a) as a maximally fronto-central (Fz-Cz) effect, and the target P300 (often referred to as P3b) as a maximally parietal (Pz) effect (Comerchero and Polich, 1999).

Expectation
The ERP tone task may be a general motivator for being more aware of the driving environment for drivers not overburdened by manual responses (see resource allocation overview in Table 1-1). Therefore, measures focusing on environmental awareness (such as the sign response task) may exemplify higher levels of performance than while simultaneously performing the ERP task and not being burdened by the In-Vehicle or Cell Phone tasks. This effect may counteract the distracting effects of the secondary-task conditions, whereby drivers conversing on the Cell Phone or completing In-Vehicle tasks are expected to have lower accuracy on the tone task.

As workload in a primary task increases, P300 responses to a secondary-task are typically diminished. Therefore, it is expected that drivers completing the secondary-tasks will have weaker P300 responses to the target tones and novel car-relevant sounds than those in the Baseline condition as measured at the frontal/anterior (Fz), central (Cz), and parietal/posterior (Pz) locations. Specifically, P300 responses to target tones should contain a strong decision-making response in the more posterior regions (Pz and Cz). P300 responses to the novel stimuli, both car-related and irrelevant, contain a strong orienting response in the more anterior regions (Fz and Cz).

Environmental Awareness

During the car-following scenario (continuous primary task), drivers also encountered four different types of yellow diamond sign on the right side of the road (for examples, see the instruction summaries in Appendix D). Signs were consistently spaced 300 m apart from the beginning of the scenario onward. Participants were asked to respond as quickly and accurately as possible by signaling their bright lights whenever they saw the pedestrian crossing sign (nine instances), and ignoring the other signs (38 instances).

Environment awareness was quantified by the following measures:

- Mean reaction time (RT) for accurate sign responses [seconds]
- Percentage of correct sign responses
- Count of detection errors (false alarms + misses) in sign responses

Good performance on these measures would be indicated by faster (smaller) RTs, a larger percentage of correct responses, and a smaller number of errors. Impaired performance would be indicated by slower (larger) RTs, smaller percentage of correct responses, and a larger number of errors.

PROCEDURES

Experimental Procedure

Figure 2-6 presents an updated summary of the time it took to complete the study, with predicted and actual times on a timeline relative to the predicted effects of alcohol. By counter-balancing drives one, two, and three, the peak effect of alcohol was still evenly distributed across all conditions. Over the course of this study, it was apparent that our predicted time estimates were generous. However, no participant completed the simulator portion of the study within 50 minutes, which still takes advantage of the proposed peak effects of alcohol in our counter-balanced design.

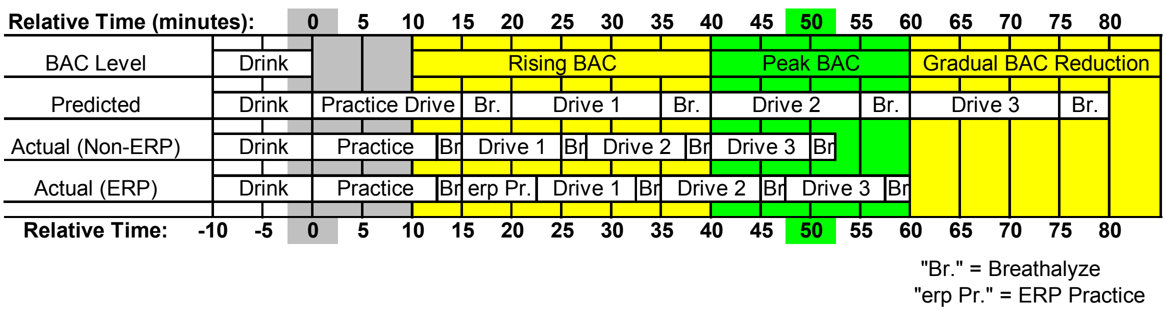


Figure 2-6 – Procedure timeline relative to alcohol dosing

Potential participants were recruited by means of ads in the student newspaper and by hanging flyers on campus. Potential participants were screened using a combination of the CAGE Questionnaire to identify potential alcoholics (Mayfield, McLeod, and Hall, 1974) and a standard screener to find those that might have the potential to feel simulator induced discomfort or could walk or ride the bus to the university (Appendix B). Eligible participants were scheduled and reminded over the phone and email to:

- Bring valid identification with their date of birth.
- Eat a light meal only (sandwich) 2-3 hours prior to the session.
- Do not take any non-essential medication 24 hours prior to the session.
- Do not drink energy drinks or caffeine (i.e., tea, coffee, cola, chocolate) 24 hours prior to the session.
- Do not drink alcohol 24 hours prior to the session.
- Do not drive to or from the session.

At the time of the experiment, participants were greeted in the staging room and were then re-screened again (no participants were excluded at this stage). Participants were weighed and an initial Breathalyzer reading was taken before filling out the first set of demographic questionnaires. Then they were given the study summary to read as the general procedure for the simulator portion of the experiment (Appendix D). Participants in the ERP condition were fitted with the Neuroscan Quick Cap and impedances were checked for the cap and arm leads.

All participants were then taken into the simulator. During this time, the verbal protocol (Appendix D) was used to further explain the tasks required of them in the experiment. Once completed, participants returned to the staging room were they were presented two cups containing their beverage (cranberry or cranberry and alcohol solution). Participants were told that they had ten minutes to drink the contents of the cups and shown a countdown timer to pace their drinking. They were given an extra five minutes to drink if they had trouble finishing the entire dose in time.

After drinking, participants returned to the simulator and drove the practice drive. This route allowed them to get a feeling for how the car handled by practicing the car-following task they would be doing in the experimental drives. This drive consisted of approximately ten minutes of driving on the same road as the experiment, only driven in the opposite direction. During this practice, they followed a lead vehicle with slowly increasing difficulty in order to let them get a feel for the vehicle as well as get practice at the continuous-driving task they would experience during the experiment. Participants were able to practice until they reported being comfortable with the realistic driving of the simulation.

Near the end of the practice drive, once they were more comfortable with handling the simulated vehicle, the participants were instructed on how to perform the in-vehicle and cell phone secondary-tasks. Participants were also given practice completing five in-vehicle and five cell phone tasks (four conversation style, one monologue) in order to get accustomed to how they operated. After the drive was complete, drivers were given a chance to ask questions about the secondary-tasks, given the workload and driving capability questionnaires, and a Breathalyzer reading was taken.

ERP condition participants were then instructed and practiced the oddball target tone task. This 140 trial practice presented only standard (112 trials, 80 percent) and target stimuli (28 trials, 20 percent). In order to maximize the response to the first novel sound in the experimental session, novel sounds were omitted from the practice. Participants were instructed to listen for the high tone (target tone) and respond to it by pressing the pedal with their left foot. The same instructions were given prior to each experimental condition and participants were reminded that driving was always their primary task, and if relevant, the cell phone and in-vehicle tasks were the secondary-task, always leaving the oddball task as a tertiary task that they should complete if they were able to do so.

Participants then completed the three experimental drives. ERP condition participants drove all three drives while simultaneously completing the target tone task. Following the third experimental drive, all participants were led back to the staging room where they filled out the second set of demographic questionnaires and a final driving capability questionnaire. The Quick-Cap and leads were then removed from ERP participants. Alcohol condition participants were taken to a recovery room where they were given a breathalyzer reading every ten minutes and were not allowed to leave until they recovered.

Alcohol-Dosing Procedure

The alcohol (BAC) group manipulation was a between-subjects factor (Control vs. Alcohol groups). Participants were blind to their assignment to either the Control or Alcohol group. Previous research has found that a BAC of 0.50 ("50 mg%") is the level at which deterioration of driving skills begins (Council on Scientific Affairs, 1986). Figure 2-7 shows the BAC over time after the rapid consumption of different amounts of alcohol by eight adult male participants. As can be seen, it takes just under an hour to peak at a BAC between 0.07 and 0.08 after having consumed the equivalent of three to four drinks (Typically one "drink" = 12 ounce beer, or 5 ounce glass wine, or 1.5 ounce shot of hard liquor).

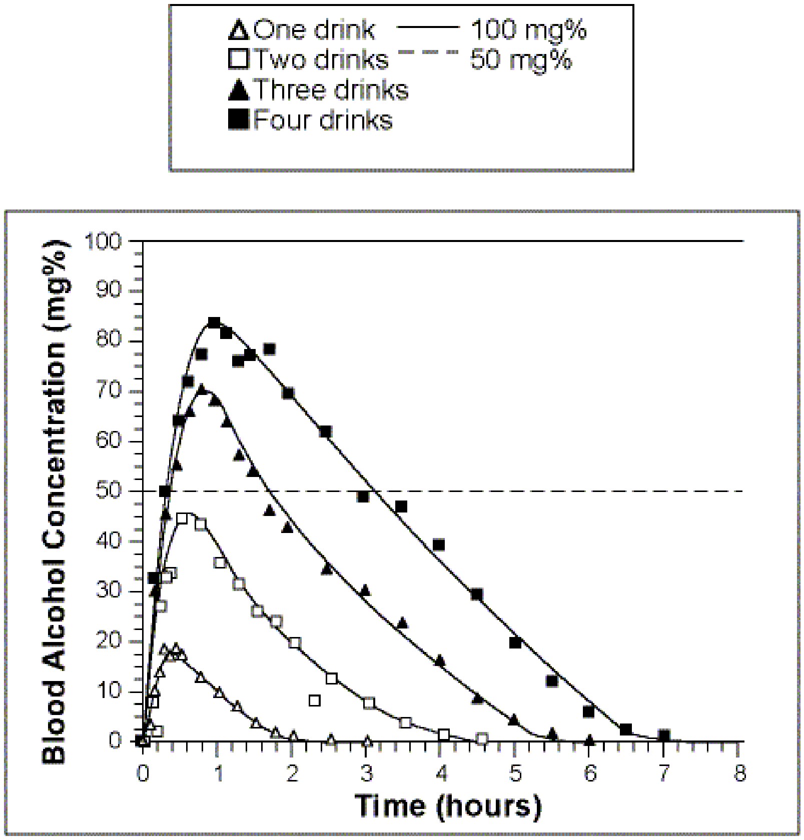


Figure 2-7 – Results showing BAC after rapid consumption of different amounts of alcohol (100 mg% = 0.10 BAC; Figure adapted from Wilkinson et al.,1977)

Our Alcohol group was administered a beverage containing a mixture of one part ethyl alcohol (190 proof) to six parts cranberry juice. The calculation of alcohol dosing was implemented in an Excel spreadsheet where the weight was entered and the alcohol and cranberry juice dosages were presented and recorded (see Appendix B). Beverage volume administered was based on body weight to achieve a predicted BAC of 0.08 at 50 minutes from consumption (see Figure 2-6) based on the 8/10 version of Widmark's formula (NHTSA, 1994). The Control group was given a placebo beverage consisting of seven parts cranberry juice in an alcohol-swabbed cup. All participants were given ten minutes to consume the drink.

During the experiment, participants' BAC was measured using a Draeger brand Breathalyzer (Figure 2-8). After the experiment, participants were required to recover under nurse supervision for one hour or until their BAC < 0.05. All participants needed the full hour to recover.

Figure 2-8 – Draeger brand Breathalyzer unit

BAC Manipulation Validation

As seen in Figure 2-9, there was a significant difference in Blood Alcohol Level (BAC) between the Alcohol and Control conditions [$F(1,44)= 832.2$, $p< .001$]. As expected, participants in the Alcohol group ($M= 0.073$) had significantly higher BACs than those in the Control group ($M= 0.001$) for all three task conditions, indicating that the alcohol dosing was effective.

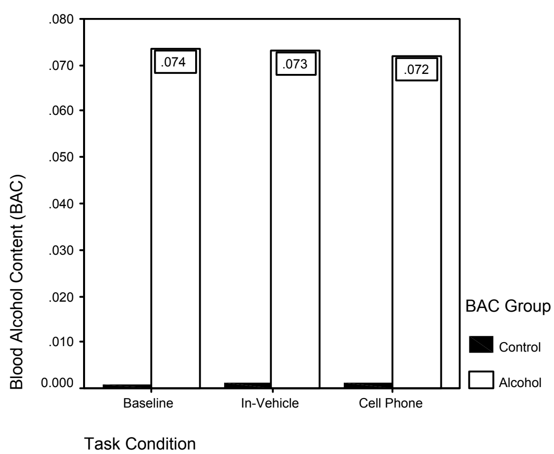


Figure 2-9 – Blood alcohol content by BAC group and task condition

All Control group BAC levels recorded were equal to 0.000, with the exception of six recordings from three drivers (P# 04 for in-vehicle and cell phone conditions; P# 18 in all three conditions; and P# 20 in the baseline condition). All of these non-zero ratings were less than or equal to 0.017 and decreased with each subsequent measurement, suggesting that these non-zero BACs were due to differences in digestion and alcohol tolerance and the null effects above suggest that they did not significantly impact the drivers' performance.

To test driver awareness of alcohol dosing and resulting intoxication, a scale was administered to participants periodically throughout the experiment to gauge their level of self-reported intoxication (Appendix E). Each question was analyzed separately and the results are presented in Appendix C. These findings indicate that drivers who consumed alcohol were more aware of their impairment to safely operate a vehicle.

Alcohol participants estimated that they had consumed a significantly higher [$F(1, 41)= 24.88$, $p< .001$, power= .998] number of alcoholic drinks (M= 3.68) than the Control participants (M= 1.98). This suggests that the Alcohol group did feel intoxicated by the administered alcohol and that Control participants overestimated the number of drinks they consumed, as they did not consume any.

In terms of psycho physiological activity, intoxication was found to cause a significant reduction in amplification of the P300 signal in intoxicated drivers, as compared to sober drivers (Figure 2-10). This figure shows the ERP response for novel sounds, highlighting (time between vertical green lines) of the P300 response. The brain images on the right show differences between sober (blue line in ERP) and intoxicated (red line) responses. The second brain image shows a black and white composite of the areas where significant differences were found between sober and intoxicated drivers' responses (significance at p=0.05 level is shown in white). These images show that intoxicated drivers had a reduced response to novel sounds, a significant difference in the central and parietal (rear) of the brain. This suggests that intoxicated drivers spent less of their mental capacity on an evaluative response to novel sounds. Thus, overall they can be said to be cognitively impaired by alcohol at a physiological level.

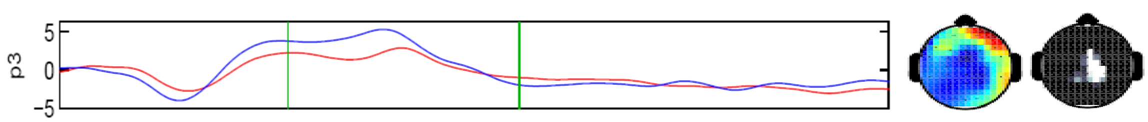


Figure 2-10 – ERP of P300 response (between vertical lines) to novel sounds for sober (blue line) and intoxicated (red) drivers

Dependent Variable Procedure

The primary driving task dependent variables for the Continuous primary task, episodic primary tasks, and eye gaze were collected continuously throughout each drive at a rate of 20 Hz. Environment awareness data was collected only during the car-following primary driving task. Secondary-task condition performance data was collected throughout the drive by the experimenter.

Several questionnaires, as described in the Subjective Measures section, were administered to participants throughout the study, as described below. See Figure 2-6 for references to the study timeline and Appendix E for the questionnaires themselves.

- The Driving Capability Questionnaire was administered at six separate times during the course of the testing session, including:
  - After completing the consent form (before drinking)
  - After the practice session
  - After each of the three experimental drives
  - After the Distraction Survey, during the recovery period
- The Rating Scale of Mental Effort, or was administered after each of the driving sessions (Baseline, Cell Phone, In-Vehicle).
- An additional modified RSME specific to the secondary-tasks was answered after the first RSME after the In-Vehicle and Cell Phone task conditions. This helped assess and compare the amount of effort it took to complete these secondary-tasks while driving.
- Drivers answered the Driving History Questionnaire after signing the informed consent form and filled out their first Driving Capability Questionnaire.
- The SSS was administered after the Driving History Questionnaire and before the study began.
- The Cellular Phone Survey was administered after all of the driving conditions were complete during the recovery period.
- The Distraction Survey was administered after the Cellular Phone Survey during the recovery period.

ANALYSES

The overall design for this experiment was a 2 (BAC Group: Alcohol, Control) x 2 (ERP Group: ERP, Non-ERP) x 3 (Condition: Baseline, Cell Phone, In-Vehicle) mixed model design.

For the Driving Performance measures, Resource Allocation, and Environmental Awareness measures were analyzed using a 2 x 2 x 3 mixed model ANOVA. Box-plots were used to identify outliers by BAC group in each task condition. Because of the repeated measures design, a participant was excluded if they were an outlier in at least two of the three task conditions for a particular measure (dependent variable).

The following tests were conducted for all the simulator performance variables:

- Main Effects- A 2 x 2 x 3 ANOVA (F) was used to calculate main effects across the task conditions (baseline, cell phone, in-vehicle) and between-subjects effects for BAC and ERP groups. Follow-up tests to significant ANOVA main effect results compare task conditions using the Wilcoxon (Z_W) non-parametric signed-ranks test for the following comparisons:
    - Baseline to In-Vehicle task (B-IV)
    - Baseline to Cell Phone task (B-CP)
    - In-Vehicle task to Cell Phone task (IV-CP)
- Simple Effects- The task by group effects following significant interactions between Task condition and either BAC or ERP group were examined with a one-way Friedman's (X^2_F) non-parametric test across the task levels separately for each BAC group (sober and drunk groups) or ERP group (ERP and Non-ERP). Follow up tests to significant Friedman results compare task conditions using the Wilcoxon (Z_W) non-parametric signed-ranks test, as explained for the main effects (i.e. B-IV, B-CP, and IV-CP comparisons)
- Benchmark Tests– Specific comparisons of interest were examined to determine the relationship between intoxicated and sober driving. Mann-Whitney (Z_U) non-parametric paired test were used for the following comparisons:
    - Intoxicated drivers in the Baseline condition to sober drivers completing the In-Vehicle secondary-task [B(alc)-IV(ctrl)]
    - Intoxicated drivers in the Baseline condition to sober drivers completing the Cell Phone secondary-task [B(alc)-CP(ctrl)]
    - Intoxicated drivers in the Baseline condition to sober drivers in the Baseline condition [B(alc)-B(ctrl)]

To avoid problems with potential sphericity in the data, Huynh-Feldt results were used for all main effect and interaction ANOVA results.

The other subjective metrics (Demographics) were analyzed using Mann-Whitney (U) tests for interval and ratio data and chi-squared (X^2) tests for nominal data, unless otherwise noted. These non-parametric statistics were used for post-hoc tests because they are more conservative, and therefore, reduce the family-wise error rate.

CHAPTER 3: RESULTS

DEMOGRAPHICS

Summary results for the Driving History Questionnaire and Sensation Seeking Scale are presented in **Table 2-1** under the Participants description section (see Appendix I for complete results). Results from the Driving Capability Questionnaire are presented in the BAC Manipulation Validation section.

There were no significant differences ($p < 0.05$) between the Alcohol ($n = 24$) and Control (Sober) groups ($n = 24$) for any measures on either of these questionnaires. There were no significant differences ($p < 0.05$) between the ERP ($n = 24$) and Non-ERP groups ($n = 24$) for any measures on the Driving History Questionnaire, however the ERP group participants had lower SSS scores ($M = 6.6$) than the Non-ERP group drivers ($M = 7.8$; $Z_W = 2.05$, $p = .040$). This suggests that drivers not experiencing the ERP paradigm were bigger sensation seekers than those who completed the paradigm tasks. BAC differences on the Driving Capability Questionnaire are discussed at length in the BAC Manipulation Validation section.

Cell Phone Survey

A survey was administered (Burns et al., 2002) to quantify typical cell phone usage by the study sample. Complete results can be found in Appendix I.

A majority, 92 percent of participants reported owning or regularly having the use of a cell phone ($n = 44$). Phones were used at least every day by 84 percent of the phone owners. Most of the participants (83 percent) talked on the phone for less than half the total time driving in a particular trip. Most of these conversations were for personal use (86 percent) and constituted light, short conversations or brief messages. These owners reported talking while driving an average of 3.6 minutes during each conversation (range = 1 to 15 minutes).

More than half of the participants (52 percent) stated they would always or usually answer their cell phone if it rang while driving. Nearly half (44 percent) of all participants would initiate a call while driving. When asked what conditions would stop them from answering the phone, the main reasons were bad weather (83 percent), heavy traffic (65 percent), and when they were lost (13 percent). This generally represents high-demand conditions in which drivers are exerting effort toward the primary driving task.

Only 39 percent of our drivers had hands-free equipment for their phone. Approximately half of all participants (52 percent) thought that the use of hand-held cell phones while driving should <u>not</u> be banned, whereas another third (29 percent) stated that a ban should be dependent on the driving situation. Only 17 percent of participants supported a full ban on hands-free phones.

Distraction Survey

A survey was administered to quantify the perceived distraction effect of common secondary driving tasks (Burns et al., 2002).

The level of rated distraction for each of the identified secondary-tasks in this survey was analyzed using a one-way repeated measures ANOVA. As shown in Figure 3-1, there was a significant main effect for type of secondary-task [$F(7, 322) = 56.98$, $p < 0.001$, power= 1.00]. Text messaging was considered to be the most distracting and talking to a passenger was considered to be the least distracting activity to perform while driving. Text messaging and reading a map were the only things seen as more distracting than using a hand-held phone. Using a hands-free phone, tuning the radio, or changing the climate controls were seen to be similarly distracting and were all rated as more distracting than talking to a passenger. Notably, using a hands-free cell phone was rated to be significantly less distracting than conversing with a hand-held cell phone.

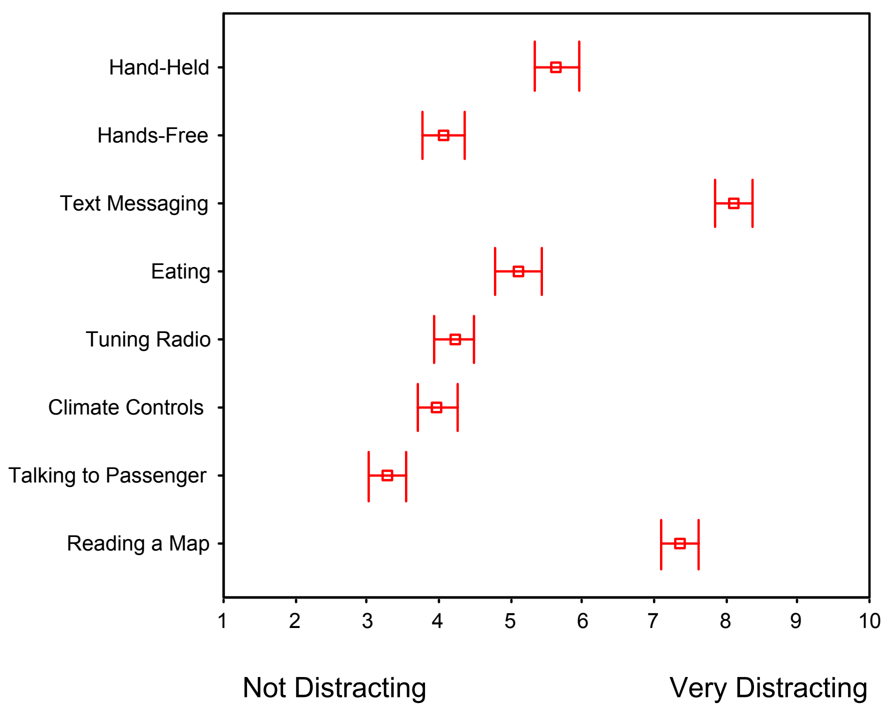


Figure 3-1 – Mean distraction ratings (± 1 standard error)

These distraction questionnaire findings are congruent with results from a British study (TRL) using the same survey (Burns et al., 2002). Just as we found, their participants rated talking with a passenger to be significantly less distracting than talking on a hands-free or hand-held phone. Our participants found eating to be more distracting then the TRL participants did. Also, our participants found hand-held and hands-free conversations to be less distracting than TRL participants rated them. Culturally this suggests that while driving Americans may find eating more distracting and phone conversations to be less distracting than British drivers do.

DRIVING PERFORMANCE

A detailed analysis of driving performance is presented for the car-following scenario that produced a continuous primary task workload for drivers (as in Figure 1-2a.). A summary of main findings is presented for the remaining tasks (Overtaking, Curve negotiation, Traffic queue, Gap acceptance, Lane change) that produced discrete workload conditions (as in Figure 1-2b).

Continuous Primary Task

Car-following presented a continuous primary task workload for drivers. There were two ranges of speed change frequency for the lead vehicle in the car-following scenario. Therefore, the analysis for the car-following scenario was a 2 (BAC Group: Alcohol, Control) x 2 (ERP Group: ERP, Non-ERP) x 2 (Frequency range: Low [.02-.04 Hz], High [.06-.12 Hz]) x 3 (Task Condition: Baseline, Cell Phone, In-Vehicle) mixed model ANOVA. This analysis was performed for each of the primary driving performance metrics: median time headway, time headway variability, coherence, modulus, phase shift (delay), steering reversals, steering entropy, and lane position variability (TLC^{-1}).

Median time headway
There was a significant main effect for task condition [$F(2,88) = 11.10$, $p < .001$]. As shown in Figure 3-2, the average headway during the entire car-following scenario was significantly longer during the in-vehicle [$W_z = 4.19$, $p < .001$] and cell phone [$W_z = 3.09$, $p < .01$] conditions compared with the baseline condition, suggesting that drivers compensated for the increased workload imposed by the distraction tasks by adopting a larger safety margin. There was no significant difference in median headway between the in-vehicle and cell phone conditions.

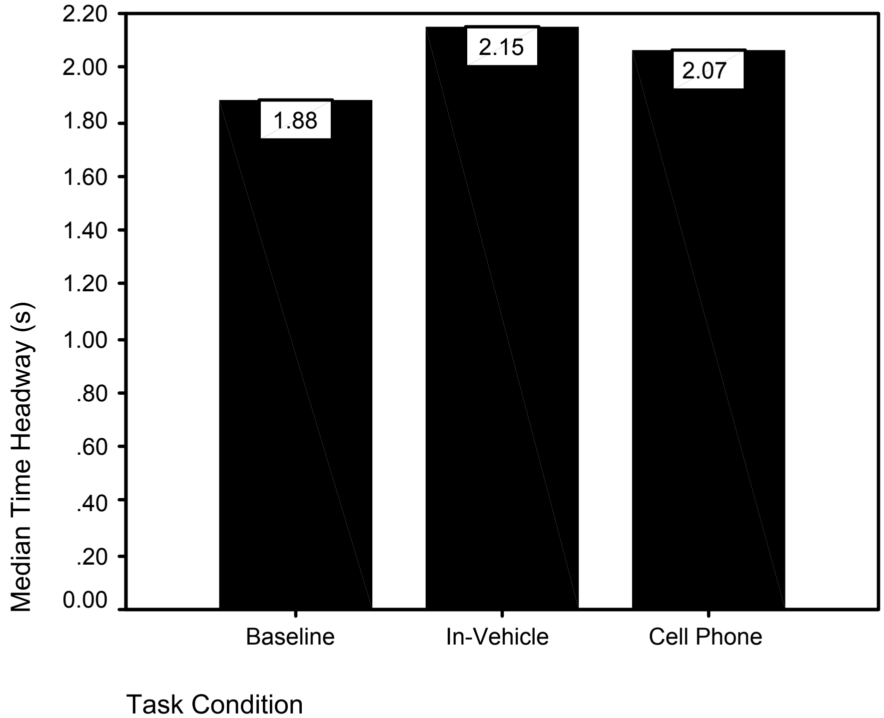


Figure 3-2 – Median time headway results during the entire car-following scenario as a function of task condition

There was a marginally significant interaction between BAC group and frequency range [$F(1,44) = 3.89$, $p < .10$]. All drivers in the low-frequency range and sober drivers in the high-frequency range kept a relatively similar time headway, as seen in Figure 3-3. However, intoxicated drivers experiencing the more-difficult high-frequency car-following maintained longer time headways, suggesting that intoxicated drivers were more affected by the increased workload imposed by the more-difficult car-following.

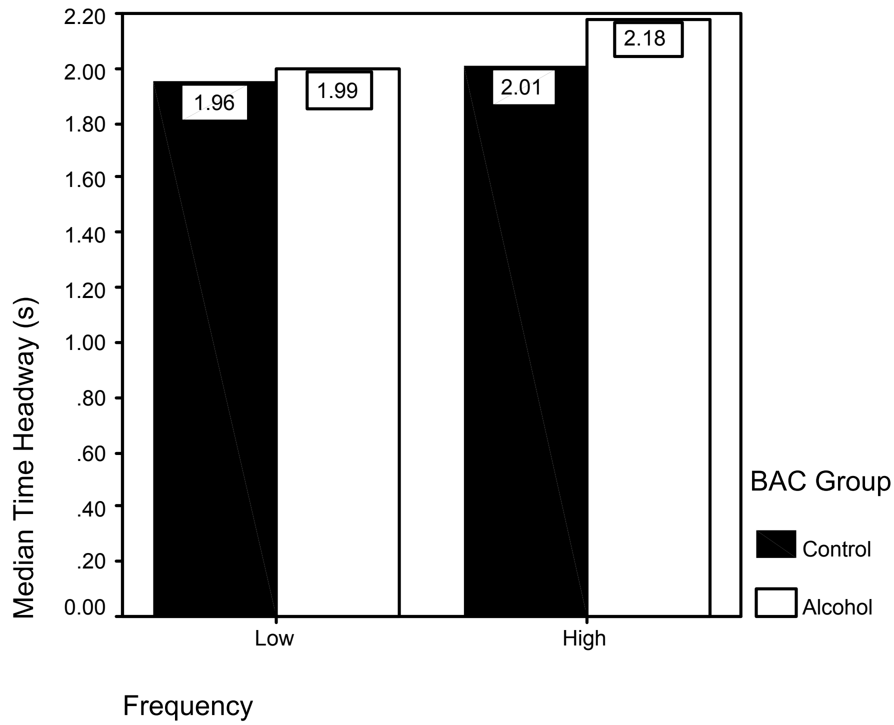


Figure 3-3 – Median time headway results during the entire car-following scenario as a function of BAC group and frequency

There was also a marginally significant interaction between frequency range and Task condition [$F(2,88) = 2.64$, $p = .10$]. Drivers in both the Baseline and Cell Phone conditions appeared to compensate for the difficult car-following period by modifying their time headway, as seen in Figure 3-4. In contrast, those in the In-Vehicle condition were not sensitive to the increase in primary task demand.

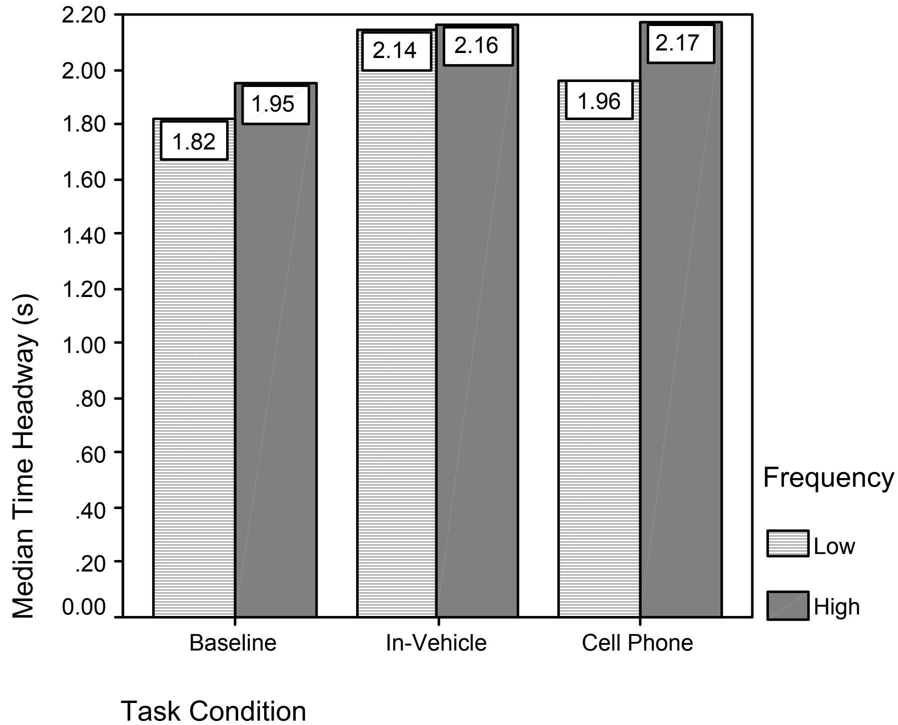


Figure 3-4 – Median time headway results during the entire car-following scenario as a function of frequency and task condition

Time Headway Variability (standard deviation)
There was a significant main effect for task condition [$F(2,88) = 27.7$, $p < .001$]. As shown in Figure 3-5, variability of time headway was significantly higher during the in-vehicle task condition compared to the baseline [$W_z = 4.51$, $p < .001$] and cell phone [$W_z = 2.65$, $p < .01$] conditions. Moreover, headway variability was also significantly higher during the cell phone condition compared to the baseline condition [$W_z = 2.42$, $p < .01$].

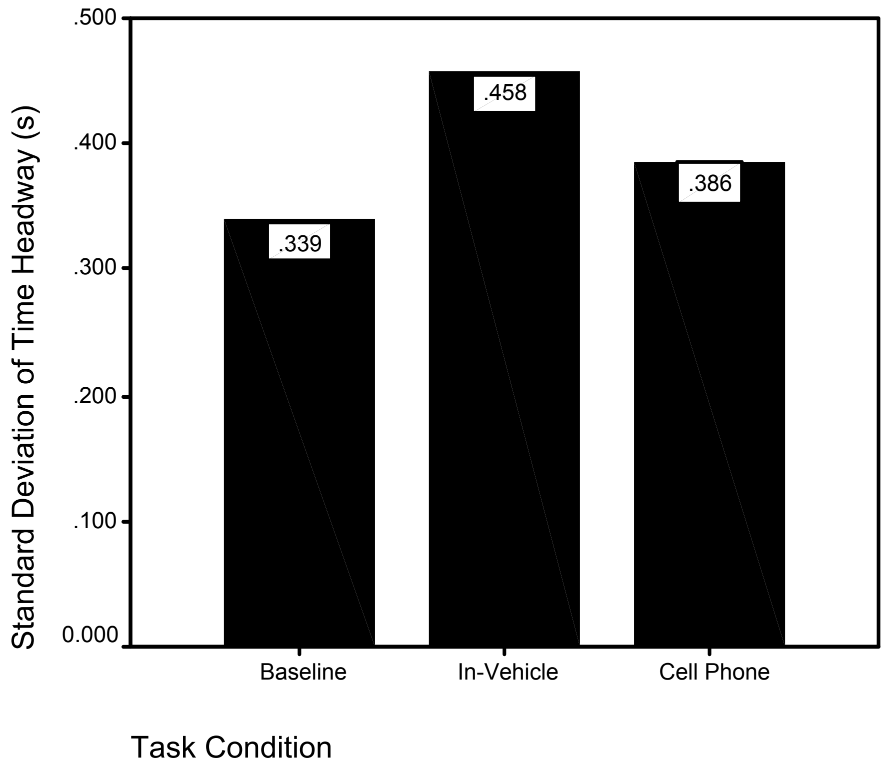


Figure 3-5 – Standard deviation of time headway during the entire car-following scenario as a function of task condition

In terms of benchmark tests (see Figure 3-6), the headway variability *during the entire car-following task* was significantly lower while drunk and performing no secondary-tasks compared to being sober and performing in-vehicle tasks [$U_z = 2.52$ $p < .01$].

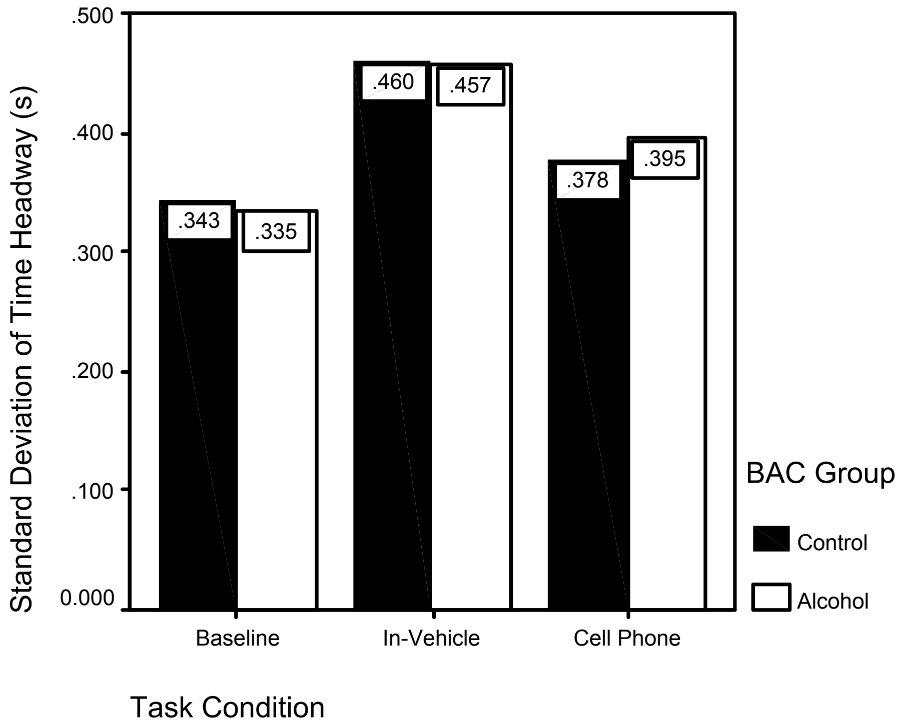


Figure 3-6 – Standard deviation of time headway (overall) results during the entire car-following scenario as a function of BAC group and task condition

Coherence

Coherence is a measure of correlation between the speed signals from the lead vehicle and the participant's vehicle. Values approaching 1 indicate a perfect correlation. There was a significant main effect of frequency range [$F(1,44) = 104.00$, $p < .001$] with a lower coherence evident during the high-frequency speed range ($M = .69$) than with the lower frequency speed range ($M = .84$). This is consistent with the design intent of producing a more-difficult driving task by imposing a higher speed range condition.

There was also a significant main effect for task condition [$F(2,88) = 28.60$, $p < .001$]. As shown in Figure 3-7, coherence was significantly worse during the in-vehicle task condition [$W_z = 5.53$, $p < .001$] and the cell phone condition [$W_z = 2.97$, $p < .01$] compared to the baseline condition with no secondary-tasks.

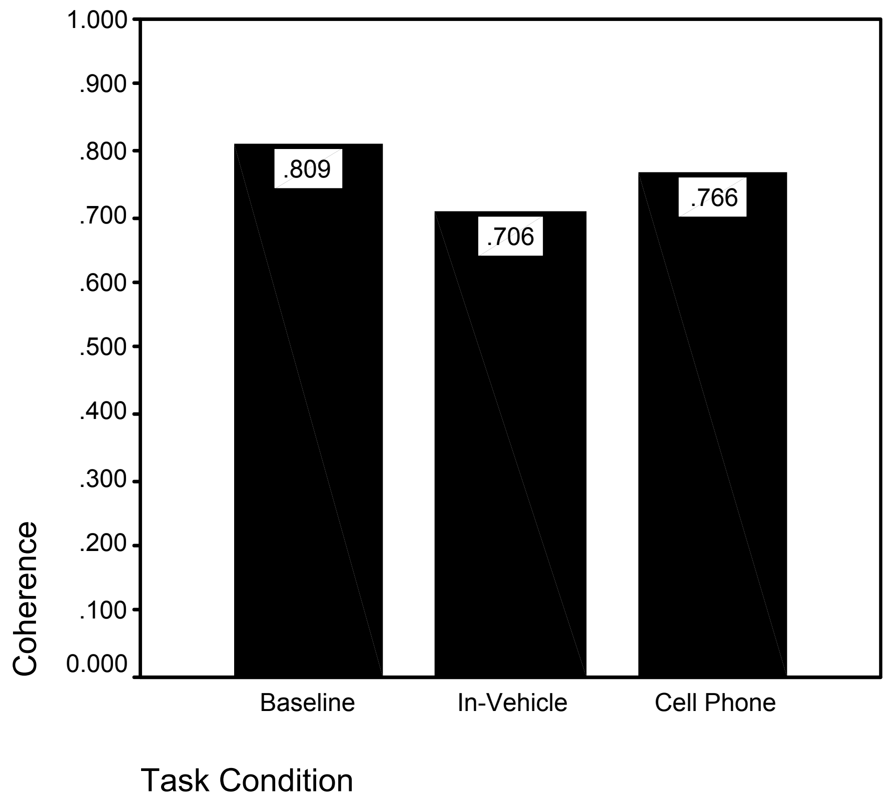


Figure 3-7 – Coherence results during the entire car-following scenario

Moreover, coherence was significantly worse during the in-vehicle task condition compared to the cell phone condition [$W_z = 3.69$, $p < .001$].

There was also an interaction between task condition and frequency range [$F(2,88) = 6.28$, $p < .01$]. As shown in Figure 3-8, coherence was significantly lower during the cell phone condition compared to the baseline condition during the (more demanding) high-frequency period, but not during the (less demanding) low-frequency period. All other differences are significant in Figure 3-8 consistent with reported main effects.

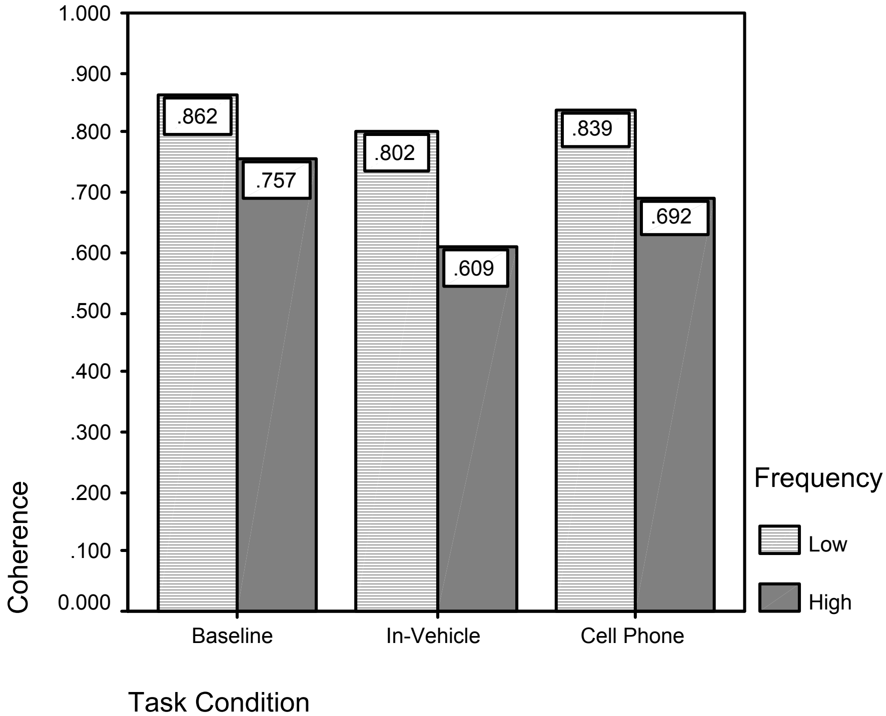


Figure 3-8 – Coherence results during the entire car-following scenario as a function of frequency range and task condition

In terms of benchmark tests, there was a marginal trend for coherence *during the entire (both high and low-frequency) car-following scenarios* to be better while drunk and performing no secondary-tasks compared to being sober and performing in-vehicle tasks [$U_z = 1.86$, $p < .06$]. This benchmark effect was statistically significant [$U_z = 2.19$, $p < .05$] *for the high-frequency speed range* section as shown in Figure 3-9.

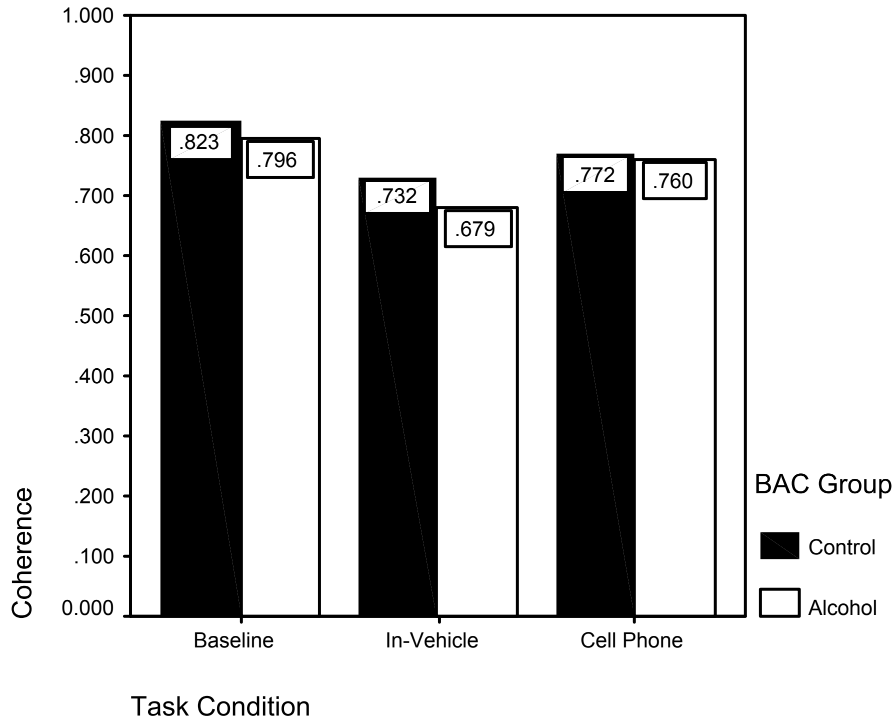


Figure 3-9 – Coherence results during the high-frequency car-following scenario as a function of BAC group and task condition

Modulus

Modulus is a measure representing the amplification of the participants' speed signal with respect to the lead vehicle. Values above 1 indicate a positive amplification and values below 1 indicate a negative amplification (i.e., attenuation). There was a significant main effect for task condition [$F(2,88) = 7.74$, $p < .001$]. As shown in Figure 3-10, the modulus was significantly lower during the in-vehicle task condition compared to the baseline [$W_z = 3.55$, $p < .001$] and cell phone [$W_z = 3.15$, $p < .01$] conditions. There was no significant difference in modulus between the baseline and cell phone conditions.

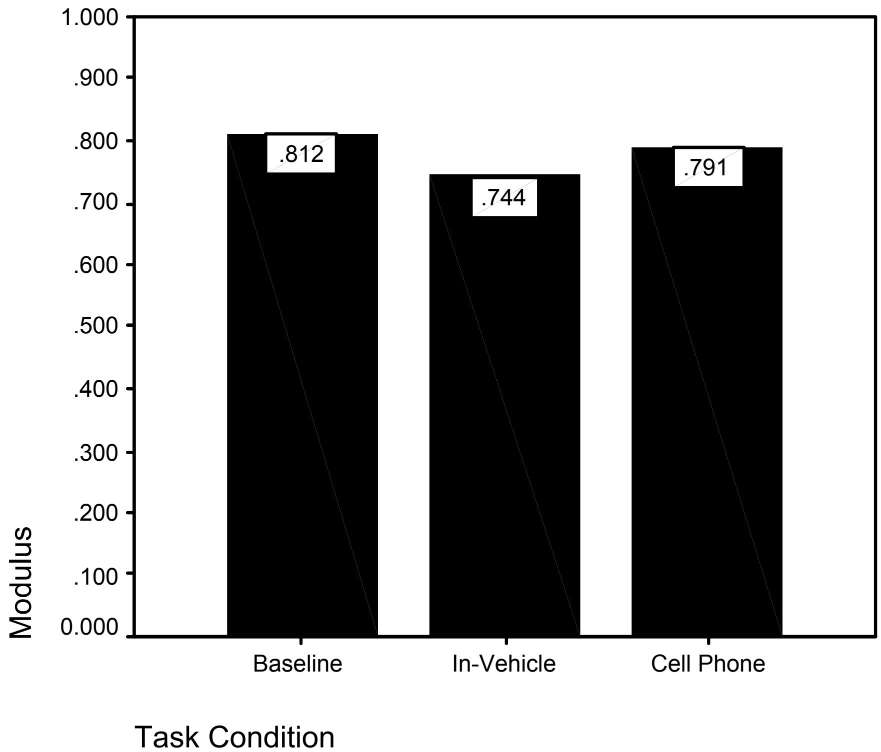


Figure 3-10 – Modulus results during the entire car-following scenario as a function of task condition

In terms of benchmark tests (see Figure 3-11), there was a marginal trend for modulus *during the entire car-following task* to be higher while drunk and performing no secondary-tasks compared to being sober and performing in-vehicle tasks [$U_z = 1.65$ $p < .10$].

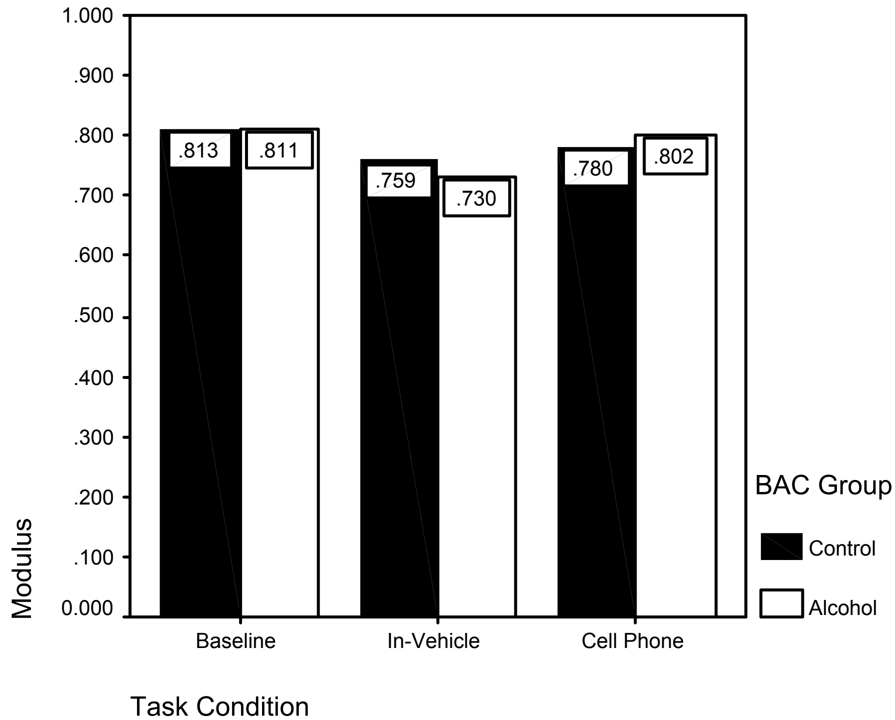


Figure 3-11 – Modulus results during the entire car-following scenario as a function of BAC group and task condition

Phase shift (delay)

Phase shift (or delay) is a measure of the time lag between the speed signals of the lead vehicle and the participants' vehicle. Larger lags indicate a larger delay in the participant changing speed in response to the lead vehicle. There was a significant main effect for task condition [$F(2,88) = 27.7$, $p < .001$]. As shown in Figure 3-12, the delay was significantly longer during the in-vehicle task condition compared to the baseline [$W_z = 5.11$, $p < .001$] and cell phone [$W_z = 4.31$, $p < .001$] conditions. Moreover, the delay was marginally longer during the Cell Phone condition compared to the baseline [$W_z = 1.61$, $p < .10$].

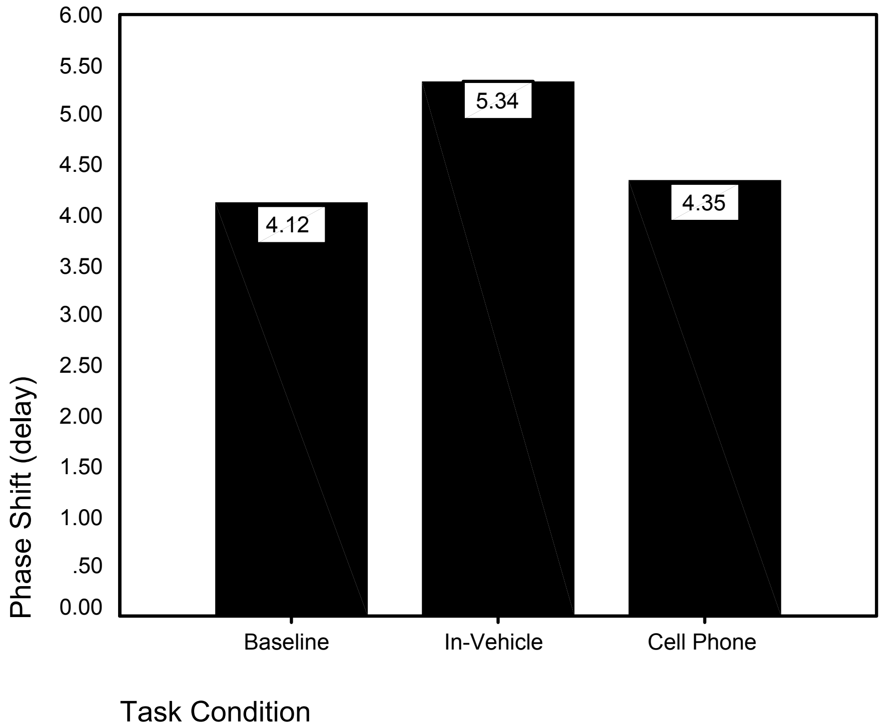


Figure 3-12 – Phase shift (delay) results during the entire car-following scenario as a function of task condition

In terms of benchmark tests (see Figure 3-13), the delay *during the entire car-following task* was significantly faster while drunk and performing no secondary-tasks compared to being sober and performing in-vehicle tasks [$U_z = 2.00$ $p < .05$].

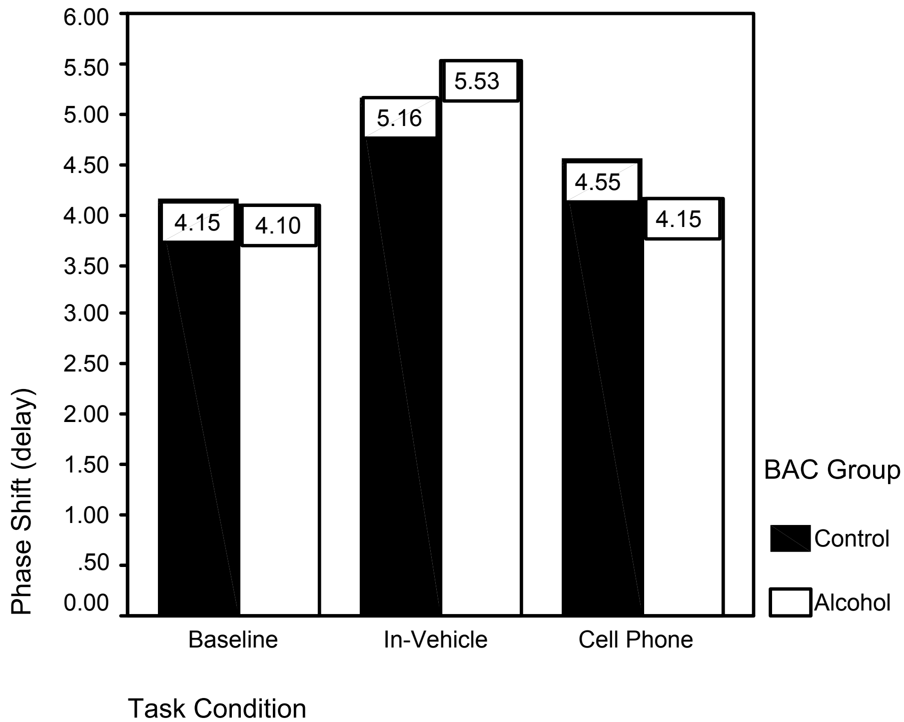


Figure 3-13 – Phase shift (delay) results during the entire car-following scenario as a function of BAC group and task condition

Steering Reversals

There was a significant main effect of ERP group [$F(1,44) = 9.27$, $p < .01$] with more steering reversals indicated for those drivers with the ERP protocol ($M = 49.2$) than the group of drivers exempt from the ERP protocol ($M = 31.2$). This suggests that the ERP methodology may have imposed a tertiary task load on the drivers.

There was also a significant main effect for task condition [$F(2,88) = 23.10$, $p < .001$]. As shown in Figure 3-14, there was significantly more steering activity during the in-vehicle task condition compared to the baseline [$W_z = 5.02$, $p < .001$] and cell phone [$W_z = 3.30$, $p < .001$] conditions. Moreover, steering activity was also significantly higher during the cell phone condition compared to the baseline condition [$W_z = 2.91$, $p < .01$].

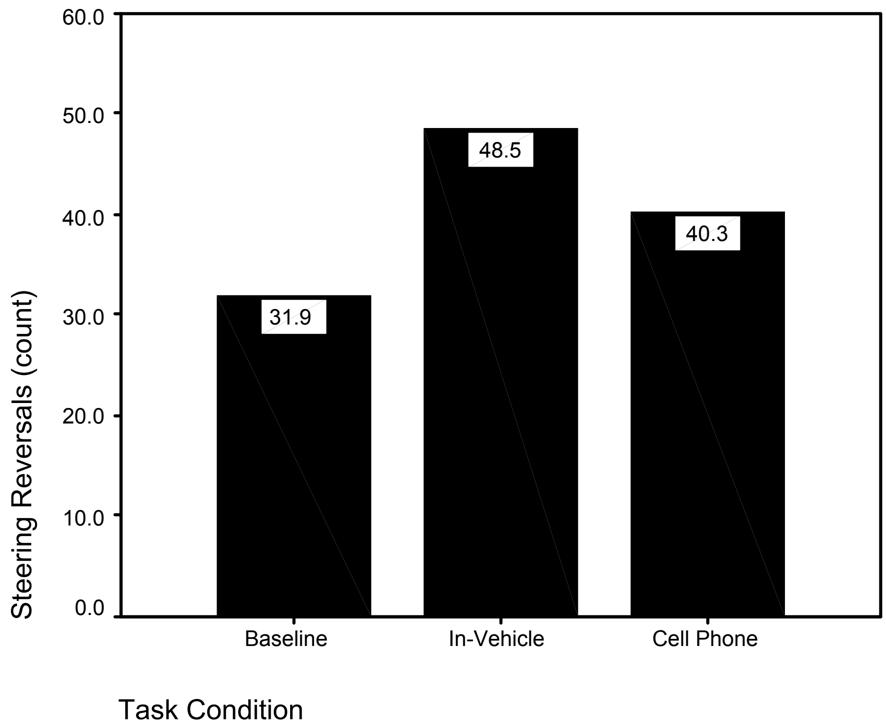


Figure 3-14 – Steering Reversals during the entire car-following scenario as a function of task condition

A significant three-way interaction was present between frequency range, BAC, and ERP groups [$F(2,88) = 4.05$, $p = .05$]. As seen in Figure 3-15, the ERP group main effect, where those experiencing the ERP methodology had more steering reversals, is present during both the low- and high-frequency car-following. However, it is apparent that intoxicated drivers experiencing the ERP methodology exhibited more steering reversals during the high-frequency car-following (b.) than their sober counterparts, whereas this effect was not as drastic during low-frequency range (a.). The difference between BAC groups not exposed to the ERP methodology appears to be minimal.

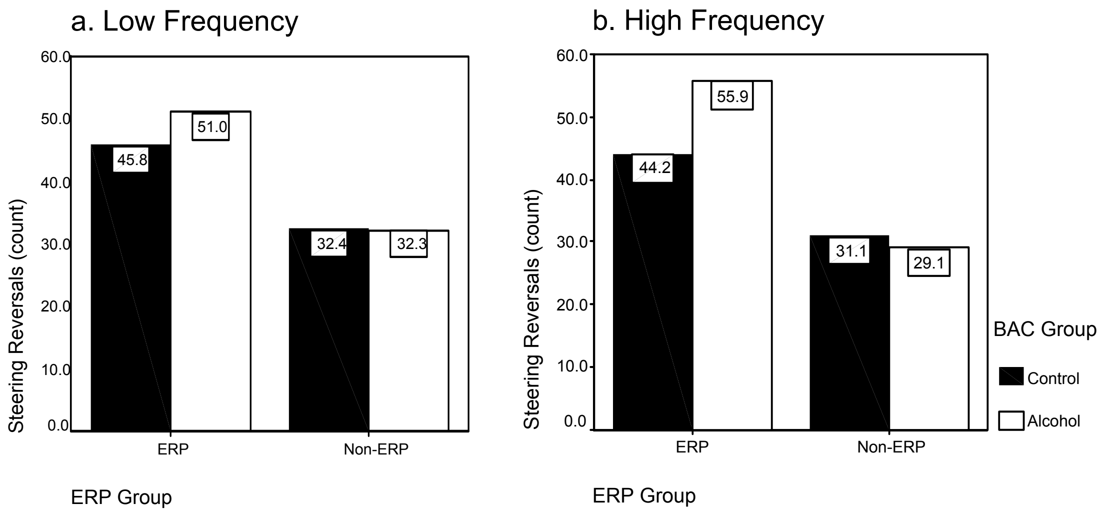


Figure 3-15 – Steering Reversals during the entire car-following scenario as a function of BAC group and ERP group for a) low-frequency, and b) high-frequency ranges

Steering Entropy

Steering entropy is a measure of the randomness within the input steering signal (see Boer, 2000). Larger values represent less predictability in steering input. There was a significant main effect of ERP group [$F(1,44) = 9.85$, $p < .01$] with higher steering randomness indicated for those drivers with the ERP protocol ($M = 0.69$) than the group of drivers exempt from the ERP protocol ($M = 0.56$). This suggests that the ERP methodology may have imposed a tertiary task load on the drivers.

There was also a significant main effect for task condition [$F(2,88) = 23.10$, $p < .001$]. As shown in Figure 3-16, there was significantly less predictable steering activity during the in-vehicle task condition compared to the baseline [$W_z = 5.36$, $p < .001$] and cell phone [$W_z = 2.81$, $p < .01$] conditions. Moreover, steering activity was also significantly higher during the cell phone condition compared to the baseline condition [$W_z = 4.71$, $p < .001$].

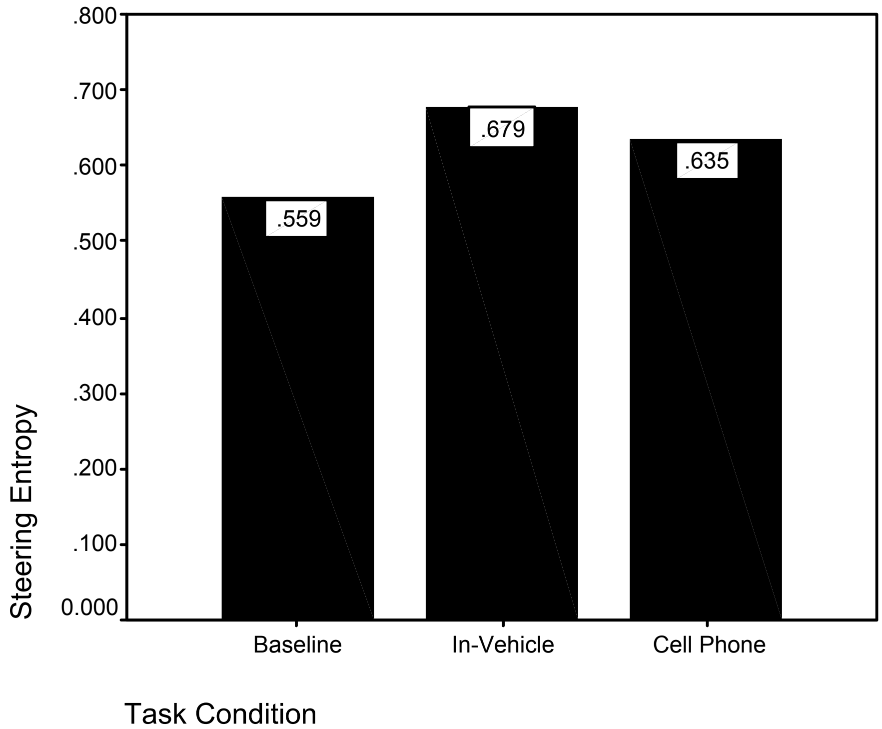


Figure 3-16 – Steering entropy during the entire car-following scenario as a function of task condition

However, there was an interaction between task condition and ERP group [$F(2,88) = 3.63$, $p < .05$]. As shown in Figure 3-17, differences in steering entropy between the cell phone condition and both the baseline and in-vehicle conditions were only statistically significant for those drivers experiencing the ERP protocol. At least for this single measure, significant task condition effects were strongest within the apparent higher workload conditions produced by the ERP (tertiary) task (see also Figure 3-8). This may suggest that distraction effect of cell phones may be highest under existing high-workload conditions while driving.

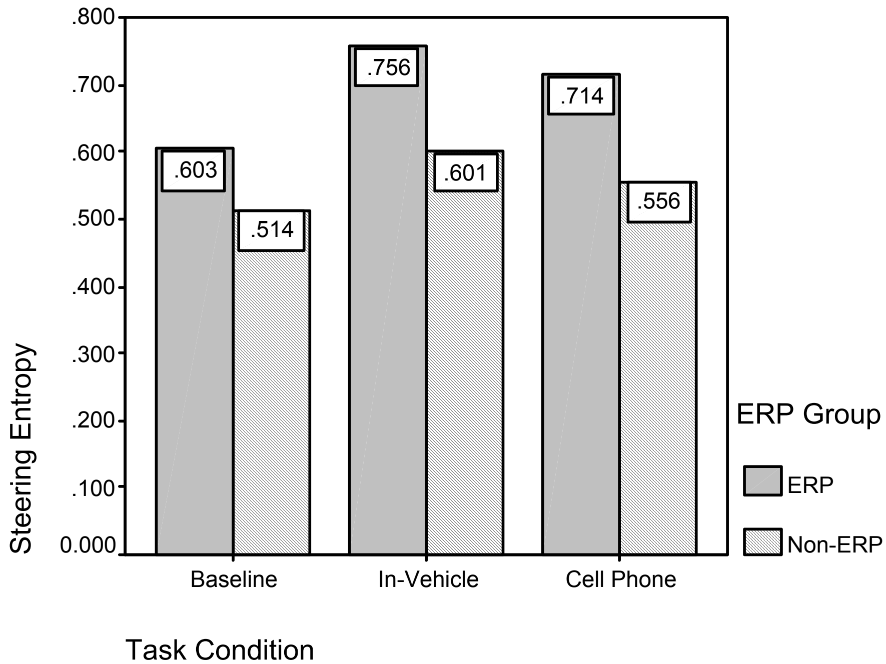


Figure 3-17 – Steering entropy during the entire car-following scenario as a function of ERP group and task condition

In terms of benchmark tests (see Figure 3-18), the steering entropy *during the entire car-following task* was significantly lower while drunk and performing no secondary-tasks compared to being sober and performing in-vehicle tasks [$U_z = 2.52$ $p < .01$]. Moreover, steering entropy was also marginally lower while drunk and performing no secondary-tasks compared to being sober and engaged in cell phone conversations [$U_z = 1.71$ $p < .10$].

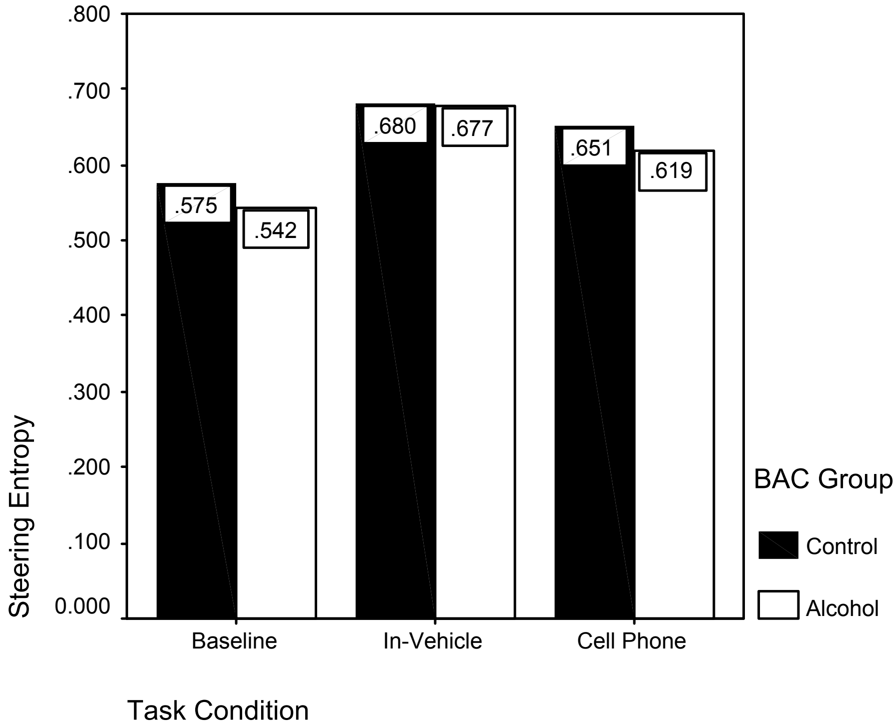


Figure 3-18 – Steering entropy during the entire car-following scenario as a function of BAC group and task condition

Lane Position Variability (standard deviation)

Safety margin variability was measured in terms of time-to-line Crossing (TLC). TLC is a time-based measure of proximity to the lane boundary. Data was analyzed as the reciprocal of TLC (TLC^{-1}) to eliminate large values (infinity) when the vehicle vector is parallel to the lane boundary. There was a significant main effect of BAC group [$F(1,44) = 5.79$, $p < .05$] with higher safety margin variability evident for drunk drivers (M = 0.29) compared to sober drivers (M = 0.06).

There was also a significant main effect for task condition [$F(2,88) = 8.48$, $p < .01$]. As shown in Figure 3-19, there was significantly more safety margin variability during the in-vehicle task condition compared to the baseline [$W_z = 5.87$, $p < .001$] and cell phone [$W_z = 6.03$, $p < .001$] conditions. There was no significant difference in safety margin variability between the cell phone and baseline conditions.

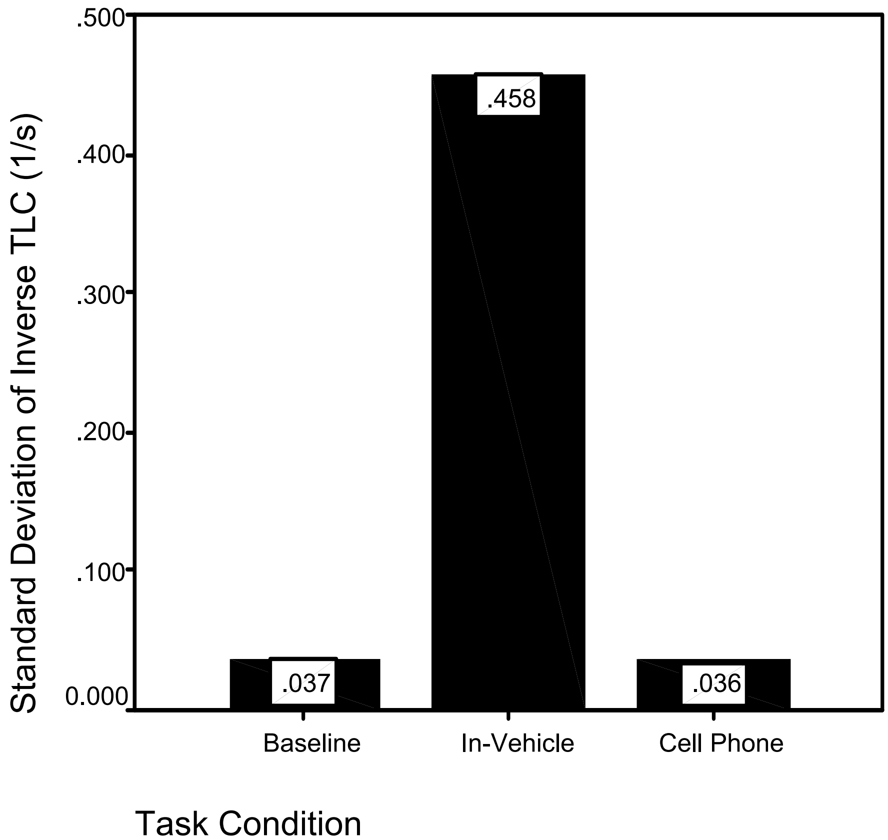


Figure 3-19 –Safety margin variability (TLC^{-1}) during the entire car-following scenario as a function of task condition

However, there was an interaction between task condition and BAC group [$F(2,88) = 5.65$, $p < .05$]. As shown in Figure 3-20, whereas safety margin variability was highest for the in-vehicle task condition for both BAC groups, alcohol significantly exaggerated the impairment effect of driving while engaged in in-vehicle tasks.

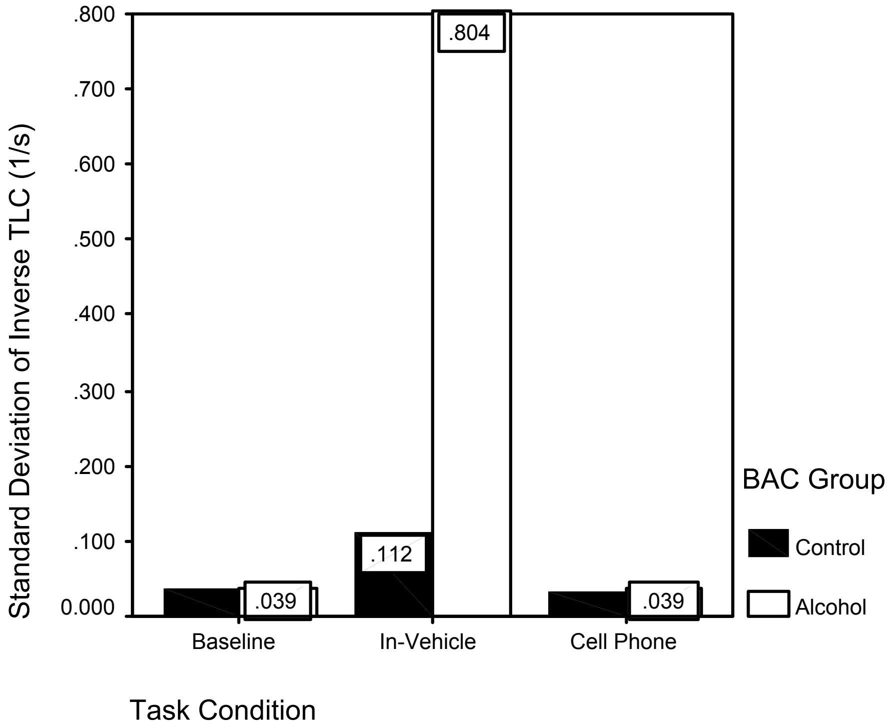


Figure 3-20 – Safety margin variability (TLC^{-1}) during the entire car-following scenario as a function of BAC group and task condition

In terms of benchmark tests (see Figure 3-20), the safety margin variability *during the entire car-following task* was significantly lower while being drunk and performing no secondary-tasks compared to being sober and performing in-vehicle tasks [$U_z = 4.64$ $p < .001$].

Continuous Primary Task Summary

Driving performance during the in-vehicle task condition was consistently worse compared to baseline driving with no secondary-task. In fact, sober drivers interacting with in-vehicle tasks were often more impaired than drunk drivers without any secondary-task.

Alcohol influenced lane position variability by exacerbating the impairment effect of interacting with the in-vehicle tasks.

Driving performance during the cell phone condition was consistently worse compared to baseline driving with no secondary-task. However, impairment of driving performance during the cell phone condition was usually less severe compared to driving while intoxicated or interacting with in-vehicle tasks.

There was some indication that impairment effects may be greatest during the highest workload environments.

There was minimal evidence that the ERP protocol imposed a significant tertiary workload.

The summary of primary effects for driving performance during the continuous car-following scenario is presented in Table 3-1. This table summarizes these main effect comparisons for continuous-task driving performance:

- Completing the in-vehicle task to baseline driving (IV - B)
- Completing the cell phone conversation to baseline driving (CP - B)
- Completing the in-vehicle task to conversing on a phone (IV - CP)

This table also summarizes these benchmark-effect comparisons for continuous-task driving performance:

- Sober driving while completing the in-vehicle task to intoxicated baseline driving (Alc+B - Ctr+IV)
- Sober driving while completing the cell phone task to intoxicated baseline driving (Alc+B - Ctr+CP)
- Effects of alcohol consumption are shown in the comparison of intoxicated and sober baseline driving (Alc+B – Ctr+B).

Table 3-1 – Summary of continuous-driving performance measures (with effects columns labeled as X - Y)

			Main Effects			Benchmark Effects		
		X=	IV	CP	IV	Ctr+IV	Ctr+CP	Alc+B -
Scenario	Measure	Y=	- B	- B	- CP	-Alc+B	- Alc+B	Ctr+B
Car-following	Time headway		■	■				
	Headway variability		■	■	■	■		
	Coherence		■	■	■	░		
	Modulus		■		■	░		
	Phase shift (delay)		■	░	■	■		
	Steering reversals		■	■	■	░		
	Steering entropy		■	■	■	■	░	
	Safety margin		■		■	■		

B = Baseline condition
IV = In-Vehicle task condition
CP = Cell Phone task condition

■ = X is significantly more impaired than Y
░ = X is marginally more impaired than Y

Episodic Scenarios

Overtaking
There were no significant effects for the driving performance measures in this scenario.

Curve
There was a significant main effect of task condition for *speed at the curve apex* [$F(2,88) = 2.94$, $p = .05$]. As shown in Figure 3-21, apex speed was significantly faster during the cell phone condition than during the in-vehicle task condition [$W_z = 2.20$, $p < .05$]. There was no significant difference in apex speed between baseline driving and either secondary-task condition.

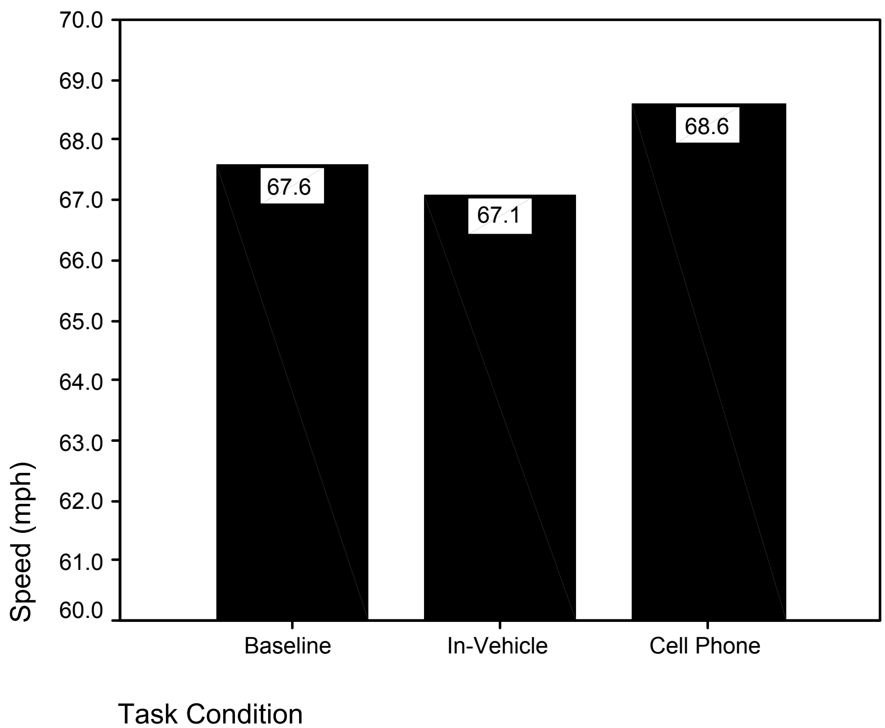


Figure 3-21 – Speed at curve apex as a function of task condition

There was a marginal main effect of task condition for *85th Percentile Deceleration* within the curve [$F(2,88) = 2.63$, $p < .10$]. As shown in Figure 3-22, deceleration was significantly slower during the cell phone condition than during the in-vehicle task condition [$W_z = 2.20$, $p < .05$].

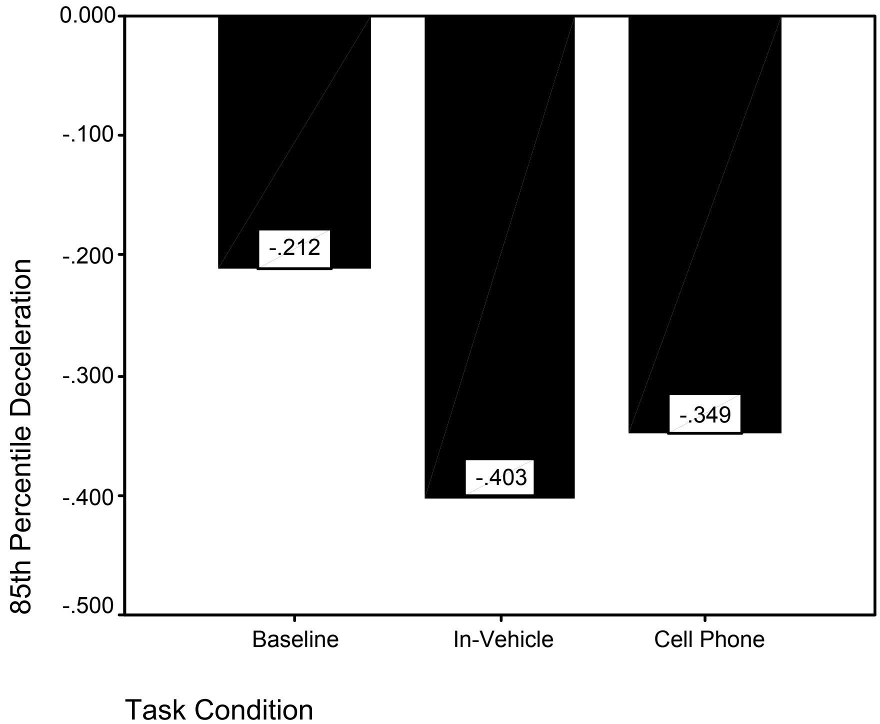


Figure 3-22 – Deceleration (85th Percentile) within curve as a function of task condition

There was a significant marginal main effect of BAC group for *85th Percentile Deceleration* [$F(1,44) = 4.85$, $p < .05$] with drunk drivers exhibiting a faster deceleration during the curve than sober drivers (Figure 3-23).

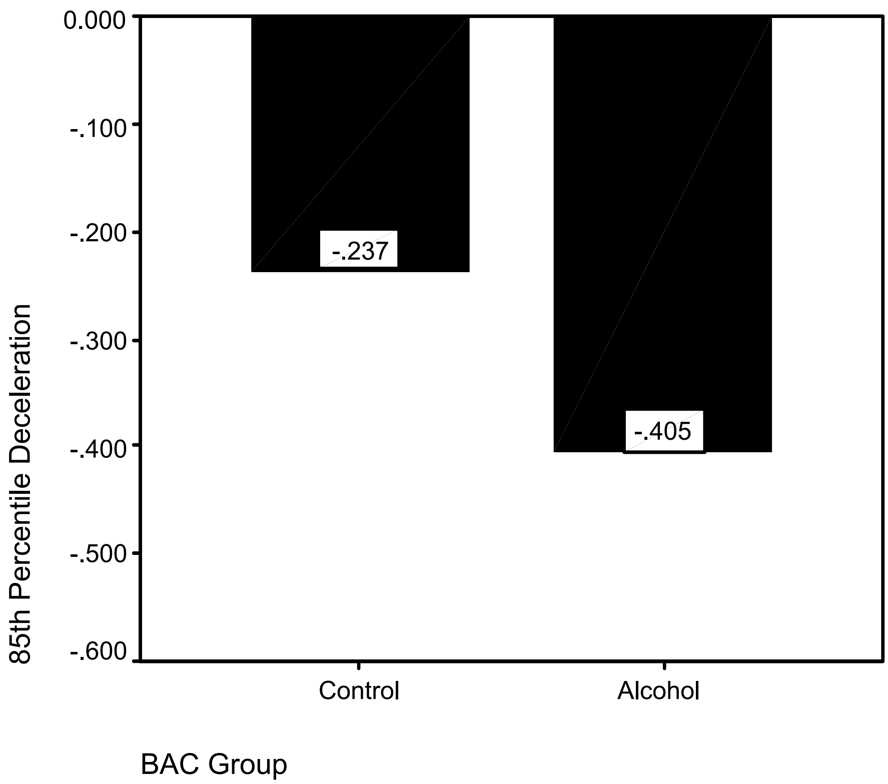


Figure 3-23 – Deceleration (85th Percentile) within curve as a function of BAC group

There was also a significant main effect of task condition for *variability in lane position* [$F(2,88) = 14.80$, $p < .001$]. As shown in Figure 3-24, there was significantly more variability of lane position during the in-vehicle condition than during both the baseline [$W_z = 3.45$, $p < .001$] and cell phone [$W_z = 4.56$, $p < .001$] conditions. There was no significant difference in lane position variability between the baseline and cell phone conditions.

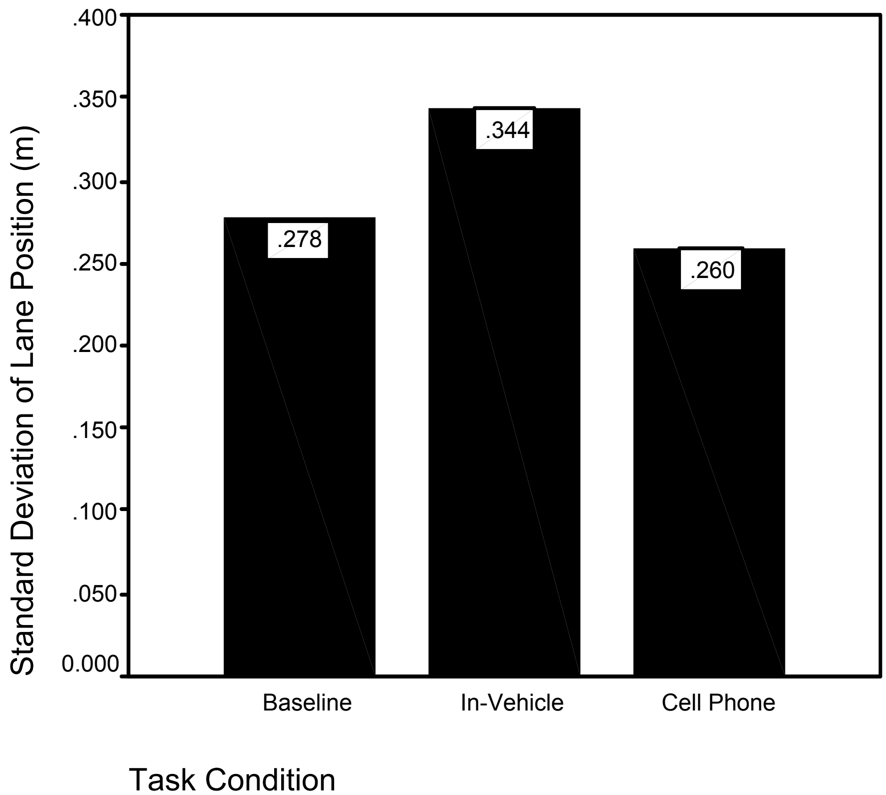


Figure 3-24 – Variability in lane position during curve as a function of task condition

Traffic Queue Pullout Event

Reaction time was defined as the elapsed time from the start of the pullout event to accelerator pedal release. There was a marginal main effect of task condition for reaction time to the pullout event [$F(2,88) = 2.36$, $p < .10$]. As shown in Figure 3-25, reaction time was significantly slower during the in-vehicle task condition compared to the baseline driving condition [$W_z = 2.12$, $p < .05$]. There was no significant difference in reaction time between the cell phone condition and either the baseline or in-vehicle task conditions. Benchmark testing also indicated that the reaction time while sober and interacting with the in-vehicle tasks ($M = 1.41$ s) was significantly slower [$W_z = 2.68$, $p < .01$] than drunk and driving with no other secondary-tasks ($M = 1.11$ s).

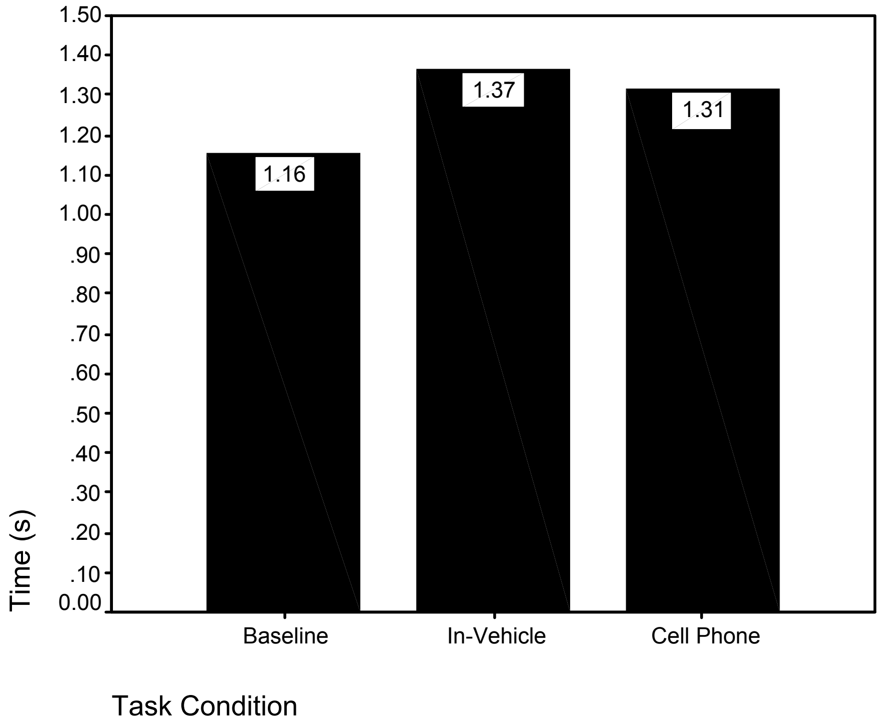


Figure 3-25 – Reaction time for the pullout event as a function of task condition

Movement time was defined as the elapsed time from the release of the accelerator pedal to the activation of the brake pedal. Two ERP group participants were removed as outlying cases for this analysis. There was a significant main effect of task condition for movement time to the pullout event [$F(2,86) = 3.43$, $p < .05$]. As shown in Figure 3-26, movement time was significantly faster during the cell phone condition compared to the baseline driving condition [$W_z = 3.04$, $p < .01$]. There was also a marginal effect for movement time to be faster in the in-vehicle condition compared to the baseline driving condition [$W_z = 1.85$, $p < .10$].

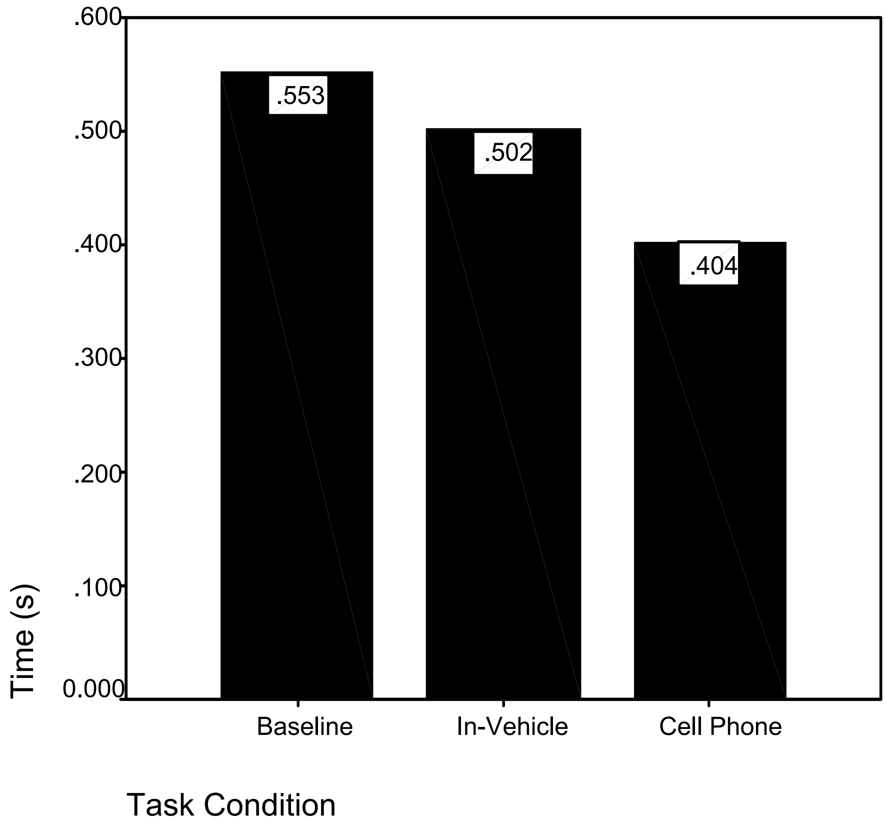


Figure 3-26 – Movement time for the pullout event as a function of task condition

Response time was defined as the elapsed time from the start of the pullout event to the activation of the brake pedal. There was a significant main effect of task condition for response time to the pullout event [$F(2,88) = 5.16$, $p < .01$]. As shown in Figure 3-27, response time was significantly slower during the in-vehicle task condition compared to the baseline driving [$W_z = 2.72$, $p < .01$] and cell phone [$W_z = 2.57$, $p < .01$] conditions. There was no significant difference in response time between the cell phone condition and the baseline driving condition. Benchmark testing also indicated that the reaction time while sober and interacting with the in-vehicle tasks (M = 1.92 s) was significantly slower [$W_z = 2.96$, $p < .01$] than drunk and driving with no other secondary-tasks (M = 1.61 s). There was no significant difference in response time between the cell phone condition and the baseline driving condition.

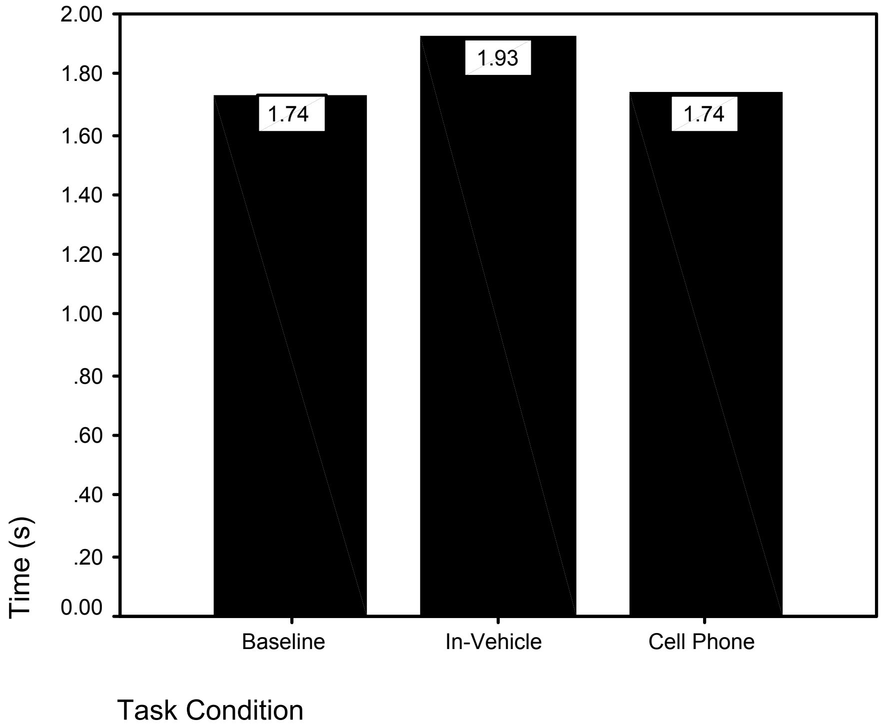


Figure 3-27 – Response time for the pullout event as a function of task condition

There was also a significant interaction for response time between BAC group and task condition [$F(2.88) = 4.19$, $p < .05$]. As shown in Figure 3-28, alcohol only influenced response time during the baseline driving condition [$W_z = 2.44$, $p < .05$].

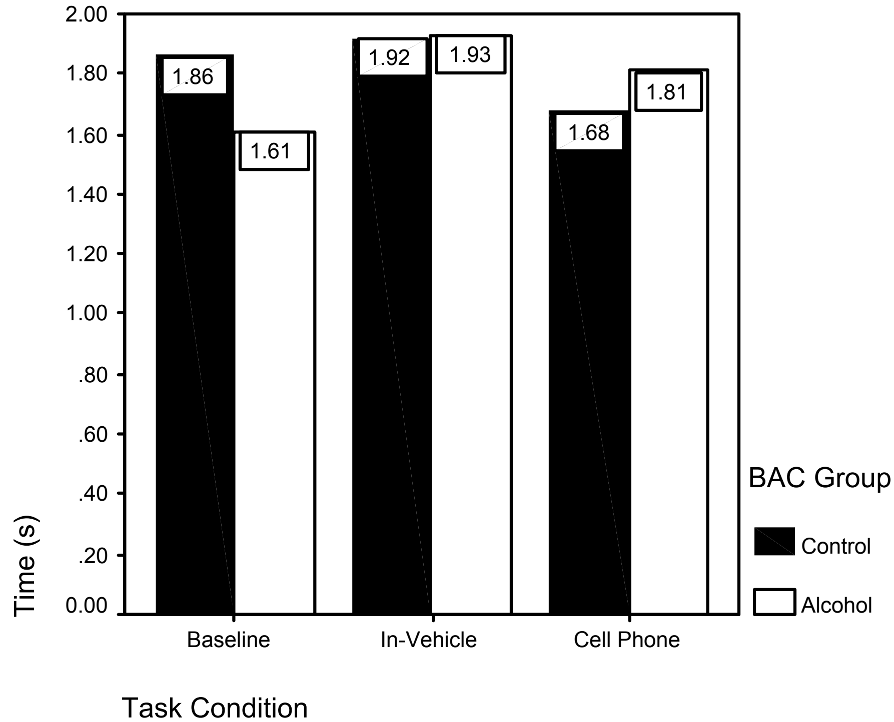


Figure 3-28 – Response time for the pullout event as a function of BAC group and task condition

While intoxicated, response time for the in-vehicle task condition was significantly slower than for the baseline driving condition [$W_z = 3.11$, $p < .01$]. While sober, response time in the cell phone condition was significantly *faster* than during the baseline driving condition [$W_z = 2.41$, $p < .05$] and in-vehicle task condition [$W_z = 2.94$, $p < .01$].

Brookhuis, De Vries, and De Waard (1991) found a similar trend for drivers taking on a cell phone (either handheld or hands-free) to have lower standard deviation in their lane position while driving calmly on a quiet road. The researchers suggested that this was an alerting effect, whereby drivers may have been aware of the potential distracting effects of talking on a phone so they became more aware of their performance, whereas drivers who were not engaged in conversation may have been more relaxed in their driving performance.

Gap acceptance

For most participants, the ERP task ended just after they arrived at the STOP sign of the intersection for the gap acceptance task. For this reason, no ERP group effects were analyzed for this scenario.

One Alcohol participant's (P#38) data was excluded from these analyses for not stopping at the intersection during the Cell Phone condition. There were a large number of drivers (13) who, at most, completed half of the In-Vehicle tasks during the gap acceptance task.

Therefore, we do not expect to see as many strong effects for the In-Vehicle condition during this scenario.

For *time headway of accepted gap*, there was a significant main effect for BAC group [$F(1,45) = 4.69$, $p < .05$] with drunk drivers appearing more cautious in accepting larger gaps (M = 3.70 s) than the sober drivers (M = 3.13 s). As a result, benchmark testing indicated that drunk drivers in the baseline condition accepted significantly longer gaps than the sober drivers in both the cell phone [$U_z = 1.82$, $p < .10$] and in-vehicle task [$U_z = 2.06$, $p < .05$] conditions (see Figure 3-29).

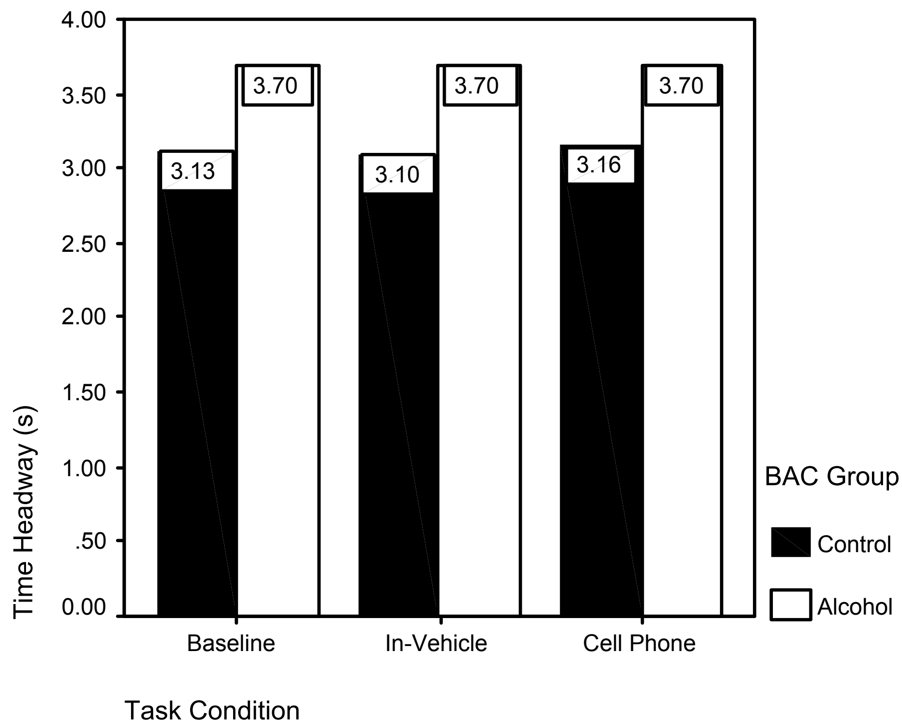


Figure 3-29 – Gap size accepted as a function of BAC group and task condition

For *movement time*, there were no significant effects.

For *safety margin* (minimum TTC^{-1}) during gap acceptance maneuver, there was a significant main effect for BAC group [$F(1,40) = 10.90$, $p < .01$] with drunk drivers appearing to maintain a larger safety margin (M = 0.33 s^{-1}) than the sober drivers (M = 0.41 s^{-1}) [1]. As a result, benchmark testing indicated that drunk drivers in the baseline condition maintained a significantly larger safety margin than the sober drivers in both the cell phone [$U_z = 2.45$, $p < .01$] and in-vehicle task [$U_z = 2.60$, $p < .01$] conditions (see Figure 3-30).

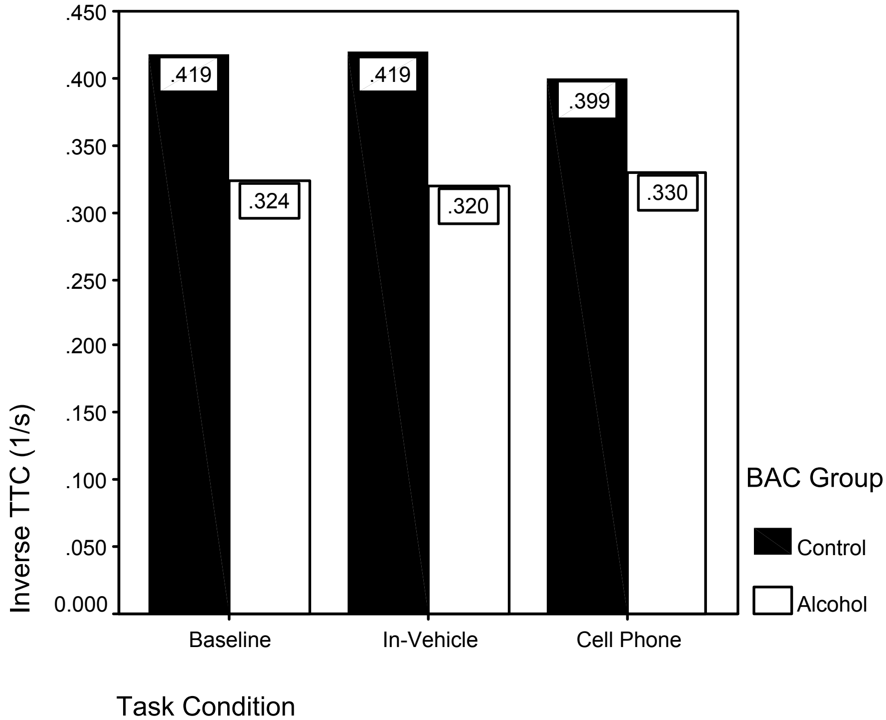


Figure 3-30 – Minimum TTC^{-1} accepted as a function of BAC group and task condition

Table 3-2 indicates the number of condition trials during which a collision was observed. The observed trend is for more crashes amongst the alcohol group.

Table 3-2 – Condition trials with a collision during the gap acceptance maneuver

	Task Condition			BAC Total
BAC Group	**Baseline**	**In-Vehicle**	**Cell Phone**	
Control	1	0	1	2
Alcohol	3	2	1	6
TOTAL	4	2	2	8

Summary of Episodic Events

Various types of impairment effects were observed depending on the characteristics of each particular discrete scenario and the measure of impairment that is examined. Moreover, most impairment was again observed for the in-vehicle task condition.

While negotiating a curve, higher speeds were observed while drivers were engaged in cell phone conversations than while they interacted with in-vehicle tasks or drove without any secondary-task. This higher speed resulted in a significantly faster (peak) deceleration rate within the curve while engaged in the cell phone conversations.

Drivers completing the in-vehicle task condition had slower reaction times and response times to a vehicle unexpectedly pulling out in front of them compared to drivers not completing a secondary-task. Sober drivers completing the in-vehicle task were also slower on these measures as compared to drunk drivers not completing any task.

Alcohol caused drivers to be more cautious when crossing through traffic, as intoxicated drivers waited for larger gaps and chose gaps with larger safety margins. However drunk drivers had more than twice the number of total collisions with these same vehicles. This suggests that though drivers seemed aware of their impairment and took efforts to exhibit safe driving behavior, they were unable to overcome the detrimental effects of intoxication.

The summary of primary effects for driving performance during the episodic car-following scenarios is presented in Table 3-3. This table summarizes these main effect comparisons for episodic task driving performance:

- Completing the in-vehicle task to baseline driving (IV - B)
- Completing the cell phone conversation to baseline driving (CP - B)
- Completing the in-vehicle task to conversing on a phone (IV - CP)

This table also summarizes these benchmark-effect comparisons for episodic-task driving performance:

- Sober driving while completing the in-vehicle task to intoxicated baseline driving (Alc+B - Ctr+IV)
- Sober driving while completing the cell phone task to intoxicated baseline driving (Alc+B - Ctr+CP)
- Effects of alcohol consumption are shown in the comparison of intoxicated and sober baseline driving (Alc+B – Ctr+B)

Table 3-3 – Summary of episodic driving performance measures (with effects columns labeled as X - Y)

		Main Effects			Benchmark Effects		
	X=	IV	CP	IV	Ctr+IV	Ctr+CP	Alc+B -
Scenario	Measure Y=	- B	- B	- CP	-Alc+B	- Alc+B	Ctr+B
Overtake	TTC^{-1} @ start						
	TTC^{-1} @ end	░					
	Duration						
	Max lateral accel						
Curve	Speed @ apex			░			
	Deceleration rate		░				
	Lane pos variability	■	░	■			
Traffic Queue Pullout Event	Reaction time	░			■		
	Movement time	░ *	■ *				░ *
	Response time	■		■	■		░
Gap Acceptance	Time headway				■	░	■
	Movement time						
	Safety Margin				■ *	■ *	■ *
	Collisions						░

B = Baseline condition
IV = In-Vehicle task condition
CP = Cell Phone task condition

■ = X is significantly more impaired than Y
░ = X is marginally more impaired than Y
* = Y is more impaired than X

RESOURCE ALLOCATION

Subjective Effort (RSME)

There was a significant main effect for task condition [$F(2,88) = 8.40$, $p < .001$]. As shown in Figure 3-31, both the secondary-task conditions (in-vehicle, cell phone) resulted in higher subjective effort during the entire drive than the baseline condition without any secondary-task.

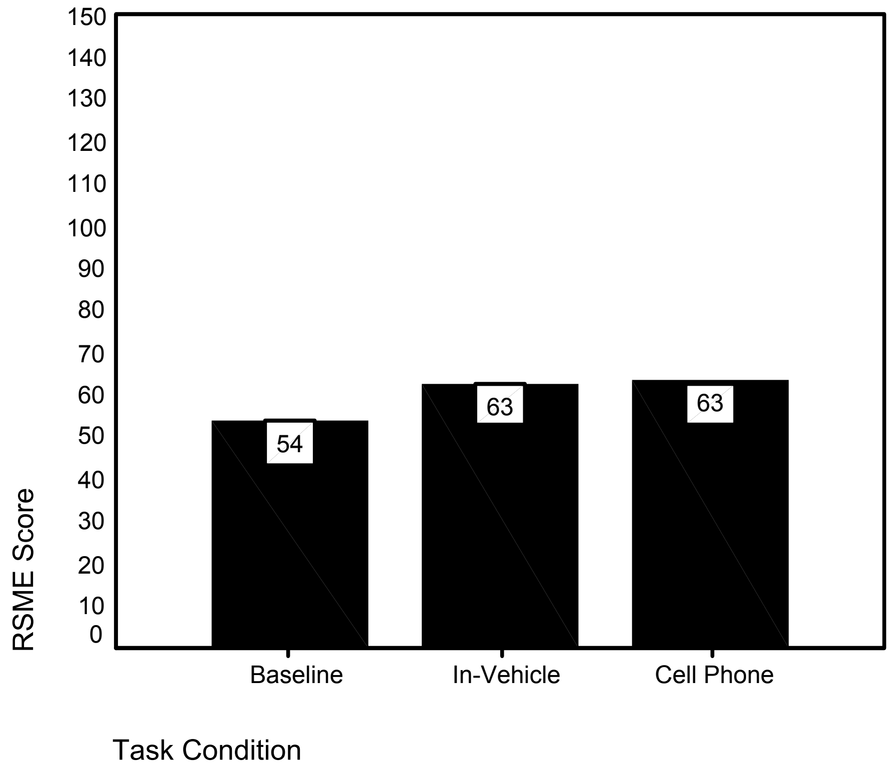


Figure 3-31 – Subjective mental workload ratings during car-following task as a function of task condition

Physiological Effort (IBI)

Measuring heart rate IBI (Inter-Beat Intervals) was done in conjunction with the ERP measurements and therefore the following validation was taken only from the ERP group participants during the car-following scenario. A resting heart rate (taken during the ERP practice session) was used as a significant covariate [$F(1,18) = 86.6$, $p <.001$].

There was a significant main effect for task condition [$F(2,36) = 4.93$, $p < .01$]. As shown in Figure 3-32, physiological indications of workload were significantly higher during the hands-free cell phone condition than during baseline driving without any secondary-task [$W_z = 2.48$, $p < .01$]. Moreover, the measured workload in the cell phone condition was also marginally higher than during the in-vehicle task condition [$W_z = 1.76$, $p < .08$]. There was no significant difference in workload between the baseline and in-vehicle task conditions.

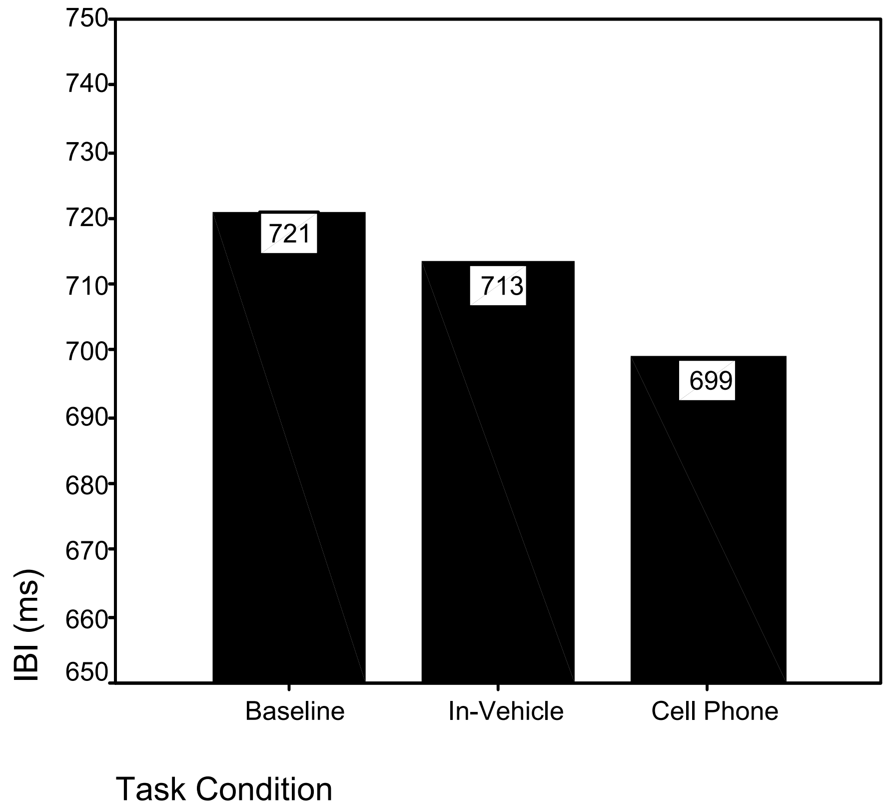


Figure 3-32 – Heart rate IBI (covariate adjusted) during car-following scenario as a function of task condition

Psycho physiological Measures (Mental Processes)

The ERP protocol provided performance measures based on response time (RT), response accuracy, and response errors for the target stimulus tones. The protocol also provided measures of the attention resource allocation to the novel stimulus tones (P300).

Performance Measures

Performance on the tertiary ERP task was measured in terms of average reaction time to correctly identified target tones, percentage of target tones correctly detected, and the number of errors (sum of misses and false alarms).

Reaction Time

There was a significant main effect of task condition for response time to target tones [$F(2,36) = 19.00$, $p < .001$]. As shown in Figure 3-33, response time was significantly slower during the in-vehicle task [$W_z = 3.70$, $p < .001$] and cell phone [$W_z = 3.74$, $p < .001$] conditions compared to the baseline driving. Reaction time during both secondary-task conditions was similar. However, benchmark testing indicated that the reaction time while drunk and driving with no other secondary-tasks was marginally faster ($M = 683$ ms) than while sober and engaged in cell phone conversations ($M = 825$ ms) [$U_z = 1.85$, $p < .10$].

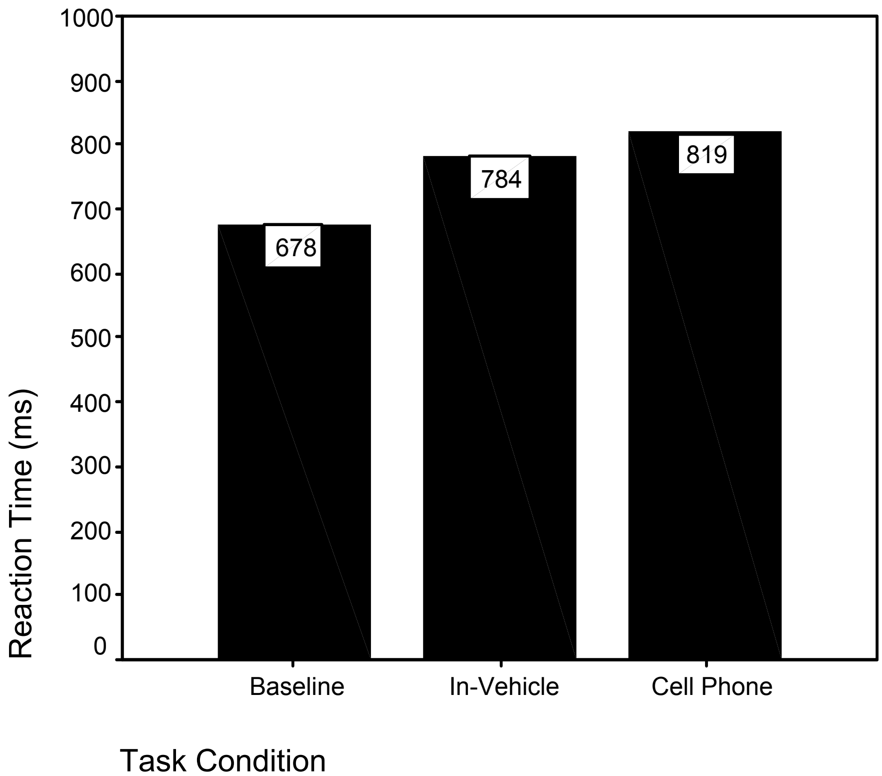


Figure 3-33 – Reaction time to target tones in ERP task across all driving scenarios as a function of task condition

Target Tone Accuracy

There was a significant main effect of task condition for response accuracy to detect target tones [$F(2,36) = 15.86$, $p < .001$]. As shown in Figure 3-34, response accuracy was significantly lower during the cell phone condition compared to the baseline driving [$W_z = 3.90$, $p < .001$] and the in-vehicle task condition [$W_z = 3.70$, $p < .001$]. Indeed, benchmark testing indicated that the response accuracy while drunk and driving with no other secondary-tasks ($M = 93$ percent) was significantly higher than while sober and engaged in cell phone conversations ($M = 73$ percent) [$U_z = 3.03$, $p < .01$].

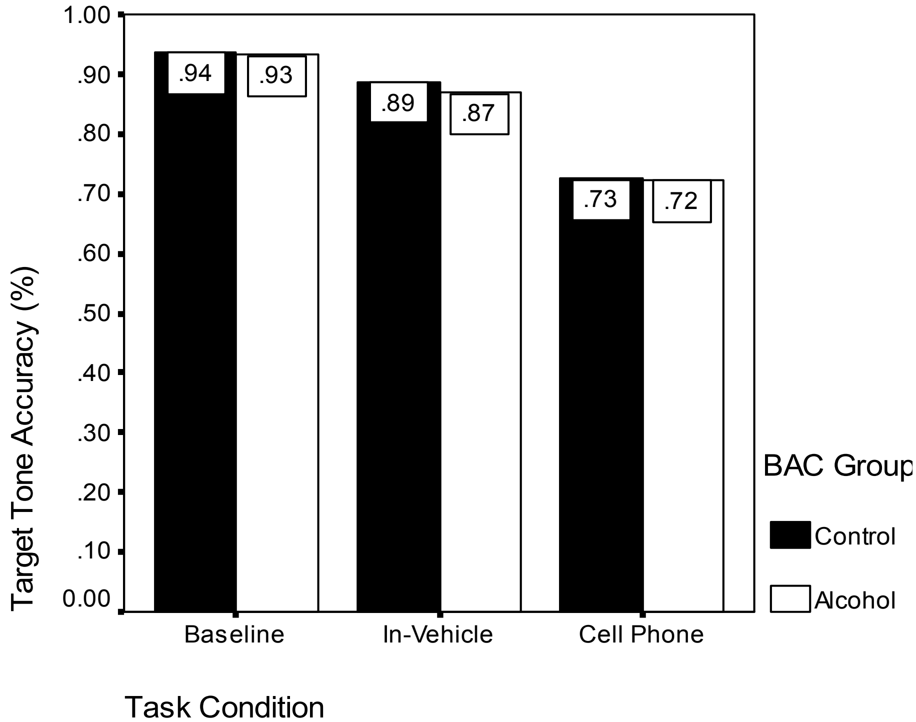


Figure 3-34 – Detection accuracy of target tones in ERP task across all driving scenarios as a function of task condition

Total Errors

There was a significant main effect of task condition for total detection errors [$F(2,36) = 14.00$, $p < .001$]. As shown in Figure 3-35, the total number of errors was significantly higher during the cell phone condition [$W_z = 3.50$, $p < .001$] compared to the baseline driving. Response accuracy during the cell phone condition was also lower than for the in-vehicle task condition [$W_z = 3.04$, $p < .01$]. Moreover, benchmark testing indicated that the response accuracy while drunk and driving with no other secondary-tasks ($M = 2.7$ errors) was significantly lower than while sober and engaged in cell phone conversations ($M = 8.9$ errors) [$U_z = 2.91$, $p < .01$]. Notably, the total number of errors during the in-vehicle condition was not significantly different from the baseline condition.

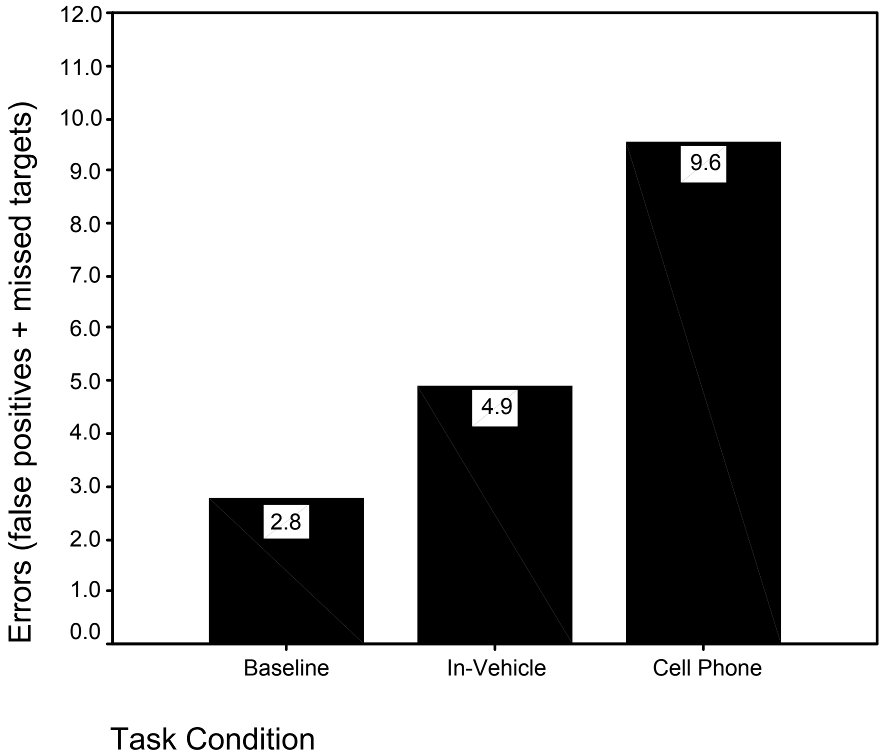


Figure 3-35 – Total number of errors for target tones in ERP task across all driving scenarios as a function of task condition

Performance Measure Summary
In general, drivers while engaged in the secondary-tasks were less able to perform the tertiary ERP tone detection task. This implies that drivers interacting with in-vehicle devices (visual input, manual output) or engaging in cell phone conversations (auditory input, verbal output) had less spare mental capacity to apply to the driving task. Notably, performance impairment was largest for the cell phone condition. Indeed, benchmark tests suggested that drunk drivers (without any secondary-task) could perform better than the sober drivers conversing on a cell phone.

These results may be "real," or a potential artifact resulting from the use of an auditory ERP stimulus that conflicted with the auditory conversations used as input for the cell phone condition. However, there is still a significant performance impairment for the in-vehicle task condition that utilizes visual rather than auditory input. This suggests that the level of impairment observed in the cell phone condition cannot exclusively be attributed to the sensory conflict.

Attention Resource Allocation
The capacity for attention resource allocation was measured in terms of the P300 component for both the target tone and the novel sounds. Target tone P300 analyses focus on recordings from the parietal (Pz) and central (Cz) locations. Novel sound P300

analyses focus on recordings from the frontal (Fz), central, and parietal locations. Lower amplitude values imply an increase in workload with a commensurate reduction of allocable resources (reduced processing capacity). An analysis of responses at all locations was also completed for both the target and novel sound analyses. One Alcohol and one Control condition participant[ii] were excluded from all of these analyses due to bad P300 data.

Novel Sounds P300
At the frontal location (Fz), benchmark testing indicated that drunk drivers in the baseline condition displayed a significantly smaller P300 response than the sober drivers in the cell phone condition [$U_z = 2.40$, $p < .05$] (see Figure 3-36). This suggests that sober drivers on the cell phone are better able to orient to unexpected sounds than drunk drivers not completing a secondary-task.

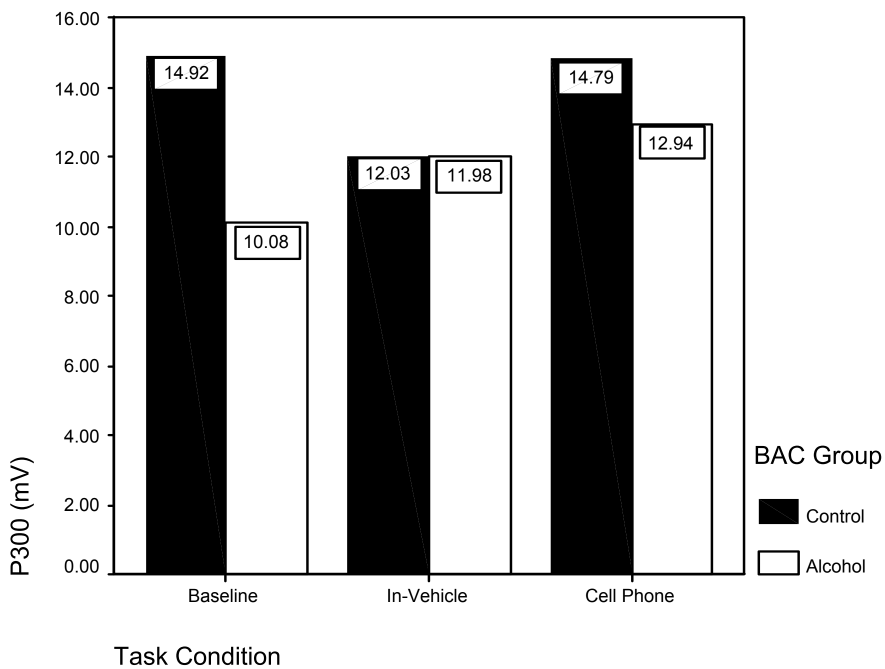


Figure 3-36 –Novel sound P300 located at Fz across all driving scenarios for BAC group by task condition[iii]

This response was expected to be smaller for the cell phone condition, as we thought attention would be placed in the cell phone task as opposed to listening for the ERP tones. Instead, the heightened response could be due to synergy of attention to two stimuli in the same modality. That is, drivers in the Cell Phone condition were primed for auditory input and so may be been more sensitive to the ERP tones.

At the parietal location (Pz), the main effect of BAC Condition was significant [$F(1,20) = 5.40$, $p < .05$]. P300 amplitude had a tendency to be reduced for the alcohol group ($M = 9.71$ μV) compared to the sober group ($M = 12.38$ μV). Drivers in the Baseline condition experienced the largest significant difference between Alcohol (M = 10.26 µv) and Control (M = 14.27 µv) group drivers [$W_z = 2.46$, $p < .01$]. Alcohol group drivers had significantly smaller P300 amplitudes at Pz than their Control counterparts as seen in Figure 3-37, and also true for Fz. This suggests that driving while intoxicated produces a diminished orienting response to unexpected sounds. Furthermore, this alcohol effect was not as strongly seen in the secondary-tasks conditions, suggesting they had fewer resources to spare while sober as compared to baseline driving.

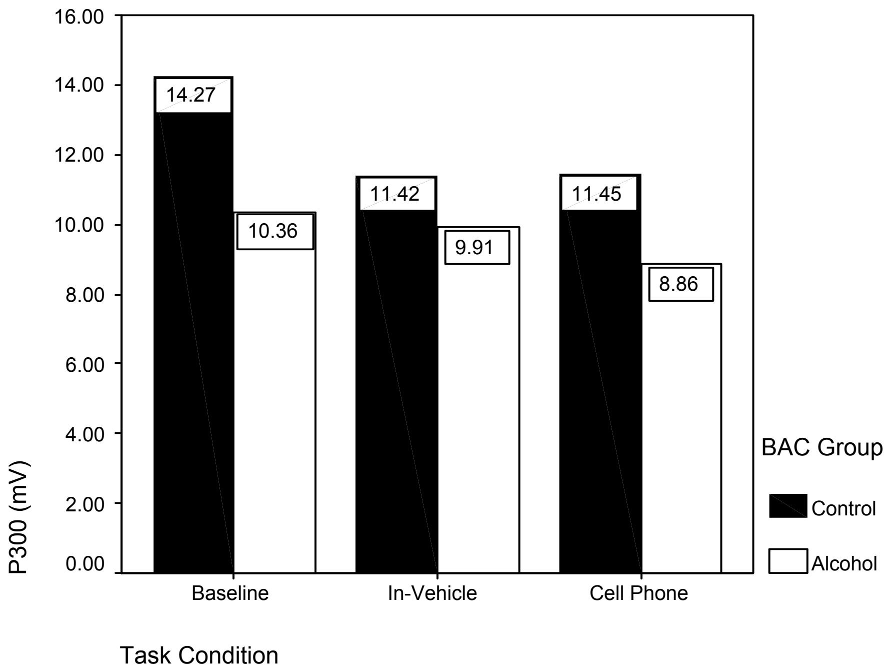


Figure 3-37 – Novel sound P300 located at Pz across all driving scenarios for BAC group by task condition[iii]

Also at the Pz, there was a significant quadratic contrast effect for task condition for the novel sounds [$F(1,20) = 4.72$, $p < .05$]. As shown in Figure 3-38, the P300 amplitude during the Cell Phone [$W_z = 1.77$, $p < .10$] and In-Vehicle [$W_z = 1.96$, $p = .11$] conditions was significantly lower than for the baseline condition. This suggests that drivers in the baseline condition had more mental capacity for evaluating the unexpected sound than did those in the secondary-task conditions.

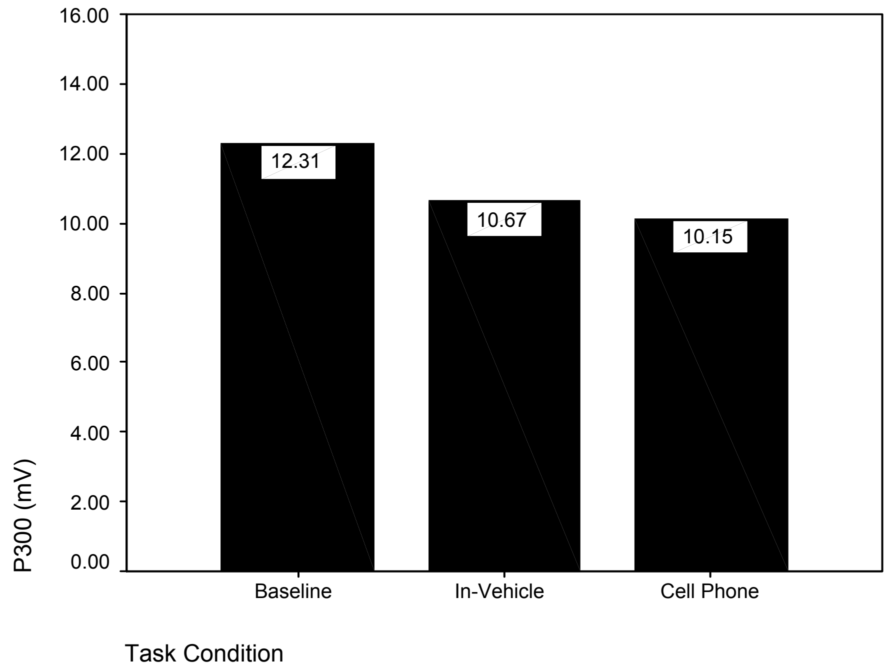


Figure 3-38 – Novel sound P300 located at Pz across all driving scenarios by task condition[iii]

Novel Sounds Topographical P300

Analysis of the P300 response to the novel sounds showed that the combined cell phone and in-vehicle tasks caused a significant reduction in amplification of the P300 signal compared to baseline drivers. Figure 3-39 shows the ERP response for novel sounds, highlighting (time between green lines) of the P300 response. The brain images on the right show differences between responses while completing the Baseline (blue line in ERP) and secondary-task (red line) conditions. The second brain image shows a black and white composite of the significant differences between drivers completing the baseline and secondary-task conditions (significance at p=0.05 level is shown in white). As there were more significant differences in the rear of the brain, these images show that secondary-tasks produced less evaluation activity toward unexpected sounds.

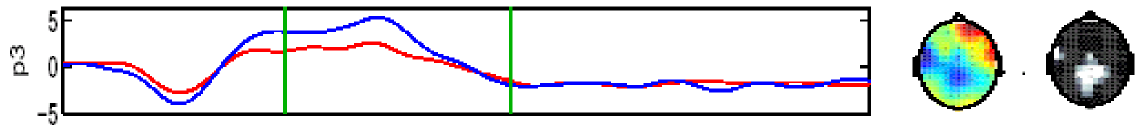


Figure 3-39 – ERP of P300 response (between vertical lines) for drivers' responses during baseline (blue line) and combined secondary-task (red) conditions

When the distraction tasks were analyzed separately, compared to the baseline condition the cell phone condition showed the largest impairment to processing in the parietal region (evaluation processing; Figure 3-40). This suggests that drivers completing the cell phone condition were more cognitively impaired at a physiological level.

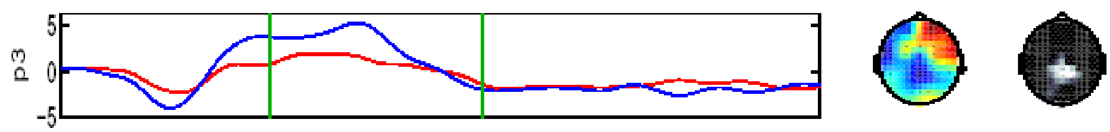


Figure 3-40 – ERP of P300 response (between vertical lines) for drivers' responses during baseline (blue line) and the cell phone (red) conditions

A less-significant effect is seen when comparing the in-vehicle task alone (Figure 3-41), suggesting that drivers were more cognitively impaired at a physiological level during the cell phone condition than while completing in-vehicle tasks. The fact that drivers performed worse on the performance measures while completing the in-vehicle task, yet showed the least amount of physiological impairment suggests that drivers were better able to compensate for their alcohol (Figure 2-10) and cell phone (Figure 3-40) impairments.

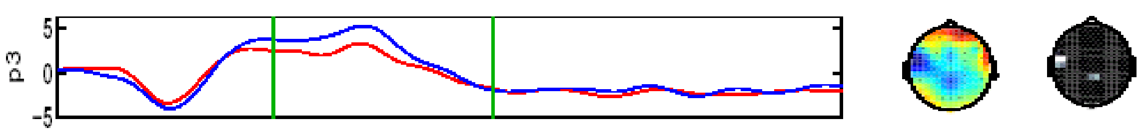


Figure 3-41 – ERP of P300 response (between vertical lines) for drivers' responses during baseline (blue line) and the in-vehicle (red) conditions

Resource Allocation Summary

Both secondary-task conditions were perceived to invoke higher mental workload and less-intense responses to tertiary stimuli than baseline driving. Also, participants had a faster heart rate during the secondary-task conditions, especially during the cell phone conversation, indicating a greater physiological load.

Alcohol was shown to have a consistent negative effect on performance on the ERP measures. The performance measures and ERP to the novel tones show strong evidence that completing the cell phone condition impaired performance for sober drivers. Specifically, drivers that conversed had larger reaction times and lower accuracy than those in the baseline or in-vehicle conditions. The in-vehicle task impaired performance similarly, but to a lesser extent. Finally, P300 response waves showed that the cell phone condition had a significantly smaller evaluation response to novel tones than the baseline condition. Overall it seems that engagement in cell phone conversations resulted in higher psycho physiological mental load as compared to interacting with in-vehicle tasks and driving without any secondary-task.

The summary of primary effects for resource allocation measures are presented in Table 3-4. This table summarizes these main effect comparisons:

- Completing the in-vehicle task to baseline driving (IV - B)
- Completing the cell phone conversation to baseline driving (CP - B)
- Completing the in-vehicle task to conversing on a phone (IV - CP)

This table also summarizes these resource allocation benchmark-effect comparisons:

- Sober driving while completing the in-vehicle task to intoxicated baseline driving (Alc+B - Ctr+IV)
- Sober driving while completing the cell phone task to intoxicated baseline driving (Alc+B - Ctr+CP)
- Effects of alcohol consumption are shown in the comparison of intoxicated and sober baseline driving (Alc+B – Ctr+B)

Table 3-4 – Summary of resource allocation measures (with effects columns labeled as X - Y)

			Main Effects			Benchmark Effects		
		X=	IV -	CP	IV	Ctr+IV	Ctr+CP -	Alc+B -
Category	Measure	Y=	B	- B	- CP	-Alc+B	Alc+B	Ctr+B
Subjective rating of mental effort			■	■				
Physiological effort (heart rate IBI)				■	▒ *			
Psycho-physiological Measures	Target reaction time		■	■			▒	
	Target accuracy		■	■	■ *		■	
	Total errors			■	■ *		■	
	P300 target tones							
	P300 novel sounds		■	■			■ *	■
	Mapping ERP novel			■				

B = Baseline condition
IV = In-Vehicle task condition
CP = Cell Phone task condition

■ = X is significantly more impaired than Y
▒ = X is marginally more impaired than Y
* = Y is more impaired than X

ENVIRONMENT AWARENESS

Performance measures for this task were taken over both frequencies of car-following modulation, therefore the analysis is a 2 x 2 x 3 mixed model design; 2 (BAC: Alcohol, Control) x 2 (ERP: ERP, Non-ERP) x 3 (Condition: Baseline, Cell Phone, In-Vehicle).

Awareness of the driving environment was assessed based on performance for the sign recognition task during the car-following scenario. Performance was measured in terms of reaction time (RT) to identify the target sign, percentage of target signs detected, and detection errors (false positives and missed targets). These analyses exclude seven participants from the Alcohol group and five participants from the Control group who did not complete the sign-detection task during one or more experimental drives.

Reaction Time (RT)

The analysis of reaction time (RT) excluded an additional participant (Alcohol, ERP group) as an outlying case. There was an interaction between task condition and BAC group [$F(2,62) = 3.81$, $p < .05$]. As shown in Figure 3-42, the reaction time to correctly detect a target sign was significantly slower during the in-vehicle task condition compared to baseline driving [$W_z = 3.51$, $p < .001$], but only for sober drivers (Control group).

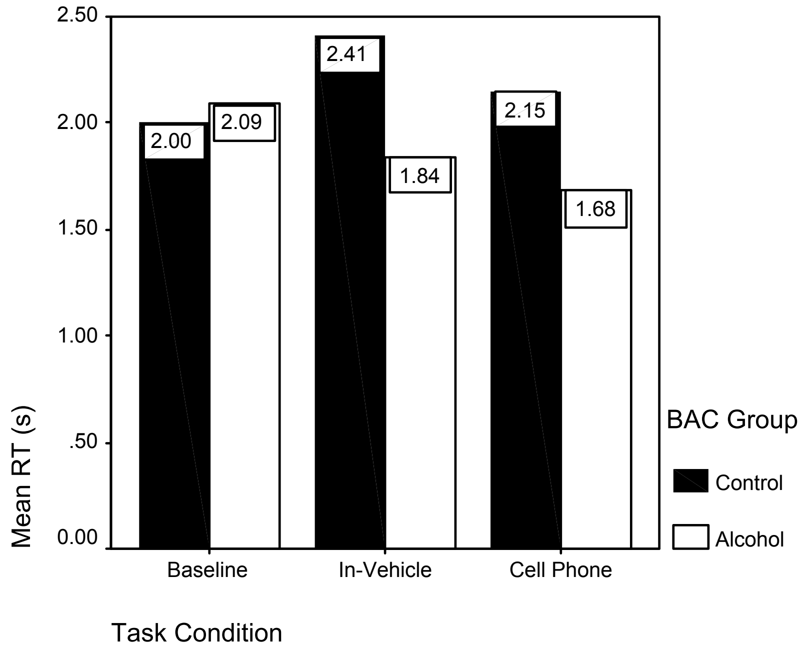


Figure 3-42 – Reaction time for sign-detection task during the entire car-following scenario as a function of BAC group and task condition

Percent Correct Responses

There was a significant main effect for task condition [$F(2,64) = 5.82$, $p < .01$]. As shown in Figure 3-43, there was significantly more target signs detected during the baseline condition without any secondary-task than during either the in-vehicle [$W_z = 2.03$, $p < .05$] and cell phone [$W_z = 2.51$, $p < .01$] conditions. The percentage of target signs correctly detected was similar to detection rates for the in-vehicle and cell phone conditions.

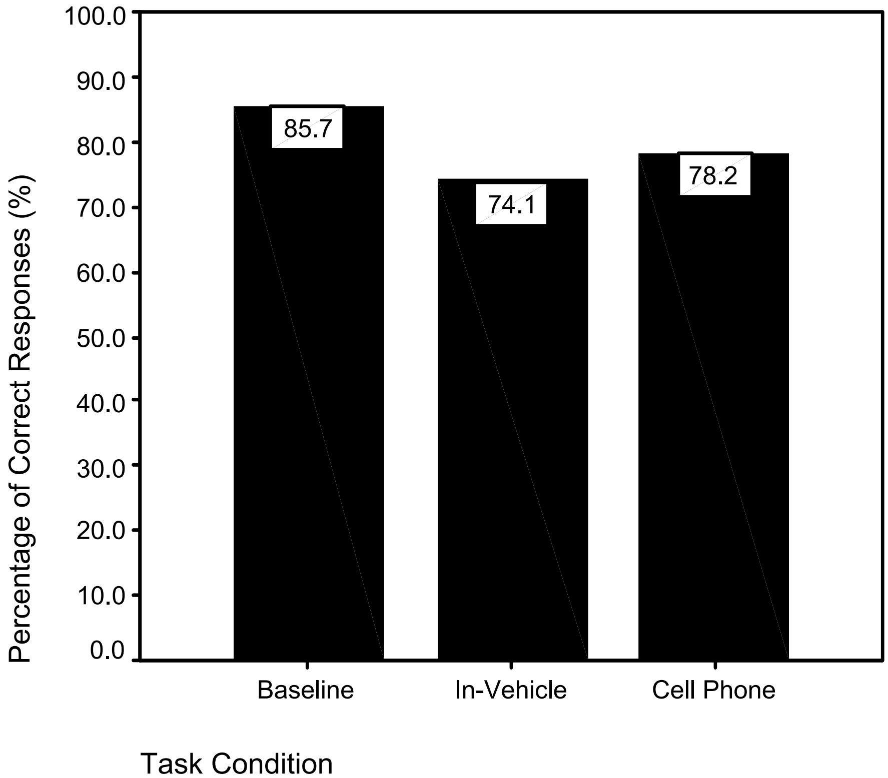


Figure 3-43 – Percent correct detection for sign-detection task during the entire car-following scenario as a function of BAC group and task condition

Detection Errors

A measure of detection errors was computed as the sum of false positives and misses for the sign-detection task. This analysis excluded an additional participant (Control, ERP group) as an outlying case. There was a significant main effect for task condition [$F(2,62) = 5.03$, $p < .01$]. As shown in Figure 3-44, there was significantly fewer detection errors during the baseline condition without any secondary-task than during either the in-vehicle [$W_z = 1.94$, $p = .05$] and cell phone [$W_z = 3.31$, $p < .001$] conditions. The number of detection errors was similar for the in-vehicle and cell phone conditions.

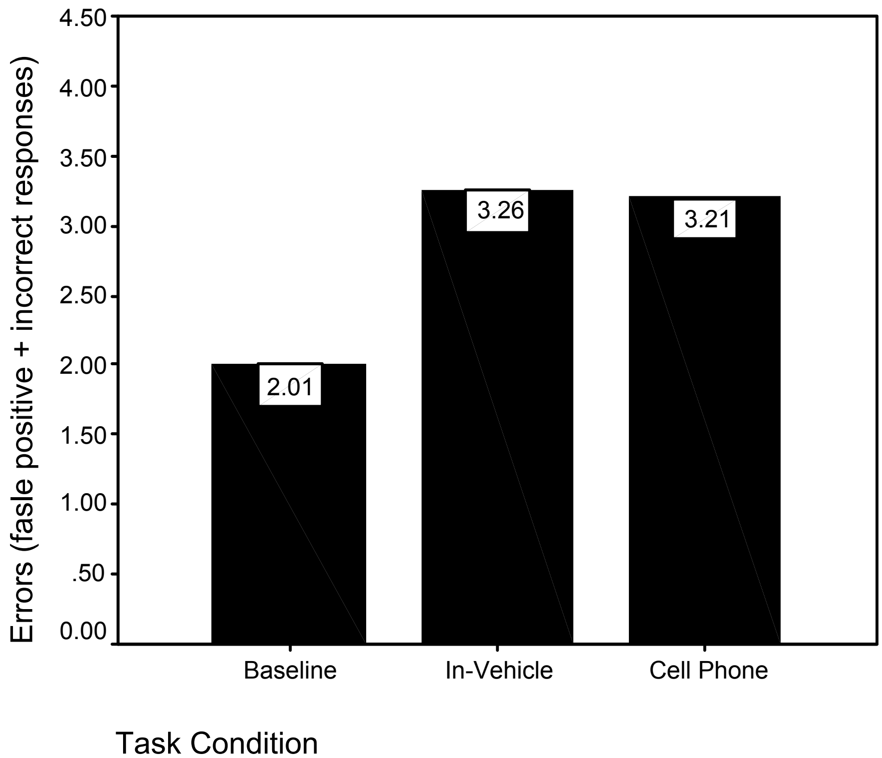


Figure 3-44 – Detection errors for sign-detection task during car-following scenario as a function of BAC group and task condition

Environment Awareness Summary

For the sign-detection measures, drivers were less aware of the driving environment during both secondary-task conditions (in-vehicle task, cell phone conversation) compared to baseline driving. Alcohol influenced reaction time by exacerbating the impairment effect of interacting with the in-vehicle tasks.

The summary of primary effects for environment awareness measures are presented in Table 3-5. This table summarizes these main effect comparisons:

- Completing the in-vehicle task to baseline driving (IV - B)
- Completing the cell phone conversation to baseline driving (CP - B)
- Completing the in-vehicle task to conversing on a phone (IV - CP)

Table 3-5 – Summary of environment awareness measures (with effects columns labeled as X - Y)

			Main Effects			Benchmark Effects		
		X=	IV	CP	IV	Ctr+IV	Ctr+CP	Alc+B -
Category	Measure	Y=	- B	- B	- CP	-Alc+B	- Alc+B	Ctr+B
Environment Awareness	Reaction time							
	% correct responses		■	■				
	Errors		■	■				

B = Baseline condition
IV = In-Vehicle task condition
CP = Cell Phone task condition

■ = X is significantly more impaired than Y

CHAPTER 4: DISCUSSION

This study compared driver performance while conversing on a cell phone to conditions of operating common in-vehicle controls and alcohol intoxication (BAC 0.08). In addition, the study examined the combined effects of being distracted and being intoxicated given that there may be a higher risk of a crash if the driver engages in a combination of risk factors. The main effect of distraction type (cell phone vs. in-vehicle tasks), the main effect of alcohol impairment (sober vs. intoxicated), and the interaction effect of combining distraction while impaired were analyzed. This was done in order to better understand the relationship between cell phone conversations while driving and engaging in consensual (in-vehicle) and sanctioned (BAC) risks. Our aim was to answer a number of questions.

How does the distraction of common in-vehicle tasks impact driving? In-vehicle tasks had a large detrimental impact on all of the continuous behavioral driving performance measures including maintaining a safe and consistent headway as well as consistent steering performance. In most instances, driving sober while completing the in-vehicle tasks proved to be more impairing than driving intoxicated without an additional distraction task (or driving sober and talking on the cell phone). In-vehicle tasks also caused drivers to maintain less-consistent lane position during curves, react more slowly to an unexpected pullout event, have more errors during the environmental awareness task, and have higher reported mental workload. Sober drivers completing these distraction tasks had slower reaction times to the unexpected vehicle pulling out than did the intoxicated drivers with no secondary-task. The in-vehicle tasks also affected drivers in the physiological measures by having worse reaction time and accuracy on the ERP tertiary task, and having lower physiological responses to the ERP task.

How does the distraction of cell phone conversations impact driving? Cell phone distraction also had an impact on most car-following continuous behavioral driving performance measures, except that conversations did not affect the difference in speed amplitude compared to the lead vehicle (modulus). Cell phone conversations also caused drivers to have a less planned response to the pullout event, have more errors in the environmental awareness task, and have higher reported mental workload. Furthermore, conversations affected drivers in the physiological measures by having a higher heart rate, worse reaction time and accuracy on the ERP tertiary task, and lower responses to novel tones in evaluative brain areas to a more broad extent than seen during the in-vehicle tasks.

How does the impairment of alcohol impact driving and compound distraction effects? Alcohol affected driving performance by making drivers slower to the unexpected pullout event and by displaying more impaired physiological responses to the ERP task. Though intoxicated drivers accepted the larger, safer gaps, these same drivers also had more collisions with the crossing traffic than did the sober drivers, thus indicating that their ability to safely cross the intersection was impaired.

Is the impact of cell phone conversations greater than performing common secondary-tasks or being intoxicated? Physiological performance during conversations (sober) was impaired as compared to performance during the in-vehicle tasks (sober) and to driving intoxicated. Namely, those having a conversation had lower reaction times and accuracy on the ERP task and a larger response to unexpected novel sounds than those completing the in-vehicle task sober or to those driving intoxicated and completing no secondary-task. Sober drivers on the cell phone had impaired steering entropy performance compared to intoxicated baseline drivers. Those conversing on a cell phone also had worse lane position variability during curves and worse reaction time to the unexpected vehicle pulling out than did drivers completing the in-vehicle task.

Thus, performance during continuous driving tasks that require sustained driver vigilance was impaired by distraction tasks. Conversations using hands-free cell phones demonstrated significant impairment compared to baseline driving without any distraction. Notably, distraction from in-vehicle tasks resulted in the most impairment. Indeed, secondary-task distraction resulted in more impairment than did alcohol intoxication. Not only were significant distraction effects more numerous than for effects of intoxication, but specific comparisons demonstrated that intoxicated drivers were less impaired than sober drivers when distracted. Higher workload was found for the secondary-tasks on the subjective scale. In addition, faster heart rate was present for both secondary-tasks and especially during the cell phone conversations, which has also been found in cell phone driving studies in the real world as a sign of higher mental effort load (Brookhuis, de Vries, and de Waard, 1991).

Brookhuis, de Waard, and Mulder (1994) also observed that driving performance on a continuous driving measure of car-following can be affected by conversing on a cell phone or alcohol consumption. Our car-following results during the cell phone and in-vehicle conditions showed that the median time headway was increased, indicating that our participants were attempting a compensation strategy for the workload imposed by the distraction tasks. Our drivers' time headway variability was increased showing overall decreased performance on primary task goal of maintaining a constant headway. Coherence, modulus, and phase shift measures were also degraded, further indicating that the conversations and tasks were affecting performance. Steering (entropy) and lane position during this time also showed that secondary-tasks were imposing a high level of workload from impairment. In this sense, these variables showed that distraction was not only impairing primary task performance (i.e., longitudinal control), but also may spill over to impact all aspects of driving (in this case, lateral control).

RESOURCE DEMAND

These findings are consistent with the driver demand model (Wickens, 1980) in that drivers did not have enough spare resource capacity to complete both the driving and secondary-tasks simultaneously. Therefore, drivers compromised resource allocation and environmental awareness to the extent that their driving performance was impaired. These differences in performance can be explained by the resource demand model, as there were clear resource conflicts between the demands for driving and the demands of the in-vehicle and cell phone tasks.

Namely, driving and in-vehicle tasks both required visual perception, spatial processing, and manual resources from the driver. Thus impairments from completing both of these tasks simultaneously are due to potential conflicts of having to visually attend to, spatially process, and manually manipulate both task sets simultaneously. This is suggested in our findings as drivers completing the in-vehicle tasks showed more extensive impairment on the car-following task than did drivers completing the cell phone task. The driving and task conflict between visual perception and manual responses is the most likely reason for drivers completing the in-vehicle task to be more impaired than those having cell phone conversations. If this is the case, allowing only hands-free phones while driving is predicted to have better performance but not completely alleviate the impairment, as has been shown in other studies (Burns et al. 2002; Greenberg et al. 2002).

Likewise, driving and completing the cell phone task both required the driver to perceive auditory stimuli and to process verbal and spatial information. Thus impairments from completing both of these tasks simultaneously are due to potential conflicts of attending to auditory stimuli then verbally and spatially processing two elements simultaneously. This was suggested in our findings as drivers conversing on the phone showed more extensive impairment than those completing the in-vehicle tasks on the physiological measurements which required additional auditory attention. This may have also been compounded by the fact that auditory attention was required by the driving task, cell phone task, and the ERP tone task, thus resulting in an overall lack of resources to cope with all three requirements (even though the ERP paradigm only incurred a small additional load on the drivers).

TASK EFFORT ALLOCATION

Drivers reported that both secondary-tasks were more effortful than baseline. Drivers also displayed larger time headways during the secondary-tasks while car-following. This supports the presumed mechanism that larger headway was a strategy used by drivers to compensate (increase safety margin) in recognition of the greater effort needed to manage both primary (driving) and secondary-tasks. To explain, drivers seemed to show that increasing the safety margin reduced the overall effort they would need to exert by increasing the overall error tolerance of the car-following task. Other studies have shown similar results in driving performance that indicate increased error tolerance, such as larger time headway (Greenberg et al., 2002; Strayer, Drews, and Crouch, 2003) and decreased average speed (Rakauskas, Gugerty, and Ward, 2004).

The level of alcohol impairment produced was intended (and succeeded) to be at the current legislated limit of BAC 0.08. Though most participants peaked at or just below this level, few results overall showed significance for the alcohol comparison. Whereas deterioration of driving skills has been shown to begin at BAC 0.05 (Council on Scientific Affairs, 1986), the level of intoxication we intended may not have been sufficient to show impairment in the scenarios used in this study.

In this study, alcohol caused drivers to be more cautious when crossing through traffic, as intoxicated drivers waited for larger gaps and chose gaps with larger safety margins. However, these same drunk drivers had more than twice the number of total collisions with other vehicles. It appears that although intoxication caused drivers to be more cautious on this event, it did not improve their ability to safely control their vehicle and navigate through traffic. This finding is confirmed during the pullout-event results, where drunk drivers displayed quicker movement times than sober drivers, similar to the performance observed while drivers were completing the secondary-tasks, suggesting that drivers' resources were overloaded.

Moreover, participants might have found it easier to compensate for alcohol impairment than for the secondary-tasks. That is, they may have found it easier to compensate for the general impairment from alcohol as opposed to the unavoidable hindrance of taking one's eyes away from the roadway and removing one's hands from the steering wheel. Past research has shown that intoxicated drivers need more time to maintain proper car-following performance (Brookhuis, de Waard, and Mulder, 1994) and avoid unexpected events (Strayer, Drews, and Crouch, 2003). Therefore our participants, potentially being aware of their intoxication, may have been able to directly compensate for the impairing effects of intoxication by focusing more attention on the driving task.

Unlike alcohol intoxication, the distraction tasks interfered with specific resources (e.g. visual processing, manual response). This amount of impairment from resource competition may have been greater than the (generic) impairment of all resources by alcohol. Thus drivers seemed to be better able to compensate for their intoxication than they were able to detect and compensate for their distraction. In addition, drivers seemed to be better able to compensate for the resources demanded by the cell phone task (primarily auditory in nature: listening and verbally responding) than those demanded by the in-vehicle task (visually searching for input and then visually looking and manually manipulating controls while responding). This suggests that looking away from the visual scene greatly hinders one's ability to maintain safe driving behavior.

Notably, sober drivers interacting with in-vehicle tasks were often more impaired than drunk drivers without any secondary-task. This is consistent with the inherent greater conflict for visual input, spatial processing, and manual output resources shared by both driving and the in-vehicle tasks. The in-vehicle task was not sensitive to alcohol impairment for such car-following measures as steering entropy (Figure 3-18) and standard deviation of time headway (Figure 3-6) and in response time to the pullout event (Figure 3-28). Part of this may be due to a ceiling effect in that those completing the in-vehicle task were already mentally loaded to their limit. By this, participants would have been so taxed that it did not matter whether they were drunk or sober as they were completely overwhelmed making them appear to be equally impaired in the sober and intoxicated conditions. Similar results have been found where drivers compensated for alcohol and secondary-tasks differently as evidenced by a number of compared performance measures (Burns et al, 2002; Strayer, Drews, and Crouch, 2003).

Drivers completing the in-vehicle task condition had slower reaction times and response times to a vehicle unexpectedly pulling out in front of them compared to drivers not completing a secondary-task. During the same event, drivers in both secondary-task conditions were faster than baseline at moving their foot from the accelerator to the brake. This suggests that drivers were caught *more* off guard by the event than baseline drivers (slower response times during secondary-tasks) and had to compensate for this late reaction by switching to the brake more quickly (faster movement times) once the danger was noticed. This also suggests that drivers completing the secondary-tasks were less able to perceive and react to unexpected maneuvers in a safe and timely manner, as has been previously observed (Lamble, et al, 1999; Hancock, Lesch, Simmons, 2003, Strayer, Drews, Johnston, 2003).

The environmental awareness measures showed that drivers had lower accuracy and more errors while completing in-vehicle and cell phone secondary-tasks. Similar decrements were seen in another study using a sign-detection task in a fixed scene (McPhee et al., 2004). The authors found that participants talking in a simulated conversation made more errors and had slower reaction times in a fixed-scene detection task.

ERP METHODOLOGY

Based on past research findings, we expected the evoked response potential (ERP) measure to show a significant difference for the target tones but we instead found only differences using the novel sounds. This suggests that using novel tones with the oddball paradigm could be used as a new measure of mental workload in that the cell phone and in-vehicle tasks showed lower amplitude towards novel sounds than the large attentive reactions of baseline drivers. The ERP oddball paradigm allowed us to confirm that alcohol reduces attention, as seen in the reduction in amplitude of the P300 responses, while also showing little evidence that the paradigm itself impaired performance.

Drivers completing a secondary-task should have less capacity to turn to the ERP task, and this is the trend that Baldwin and Coyne (2003) lean towards in their findings. Drivers completing the cell phone conversation had a weaker evaluative response to the novel tones than those completing the in-vehicle task. This is contrary to much of the driving performance data, in that many driving performance measures showed the in-vehicle task to be much more degrading. It seems that drivers were better able to compensate for their alcohol (Figure 2-10) and cell phone (Figure 3-40) physiological impairments than for the in-vehicle impairment in all of the other driving performance measures.

Novel sounds are expected to elicit more of a response in the frontal regions of the brain (specifically Fz and Cz). However the parietal response was reduced in amplitude for both secondary conditions in comparison to Baseline. This suggests inattention to the ERP task in agreement with the target tone reaction time and accuracy measures (see Figures 3-33 and 3-34) and most of the car-following continuous driving performance results (see Figures 3-2 to 3-20). Furthermore, unexpected novel sound caused increased mental activity in the frontal regions and reduced processing in the parietal (rear) regions for drivers completing the secondary-tasks. This also suggests that these drivers were caught more off guard by the sounds and did not have the capacity to evaluate what the sounds meant, in comparison to drivers not completing any task.

COMPARISON OF RESULTS TO OTHER STUDIES

It is important to compare our research findings to other studies, both to validate our results and to replicate those studies' findings. Convergent results will help identify more definite and long-term trends during distracted and intoxicated driving conditions as well as identify methods that are appropriate and useful for future research purposes.

Transport Research Laboratory

A similar study was completed in England at the Transport Research Laboratory (TRL) as documented in Burns et al., 2002. A good portion of our methods and materials were similar to this study. Results from comparable metrics are discussed below.

The TRL simulator has a limited-motion base with a 210-degree horizontal by 40-degree vertical front and 60-degree horizontal by 40-degree vertical rear fields of view. The car body has hydraulics to supply motion to simulate heave, pitch, and roll along with a force feedback steering wheel. The driving scenario had elements that were quite similar to our own: scenarios of car-following, sign-discrimination task, curves, and traffic negotiation. Participants came to the simulator three times: once to get acclimated to the simulator, and two more sessions where three trials were driven. One of these sessions was completed while using a hand-held phone, a hands-free phone, and driving without conversing; in the other session, all three trials were completed while intoxicated.

Our cell phone task was identical to that used in the TRL study. Their alcoholic beverage consisted of cream soda either with or without alcohol (80 proof vodka) and experimental timing of the drinking period and experimental sessions was similar to our own. The TRL participants were different from our driving sample in that they lived and were tested in England, split by gender, and between the ages of 21 to 45 (M= 32, SD= 7.8).

On the Rating Scale of Mental Effort (RSME), drivers in the TRL study reported similarly to ours that using a cell phone (whether hand-held or hands-free) was significantly more effortful than driving without a secondary-task. Interestingly, their drivers reported that driving while intoxicated and not completing a secondary-task was significantly more demanding than driving sober and using either phone type. Our participants did not report such a benchmark effect for either of our secondary-task conditions.

During a similar car-following task, the TRL study found no effects between driving task conditions for standard deviation of time headway or for the amount of time drivers followed closer than one second behind the lead vehicle. Our participants had higher variability in headway during the In-Vehicle task in the benchmark comparison, suggesting that our participants were more affected by this task than our Cell Phone task or the verbal tasks administered in the TRL study.

During the sign-detection task, the TRL study found that sober participants conversing on a hands-free phone (exactly like our Cell Phone condition) had slower RTs than those not conversing whether intoxicated or sober. In addition, intoxicated participants also had slower RTs than sober participants. For these reasons, it was disappointing that we only found that sober drivers completing the in-vehicle task took longer than baseline drivers.

However, our intoxicated participants tended to have more errors on the sign task than our sober participants, results that agree with those found by the TRL study (Burns et al., 2002). TRL reported that there were more errors in their hands-free phone condition (exactly like our Cell Phone condition) than not conversing (whether intoxicated or sober).

University of Utah

Researchers at the University of Utah have conducted a number of studies on the effects of distraction on driving performance in a simulated vehicle (Strayer, Drews, and Johnston, 2003; Strayer and Drews, 2004). In particular, one study focused on comparing driving performance while intoxicated to the distraction of holding a cell phone conversation (Strayer, Drews, and Crouch, 2003). They used a fixed-base simulator consisting of three front channels and force loaded steering. The driving task consisted of car-following while driving on a multi-lane highway.

Participants came to the simulator three times: once to get acclimated to the simulator, and two more sessions where three trials were driven. One of these sessions was completed while using a hand-held phone, a hands-free phone, and driving without conversing; in the other, the scenario was completed while intoxicated.

Utah's cell phone task consisted of conversing with a research assistant on a topic of interest for both a hand-held phone and on a hands-free earpiece. There were no significant differences between hand-held and hands-free conversation, and as, "The observed similarity between hand-held and hands-free cell phone conversations is consistent with earlier work [cited above] and suggests impairments to driving are mediated by withdrawal of attention from processing of info in driving environment necessary for safe operation of a motor vehicle," not from holding or dialing the phone. Thus these conditions were collapsed for the analyses. Their alcoholic beverage consisted of orange juice with alcohol (80 proof vodka) and sober participants did not receive a beverage. The Utah participants differed slightly from our own in that their average age was 25.7 (our M= 22 years).

As our study does not have a braking event per se, we have compared our results on a number of the episodic scenarios and data from the car-following scenario (continuous driving) to their results as appropriate.

Utah found that those engaged in the cell phone conversation were 8.4 percent more sluggish in reacting to the braking event. Our cell phone condition was 12.9 percent slower yet not significantly different from the baseline condition, though our in-vehicle condition was significantly (18.1 percent) slower. Utah also found that it took drivers conversing on the cell phone 14 percent longer to recover to normal speed as compared to the baseline condition, though the intoxicated participants had a similar recovery time to those sober and not conversing.

Drivers in Utah's cell phone condition drove on average 3.1 percent slower and at a 4.4 percent larger following distance than while in the baseline condition. Our drivers on the cell phone had similar decrements, as they had 2.6 percent lower modulus (speed correlation) with the lead car and 10.1 percent larger median time headways with the lead vehicle than our baseline condition. Utah's cell phone condition drivers also had 7.5 percent greater following distance and took 14.8 percent longer to recover the speed lost during braking than while intoxicated. Our sober drivers on the cell phone had 4.0 percent lower modulus (speed correlation) with the lead car and 12.5 percent larger time headways with the lead vehicle than our baseline condition Furthermore, our drivers completing the cell phone condition sober had worse steering entropy than intoxicated baseline drivers. Also drivers completing the in-vehicle tasks sober had worse performance on all measures of car-following (aside from time headway) than while driving intoxicated in the baseline condition.

The cell phone of the Utah study increased rear end collisions, producing three collisions, whereas the baseline and alcohol conditions produced no collisions. Likewise, our sober drivers had two collisions in the cell phone condition as compared to one in the baseline condition and none in the in-vehicle condition. Also, there were seven total crashes for intoxicated participants while only three total crashes for our control condition.

Utah's intoxicated participants applied 26.1 percent greater braking pressure than those conversing on the cell phone. Their intoxicated drivers also had no differences with baseline for accident rates, RT, or recovery time. However, intoxicated drivers had a more aggressive driving style, in that they had a 3 percent decreased following distance and braked with 23.4 percent more force than the baseline condition; which was speculated to be predictive of accidents. Using different measures, our cell phone drivers had marginally slower braking responses to the curves, and our intoxicated baseline drivers had significantly slower responses than our baseline sober drivers.

Overall Utah's cell phone drivers exhibited greater impairments (more accidents, less responsive driving behavior) than intoxicated drivers. Similarly, we found more severe impairments when drivers were faced with completing the in-vehicle task than while conversing on the cell phone.

Michigan Study

Greenberg et al. (2002) conducted a study on various in-vehicle and cell phone tasks on a high-fidelity motion-base simulator in Michigan. They had participants drive in a car-following task on a simulated U.S. Interstate while making climate control adjustments, tuning the radio, and use hand-held and hands-free phones (an OnStar press-then-talk system) to dial phone numbers, answering incoming calls, or retrieve and respond to voicemails. In comparison to our own study, the phone manipulations were somewhat similar to our cell phone condition, and the remaining measures, including phone dialing, can be considered comparable to our own in-vehicle tasks.

The Michigan drivers were also told to signal with their turn signal when a vehicle in front of the lead SUV made a swerving maneuver. These events are similar to our environmental awareness measures. The results showed that drivers missed more of the forward events while hand-held phone dialing, using the hand-held phone for voicemail, or when answering an incoming hands-free call as compared to driving without an additional task. Similarly we found that drivers had lower recognition of target street signs while completing the in-vehicle tasks (like their phone dialing) and conversing on the phone (like their hands-free phone answering and hand-held voicemail).

Drivers using a hand-held phone for voicemail had significantly larger headway distances than those in all other conditions, suggesting these drivers were attempting to compensate for being overextended in terms of mental resources. We also found this during our car-following for in-vehicle and cell phone conversations. The Greenberg study also found that drivers dialing a hand-held phone had the worst errors in heading (HE90, or the 90th percentile heading error) compared to all other measures. Manipulating the radio or ventilation controls, answering an incoming call (both hands-free and hand-held), and using the hand-held phone for voicemail had more errors than all measures aside from hand-held dialing. Similarly, our drivers were found to have the worst performance in headway variability during either the in-vehicle or cell phone tasks, with the in-vehicle tasks displaying the worst performance as compared to baseline driving.

Baldwin and Coyne

Baldwin and Coyne (2003) used a driving simulator to study how different levels of traffic density effected driving behavior. In doing so, they compared an array of mental workload measurement techniques, including P300 amplitude from ERPs to measure psychophysiological workload.

Baldwin and Coyne used university subject pool volunteers between the ages of 18 and 40, making our samples comparable in age though little else was reported in their review. A General Electric I-Sim was used by participants to drive through urban roadways. They had drivers respond to visual and auditory oddball tasks in order to gather the ERP responses at the Fz, Cz, and Pz sites. Below is a comparison of our auditory oddball tasks to their findings.

We found that our drivers in the cell phone and in-vehicle tasks had reduced reaction time to the target tones as compared to the baseline condition. These findings agree with the RT results of Baldwin and Coyne, who also found that responses to targets while driving in low- or high- traffic densities were significantly longer than those while not driving at all.

Furthermore, our drivers completing both secondary-tasks had reduced accuracy as compared to baseline. These findings also agree with the RT results of Baldwin and Coyne, who found that accuracy of target responses while driving in low- or high- traffic densities were significantly lower than those while not driving at all.

Similar to our lack of significant effects, Baldwin and Coyne also did not find significance for P300 target response between conditions for either visual or auditory tasks while driving in low-traffic density, high-traffic density, or not driving at all.

Though the Baldwin and Coyne study had a smaller focus than our own, our results were congruent in cases where measures overlapped.

Comparison Summary

Overall our findings correspond with a number of previous results concerning the deleterious effects of engaging in in-vehicle tasks and cell phone conversations or driving intoxicated. First off, driving while completing the secondary phone tasks was typically more impairing than driving while not completing additional tasks (Michigan: Greenberg et al., 2003). At times, the impairments of driving while engaged in a secondary-task were worse than when driving intoxicated (TRL: Burns et al., 2002; Utah: Strayer, Drews, Crouch, 2003). The ERP task provided new insight into where driving impairment is specifically localizing inside the brain, namely in the driver's ability to evaluate unexpected events (Baldwin and Coyne, 2003).

The biggest differences between our own study and the studies listed above are that 1.) we included the impairment of an in-vehicle task condition, and 2.) we examined the combined effects of alcohol and each of the secondary-tasks (cell phone conversations and in-vehicle tasks). Interesting differences in participant groups were also found between our American participants and the English (TRL), most strikingly our participants reported driving while talking on the phone more and for longer periods than TRL participants and being more liberal in allowing people to lawfully talk on phones while driving. The environmental awareness metrics showed agreement between TRL and our findings of lower accuracy on the sign-identification task while conversing compared to baseline. Also, intoxication led to more errors in both studies. Furthermore, both studies showed that ratings of subjective effort in the cell phone condition were higher than while driving without a secondary-task.

Using a different type of simulator and a different cell phone conversation task, the Utah study found differences in car-following strategies similar to those in our simulation; namely that those conversing on a cell phone had worse car-following performance than those in the baseline condition. Also, both our study and Utah's showed a tendency to have more collisions while drivers were conversing and have more delayed reactions to events. Intoxicated drivers in both studies had more aggressive driving styles.

With a similar ERP paradigm, Baldwin and Coyne showed that during a simulated driving task the target tone ERP responses did not show any significant effects. However, responses and accuracy to the tones did have congruence to our own findings, and, as we have shown, it is necessary to employ an additional strategy (i.e., the novel tones) to make apparent any effects of driving difficulty.

METHODOLOGICAL DISCUSSION

As described in the Methods, there was a greater probability of detecting impairment during the car-following (continuous) portion of our drive than during the other (episodic) portions of the drive because of a greater coincidence of peak driving and secondary-task demands. This type of car-following situation translates to driving safety in that it is a common instance that drivers are faced with daily in the real world. Driving on highways during peak times presents the driver with an endless string of separate car-following instances where rear-end collisions are the most-likely crash type. This may be why 21 percent of all road crashes are rear-end events due to inattention or tailgating/unsafe passing (Najm et al., 1995), and this lends weight to studying car-following behavior in the context of driver distraction and intoxication. Events that occurred in the episodic scenarios, such as a car pulling out in front of the driver unexpectedly, do not occur on a daily basis but are useful to determine how impaired drivers react to unusual and unexpected circumstances. Both the continuous and episodic driving task types allow us to explore what types of distraction affect driving performance during non-simulated driving situations.

Wickens (1990) found using ERPs to be useful in that as a measure of workload they may show unique variance that is not revealed through performance data. Though these measures seem obtrusive, he finds that when a measure is less intrusive on primary task performance, these measures are typically less reliable and more susceptible to other influences. Thus our application of a tertiary task where the participant was required to pay constant attention and respond can be thought to have yielded more reliable results than if we would have just played the tones and recorded the participants' passive responses (i.e., without having them use the foot pedal to respond). Plus, our implementation of the ERP oddball paradigm was not found to interfere with driving performance for the majority of our measures[iv]. Therefore, the ERP task was not considered to be a major distraction from the primary task of driving for our participants.

In review, it seems that the continuous car-following measures were more sensitive to the cognitive load of the secondary-task distractions. They were able to discern when the driver was completing the in-vehicle task and to a lesser extent, the cell phone task as well. These measures did not pick up on many alcohol-related differences, though this may have been due to the intoxicated participants compensating for their realized decrements in performance. The episodic tasks as a whole did not seem to be sensitive enough to discern between the secondary-task conditions and baseline condition, nor between intoxicated and sober drivers. A surprisingly sensitive measure was the ERP responses to the novel tones. The evaluative ERP response we observed during the novel tone tasks were unexpected and could be an indication of a new measure of workload that is more sensitive than target P300 responses both in general as well as to the context of driving. The oddball ERP paradigm with novel sounds should be further explored in the context of secondary-task distraction while driving.

It must also be recognized here that our study was limited to a ten-minute drive for each condition. In this amount of time, the in-vehicle task was perhaps a bit more demanding and frequent than what would be observed in normal driving conditions. On the other hand, the cell phone task could be said to have been a bit less demanding than it would be in normal conditions as questions were only asked at a frequency of 20 seconds, whereas normal conversations would be more continuous. In addition, our alcohol manipulation was limited in the fact that drivers were given one drink and had to consume it in a fashion they might not be accustomed to doing. Furthermore, intoxicated drivers might not have driven drunk in real life and this disconnect between actual behavior and the behavior we forced on them (i.e., driving drunk) may have affected their performance in ways that are immeasurable.

Finally, the distraction effect observed in this study is presumed to be related to the demand imposed by the tasks (cell phone, in-vehicle tasks). The task demand relates not only to the resources required to complete the task (see Table 1-1), but also the familiarity of the driver with that task itself and the experiment context. Notably, if the drivers were not familiar with the position and type of equipment inside the vehicle (in comparison to the equipment in their own vehicle), then the greater apparent distraction effect of the in-vehicle tasks compared to the cell phone conversations may be an artifact. It also may not generalize to levels of distraction in the specific vehicles commonly used by the drivers. However, the participants in this study were given practice to familiarize themselves with the tasks such that they reported similar levels of difficulty (effort) in completing both the cell phone and in-vehicle tasks. Moreover, all drivers had similar familiarity with the experiment environment (driving simulator and scenarios) across all task conditions. Thus, whereas the absolute magnitude of distraction in the real world from in-vehicle tasks may be different when considering the driver's own vehicle, it is probable that the relative level of distraction between cell phone conversations and in-vehicle tasks does generalize.

CHAPTER 5: CONCLUSION

As seen in this study, in-vehicle tasks (and by inference – hand-held phones) caused detriments in driving performance due to having drivers take their eyes off the road and physically manipulate items, but cell phones also contributed to poor performance by virtue of mental effort applied to the conversations. These results were confirmed through physiological, subjective, and environmental awareness measures. In addition, it was shown that intoxicated drivers not performing any task had better performance in comparison to sober drivers performing in-vehicle tasks. As these tasks are legally unsanctioned and typically considered to be acceptable in the driving context, drivers should also be educated in the risks from these commonly overlooked sources of impairment.

Instituting regulations to ban hand-held cell phone usage is a start to limiting the number of crashes they may produce. When a ban on hand-held phones was enacted in Japan, they found a 52.3 percent reduction in crashes and crash injuries and a 20 percent reduction in fatalities in comparison to just the year before (Japanese Directorate General for Policy Planning and Co-ordination spanning 1998-2000, as cited in RoSPA, 2002). Even so, new evidence suggests that such bans do not affect long-term behavior of drivers without sustained enforcement and publicity (Royal, 2003). This may be the reason behind the erosion in the effectiveness of the New York City ban on hand-held phones, where observed rates of hand held use are returning to pre-ban rates (Insurance Institute for Highway Safety, 2003), even though over 130,000 tickets (each for $100) were issued only nine months after enacting the law (Stashenko, 2003). Specifically, observed rates of hand-held phone usage in four areas of New York state were 2.3 percent in November 2001, before the ban; 1.1 percent several months after the ban (a "significant decline"); and were 2.1 percent by March of 2003 (not "significantly different" from the rate before the law). This suggests that sanctions against cell phones need enforcement and targeted education in order to be successful. Education is necessary to understand the risk involved and to educate when it is safe for drivers to engage in secondary-tasks.

Furthermore, other items meant to engage a driver's attention are completely unregulated. Not only that, but there are no strong grass roots movements or information sources for addressing this issue. It seems that most people see navigation and entertainment devices in the vehicle as a desirable option and either do not question or blithely accept the distraction it inherently provides. Displays for navigation systems, vehicle functions, and aftermarket applications for entertainment purposes (all of which can be equated to our in-vehicle task) are seldom the focus of legislation, education, or research. Typically research on in-vehicle devices has not had the focus of quantifying distraction; instead, the goal has been on how to improve the device to make it less distracting to the driver (as done in Fogle, 2003).

Companies are currently exploring ways to help drivers regulate their cell phone and ATIS usage while driving, depending on ambient driving conditions. BMW and Robert Bosch, funded partly by the German government, are developing a smart assistant that is intended to help drivers regulate phone and information usage by locking out access to functionality during high-workload periods (Graham-Rowe, 2003). With this technology on the horizon, though probably not available to most drivers in the near future, it is essential today more than ever to help drivers limit their own usage and recognize what are the consensual risks within their limits and the sanctioned risks they must not overstep.

Though on the right track, past research on distracting the driver's attention has not been put to good use when designing these devices. As any distracting element that takes the drivers' eyes off the road will be dangerous, there is clearly a need for more public education on this topic. Manufacturers of these products need to focus on research to maximize usability and efficiency of use of their interface designs so that drivers can spend less time engaging with the device and more time attending to the road. Furthermore, agencies including the government who choose to implement devices intended to aid the driver by using in-vehicle devices and cell phones (e.g. 511) should be careful to design a system that allows for ease of use while minimizing exposure to the potentially distracting situation of using the phone and non-driving systems while on the road.

In particular, our results suggest that ATIS technology that is visually dependant, such as digital maps that require navigation or glances away from the forward field of view, can be distracting and thus may hinder driver performance. This is not to say that completely verbal information is the solution either, as recent research has shown that a navigation system that combines visual and verbal information led to better situation awareness than completely visual or completely verbal systems (Fogle, 2003). This is also reflected in our own results which showed cell phones (a completely verbal system) showed performance decrements, though to a somewhat lesser extent than the in-vehicle (completely visual) task. As such, the combination of navigating verbally through a phone menu, as is done with the 511 traveler information system, may impair driving in that it may utilize cognitive resources needed for safe driving performance.

Further research should focus on what exactly drivers are using ATIS and 511-type systems for, specifically what information is most important to the users as well as how they would access it. Studies should also approach the interface of such systems and provide recommendations for how users will prefer to interact with traveler information and what they will find most useful. Most importantly, celerity of their interaction should be the ultimate goal of any ATIS system by making pertinent information salient and accessible to the driver during every aspect of the interaction in order to reduce cognitive interference with driving.

FUTURE RESEARCH NEEDS

Future efforts should emphasize educating the public on when they may be affected by their decision to partake in consensual risks as well as potentially legislating dangerous consensual risks into sanctioned risks. Enlightening the public about the true cost-benefits of these applications should be the focus of future efforts. In addition, public and private information sources (e.g. 511) should be tested in a similar context so as to see how performance during these new services affects driving behavior. Results that support interface structure development and improve service usability would also help to increase traffic safety on the whole.

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[i] Larger, safer safety margins are equivalent to smaller inverse TTC (TTC^{-1})

[ii] Participants number 3 and 28; psychology subject numbers s1006 and s1008, respectively

[iii] This figure has been displayed in congruence with the other graphs in this report, however when analyzed the order was changed to make the quadratic contrast comparison of Baseline performance to both In-Vehicle and Cell Phone performances.

[iv] Aside from showing more steering entropy, a higher number of steering reversals, and increasing lane position variability during the in-vehicle task.

APPENDIX A – CONSENT FORM

The format of the consent form has been slightly modified to fit on the page.

UNIVERSITY OF MINNESOTA
CONSENT FORM
Investigating the Effects of Driver impairment and distraction – Driving simulator study

In this study, we are investigating the effects of driver impairment and distraction on driving performance. Please read this form before agreeing to be in the study. We will be happy to answer any questions you might have.

Nic Ward and Mick Rakauskas, the research scientists who are in charge of this study, both work in the Program for Human Factors Interdisciplinary Research in Simulation and Transportation at the University of Minnesota.

Background Information: The purpose of the study is to study the effect of driver impairment and distraction on performance and safety in a driving simulator.

Procedures: You will be asked to drive a vehicle in the virtual environment of a driving simulator. While you drive, you will be asked to complete a number of common tasks inside the car such as operating the CD player or have a cell phone conversation. Some subjects will also be asked to consume alcohol under medical supervision before driving in the simulator. The amount of alcohol should put you near the legal limit for driving in Minnesota. The simulator will record data on your driving performance and you will be asked to complete some questionnaires that ask about your driving habits and your response to the driving tasks. You will be videotaped and the direction of your gaze will be recorded. You may also wear sensors to record data such as heart rate.

Risks and Benefits of Being in the Study: The risks in this study are minor. Some subjects may feel dizzy or nauseas as a result of driving in the virtual environment or in reaction to the alcohol. There are no direct benefits to you for participating in this study other than a payment of $50 dollars. If you terminate the study early, you will receive payment for the proportion of the sessions that you completed.

Confidentiality: In any presentation or account of this study, your name will never be used and we will not provide any information that would make it possible to identify you. We may want to use one or two brief video extracts from you driving in a presentation—if we would like to use part of your tape, we will contact you to obtain your permission first.

Voluntary Nature of the Study: If you decide to participate, you are free to withdraw at any time without consequence. Your decision about whether or not to participate will not affect your current or future relations with the University of Minnesota.

Contact and Questions: You may ask any questions at any time during the study. If you have questions after you have finished driving the test vehicle, you may contact Mick Rakauskas, 111 Church Street S.E., University of Minnesota, Minneapolis, MN 55455. Phone: 612-6244-4614. Email: mickr@me.umn.edu

If you have any questions or concerns about the study and would like to talk with someone other than the research scientists, contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware Street SE, Minneapolis, MN 55455. Phone: 612-625-1650.

Statement of Consent: I have read the above information and asked any questions that I had. I consent to participate in the study. I have been given a copy of the consent form.

Signature____ Date ____________________

Signature of Investigator ____________________________ Date ____________________

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APPENDIX B – EXPERIMENTER MATERIALS

RECRUITMENT SCREENER

Name:_____________ Phone:_________ Email:_______________

CRITERIA DESCRIPTION	INCLUDE IF	OK
Gender ___________	Male / Female	
Age __________Yrs	21 – 45	
Car Driver License __________Yrs	< 12 months	
Good Health	Check NOT Diabetic, Asthmatic, Migraines	
No Medication, regular or intermittently	Check NO Antihistamines, Blood Pressure, Caffeine based medication	
Does not need glasses to see while driving	Positive (if they do need glasses to see, they have low priority for scheduling)	
No heart, liver or kidney disorders	Check	
No Allergic reactions to alcohol	Check	
Height __________ft	Record	
Weight __________lbs	Record	
BMI ___________	Record	
Weekly consumption of alcohol _________units	< 15 (f), < 20(m) one "unit" = 12oz beer, or 5oz glass wine, or 1.5oz shot of hard liquor	
Ever had a bad reaction to alcohol	Negative	
Able to get to/from UMN without driving	Positive	
Please respond honestly to the following questions about your alcohol driving habits. State 'YES' or 'NO' in response to each of the following questions: 1. Have you ever felt you should *cut* down on your drinking? **YES NO** 2. Have people *annoyed* you by criticizing your drinking? **YES NO** 3. Have you ever felt bad or *guilty* about your drinking? **YES NO** 4. Have you ever had a drink first thing in the morning to steady your nerves or get rid of a hang-over (*eye-opener*)? **YES NO**	Less than 3 "YES" answers	

Preference Trial Days and times: ____________________________________
Dates not available: ____

Criterion Checklist

CRITERIA	OK
Participant is the person expected	
Valid Driver's License (verify age of at least 21 years old)	
No (non-essential) medication during the past 8 hours	
No caffeine drinks, (i.e., Tea, Coffee, Cola, Chocolate) during past 8 hours	
No energy drinks during the past 8 hours	
No alcohol prior to testing 24 hours before trial session	
No fatty foods on trial day	
Light sandwich meal 2 hours before the start of the study	
Please respond honestly to the following questions about your alcohol driving habits. State 'YES' or 'NO' in response to each of the following questions: 1. Have you ever felt you should *cut* down on your drinking? **YES** | **NO** 2. Have people *annoyed* you by criticizing your drinking? **YES** | **NO** 3. Have you ever felt bad or *guilty* about your drinking? **YES** | **NO** 4. Have you ever had a drink first thing in the morning to steady your nerves or get rid of a hang-over (*eye-opener*)? **YES** | **NO** **Less than 3 "YES" answers signifies "OK"**	
Participant is content to proceed with the study	
Participant Weight	
Participant BAC at arrival (BAC = .000 to proceed)	

If any criteria are failed, record the specific reason(s) for canceling the study session:

____

____

Participant's initials: ________

BAC Record Sheet

6:1 Cranberry juice to alcohol, or Cranberry juice in alcohol swabbed glass.

Record the Weight from the scale and the computed Dose and Mixer ml from the "Notes.xls" spreadsheet on the lines below:

Weight: __________lbs

Dose (Alcohol): __________ml

Mixer (Dose x 6): __________ml

BREATHALYSER RESULTS

	Time	BAC
Pre		
Practice		
Drive 1		
Drive 2		
Drive 3		
Final 1*		
Final 2*		

* After Drive 3, participant must recover for **at least 60 minutes** or until their **BAC < .05 for two consecutive measures** before being released

Secondary-task Score Sheet

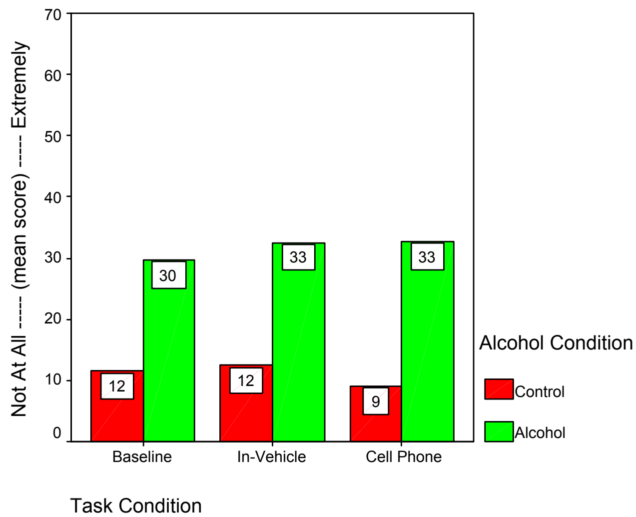
Scenario		Conversation Attempt	Conversation Miss		In-Vehicle Attempt	In-Vehicle Miss
Practice	1			1		
- tell driver to move	2			2		
closer if they don't	3			3		
activate instructions	4			4		
	5					
Car Following	1			1		
- tell driver to move	2			2		
closer if they don't	3			3		
activate instructions	4			4		
	5			5		
- tell driver to slow	6			6		
down if it sounds	7			7		
like they are going	8			8		
too fast	9			9		
	10			10		
	11			11		
	12			12		
Overtake &	1			1		
Curve 1	2			2		
	3			3		
Traffic Queue	1			1		
				2		
				3		
				4		
				5		
Curve 2	1			1		
Curve 3	1			1		
Gap Acceptance	1			1		
- tell driver not to	2			2		
proceed through	3			3		
before row of traffic	4			4		
	5			5		
Lane Change	1			1		

APPENDIX C – DRIVING CAPABILITY QUESTIONNAIRE RESPONSES (BAC VALIDATION)

BAC data was tested using a 2 (Group: Alcohol, Control) x 3 (Condition: Baseline, Cell Phone, In-Vehicle) mixed model ANOVA for each of 5 scaled questions. A one-way ANOVA was used to test their perceived number of alcoholic drinks consumed for task condition.

How intoxicated do you feel at this moment?
No significant differences were found between task conditions, although differences were found between BAC groups. Results are shown in Figure C-1 along with relevant statistics.

Figure C-1 – Responses to the question, "How intoxicated do you feel at this moment?"



Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(2, 92)= 0.96	.386	Power= .212
	BAC Group	F(1, 46)= 31.4	<.001*	Power= 1.00
Interactions	Task * BAC	F(2, 92)= 1.75	.180	Power= .358

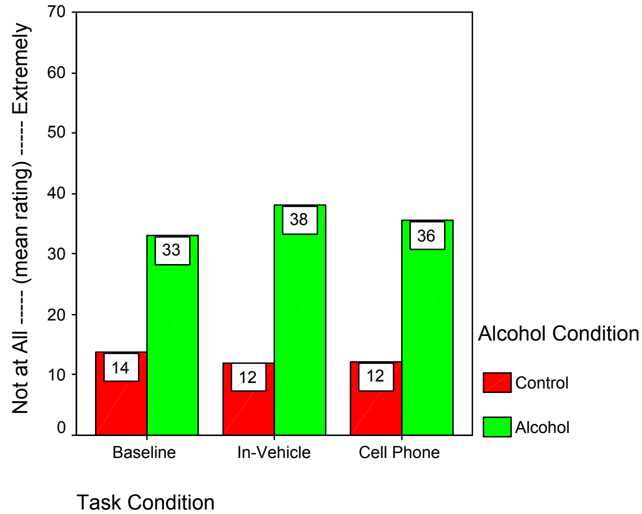
* Significant at the .05 level

Participants did rate their intoxication differently depending upon BAC group; the Alcohol group (M= 32) reported feeling significantly more intoxicated than control group (M= 11) over all three conditions.

How impaired do you feel at this moment in terms of being able to safely drive a vehicle?
No significant differences were found between task conditions although differences were found between BAC groups. Results are shown in

Figure C-2 along with relevant statistics.

Figure C-2 – Responses to the question, "How impaired do you feel at this moment in terms of being able to safely drive a vehicle?"



Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(2, 92)= 0.40	.668	Power= .112
	BAC Group	F(1, 46)= 26.4	<.001*	Power= 1.00
Interactions	Task * BAC	F(2, 92)= 1.44	.243	Power= .296

* Significant at the .05 level

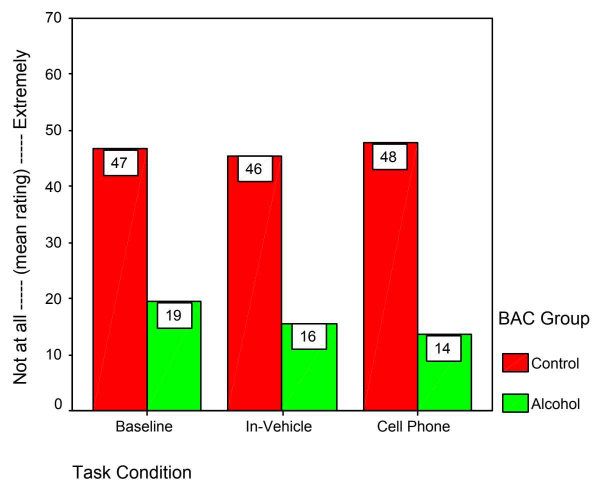
Regardless of task condition, participants felt similar as to safely driving a vehicle. Participants rated their intoxication differently depending upon BAC group; the alcohol group (M= 36) reported feeling significantly more impaired than the control group (M= 13) in all three conditions.

How willing would you be to operate a motor vehicle for an unimportant though gratifying reason (e.g. drive friends to a party)?

Significant differences were found between BAC groups and for the interaction between task condition and BAC group. Results are shown in

Figure C-3 along with relevant statistics.

Figure C-3 – Responses to the question, "How willing would you be to operate a motor vehicle for an unimportant though gratifying reason?"



Test	Comparison	Significance	p=	
Main Effects	Task Condition	$F(2, 92)=$ 3.05	.054	Power= .568
	BAC Group	$F(1, 46)=$ 28.9	<.001*	Power= 1.00
Interactions	Task * BAC	$F(2, 92)=$ 4.66	.012*	Power= .763
Task by BAC	Control	$X^2_F=$ 3.74	.154	
	Alcohol	$X^2_F=$ 10.6	.005*	B-IV: $Z_W= 2.72$, $p= .007$*
				B-CP: $Z_W= 2.78$, $p= .005$*
				IV-CP: $Z_W= 1.31$, $p= .190$

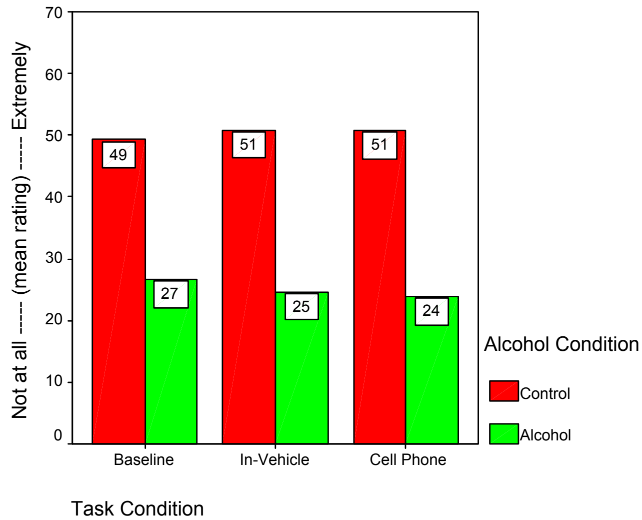
* Significant at the .05 level

Participants in the alcohol group (M= 16) were less likely than control group (M= 46) to operate a vehicle for an unimportant though gratifying reason. Specifically, the alcohol group felt less willing to operate in the in-vehicle (M= 16) and cell phone (M= 14) conditions than they did during the baseline (M= 19) condition. This was unexpected since the questions referred to physical state only, not condition impairment; the combination of secondary-task load with alcohol impairment created a more taxing environment to the drivers and would discourage them from driving for superfluous reasons. Participants rated their willingness differently depending upon BAC group; the Alcohol group reported feeling significantly less willing in all three conditions.

How willing would you be to operate a motor vehicle for an important, but avoidable reason (e.g. driving a friend home who feels mildly ill, when they could get a taxi)?
No significant differences were found between task conditions though differences were found between BAC conditions. Results are shown in

Figure C-4 along with relevant statistics.

Figure C-4 – Responses to the question, "How willing would you be to operate a motor vehicle for an important, but avoidable reason?"



Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(2, 90)= 0.09	.917	Power= .063
	BAC Group	F(1, 46)= 20.7	<.001*	Power= .994
Interactions	Task * BAC	F(2, 90)= 1.04	.357	Power= .224

* Significant at the .05 level

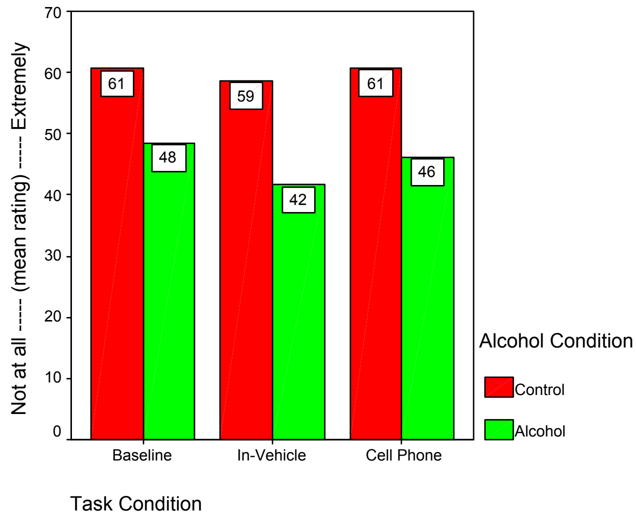
Regardless of task condition, participants felt similarly if faced with operating a vehicle for an important yet avoidable reason. Participants rated their willingness differently depending upon BAC group; the alcohol group (M= 25) reported feeling significantly less willing than the control group (M= 50) in all three conditions.

How willing would you be to operate a motor vehicle for an urgent reason (e.g. driving a sick child to the hospital)?

Significant differences were found between the task conditions and between the BAC groups. Results are shown in

Figure C-5 along with relevant statistics.

Figure C-5 – Responses to the question, "How willing would you be to operate a motor vehicle for an urgent reason?"



Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(2, 92)= 6.10	.003*	Power= .878
				B-IV: Z_W= 2.87, p= .004*
				B-CP: Z_W= 1.03, p= .304
				IV-CP: Z_W= 2.62, p= .009*
	BAC Group	F(1, 46)= 6.05	.018*	Power= .673
Interactions	Task * BAC	F(2, 92)= 1.69	.191	Power= .347

* Significant at the .05 level

Participants rated their willingness differently depending upon BAC group; the alcohol group (M= 45) reported feeling significantly less willing than the control group (M= 60) in all three conditions.

Participants also had different willingness ratings between the three conditions when the purpose of operating the vehicle was for an urgent reason. Drivers were more willing to operate vehicles while talking on a cell phone (M= 53.44) or not performing a secondary-task (baseline M= 54.54) than while performing in-vehicle tasks (M=50.13). It is interesting that participants believe that conversing on a hands-free cell phone is no more detrimental than driving normally when operating a vehicle for an urgent reason.

Driving Capability Summary

These findings indicate that drivers who consumed alcohol were more aware of their impairment towards safely operating a vehicle. Though we would have liked the participants to be blind to this factor, it is comforting to see that they can recognize when they are unfit to drive a vehicle.

APPENDIX D – INSTRUCTIONS

VERBAL PROTOCOL

The purpose of the study is to study the effect of driver impairment and distraction on performance and safety. During this experimental session you may receive alcohol.

The study will be completed in the driving simulator. You must follow the instructions given to you by the experimenter and those automatically triggered in the driving simulator either on the small in-vehicle display or through the speakers. As a general rule, instructions will be given to you by a female voice from the rear speakers, conversations will be given to you by a male voice from the front speakers. You will have a practice drive in order to familiarize yourself with the simulator before beginning the actual experimental drives.

The driving environment will be a four-lane rural highway with some other traffic. During this drive, you should drive as you would normally in the real world. **Safe driving should be your first priority at all times.**

As part of your trip, you will be required to follow a lead car at the closest distance you feel is safe. You must keep this distance constant at all times in response to the lead car. While following this lead car you will see several types of warning signs, as shown on the instruction sheet you just read (refer to instruction sheet). You will be looking for the Pedestrian Crossing sign, circled on that sheet. Whenever you see this sign you should flash your high beam lights as quickly as possible. When this portion of the drive is over, you will be instructed to pass the lead vehicle and return to the right lane.

You will then approach a line of vehicles following a semi-truck. You will be instructed to pass the row of vehicles and return to the right lane after passing. Please try to maintain the speed limit of 65 mph at all times.

You will also be required to cross an intersection after stopping at a stop sign. The cross-road at this intersection will have traffic. Please do not pass in front of the traffic coming from the right-hand side. You must choose the earliest gap you think is safe to move across the intersection.

Finally you will be asked to do something you normally would not do while driving on real roads. You will be instructed to center and keep your car on the middle, dashed line. After a little while, you will be instructed to move your car either into the right or left lane. This instruction will consist of the word “Right” or “Left” appearing in the top right or left corner of the front screen. As soon as you see this command, follow the word instruction and move your car into the correct lane. Please try to maintain the speed limit of 65 mph at all times.

You will be asked to drive the highway environment 3 times. **As a second priority behind safe driving**, in each of these drives you will be asked to complete some additional tasks:

- Drive normally without other things to do.

- Drive while also completing in-vehicle tasks such as adjusting the fan setting. For these tasks, your task is to copy the image displayed on a small in-vehicle display. For example, you may see an image of the fan knob set to the highest setting. This would tell you to move the fan knob to the highest setting to match the image. The screen will flash twice when a new instruction image is present. As soon as you see this flashing or see a new image, complete the task as soon as possible. (Positions of the different types of In-vehicle tasks are demonstrated to the participant once they are seated in the car).

- Drive while engaged in conversations that simulate cell phone use. For these tasks, you will hear a person's voice over the speakers system inside the car. This is like a hands-free cell phone conversation. There will be different types of dialogue during the drive. For example, you may be asked to repeat a phrase that was spoken to you; you may be asked a question after hearing a verbal puzzle; and you may be asked to talk about a topic as a conversation, such as "Tell me as much as you can about your office." The tasks and instructions are automatically triggered by your location in the driving environment, so please do not be offended if you are interrupted by these tasks and instructions.

In addition to this, you will also be hearing a series of low and high tones that you should be attentive to. Whenever you hear the higher of the two tones, you should press the pedal underneath your left foot as soon as you can. You will receive a practice session in order to get used to the differences between these two tones. **However, if at any time you feel you are too overloaded with things to do, remember that this task is of less importance than maintaining safe driving behavior and accurately completing the in-vehicle and conversation tasks.**

WRITTEN SUMMARIES

Study Summary
The study summary on the next page was given to participants before setting up the eye tracker, in order to familiarize them with what would be happening during the simulation portion of the experiment.

The format of this summary has been slightly modified to fit on the page.

STUDY SUMMARY

The purpose of the study is to study the effect of driver impairment and distraction on performance and safety. During this experimental session you may receive alcohol.

The study will be completed in the driving simulator. You must follow the instructions given to you by the experimenter and those automatically triggered in the driving simulator either on the small in-vehicle display or through the speakers.

The driving environment will be a four-lane rural highway with some other traffic. During this drive, you should drive as you would normally in the real world.

As part of your trip, you will be required to follow a lead car **at the closest distance you feel is safe**. You must keep this distance constant at all times in response to the lead car.

While following this lead car you will see several types of warning signs, as shown below. You will be looking for the Pedestrian Crossing sign (circled below). Whenever you see this sign you should **flash your high beam lights** as quickly as possible.

You will also be required to cross an intersection at a stop sign. The cross-road at this intersection will have traffic and **you must choose the earliest gap you think is safe** to move across the intersection.

You will be asked to drive the highway environment 3 times. In each of these drives, you will be asked to do some things in addition to the driving:

- Drive normally without other things to do.
- Drive while also completing in-vehicle tasks such as adjusting the fan setting.

  For these tasks, your task is to copy the image displayed on a small in-vehicle display. For example, you may see an image of the fan knob set to the highest setting. This would tell you to move the fan knob to the highest setting to match the image. The screen will flash twice when a new instruction image is present. As soon as you see this flashing or see a new image, complete the task as soon as possible.

- Drive while engaged in conversations that simulate cell phone use.

  For these tasks, you will hear a person's voice over the speakers system inside the car. This is like a hands-free cell phone conversation. There will be different types of dialogue during the drive. For example, you may be asked to repeat a phrase that was spoken to you. You may be asked to talk about a topic as a conversation. And you may be asked a question after hearing a verbal puzzle.

You will now have a chance to practice driving the simulator, and to practice both the in-vehicle tasks and conversations.

Baseline Summary

The following instructions were given to participants before the Baseline condition:

DRIVING TASK

During this session you will be asked to drive as you would normally in the real world. Please follow all instructions given to you by the driving simulator.

As part of your trip, you will be required to follow a lead car at the closest distance you feel is safe. You must keep this distance constant at all times in response to the lead car.

While following this lead car you will see several types of warning signs, as shown below. You will be looking for the Pedestrian Crossing sign (circled below). Whenever you see this sign you should **flash your high beam lights** as quickly as possible.

You will also be required to cross an intersection at a stop sign. The cross-road at this intersection will have traffic and **you must choose the earliest gap you think is safe** to move across the intersection.

Cell Phone Task Summary

The following instructions were given before the Cell Phone condition in addition to those instructions given before the Baseline condition:

CELL PHONE CONVERSATIONS

During this session you will be asked to do some verbal tasks. A set amount of time will be allowed to perform each task before moving on to the next. Your ability to perform these tasks will be judged and the data used when analyzing the results, so please do your best.

You will be asked to **ANSWER QUESTIONS**, speak on a variety of **TOPICS**, and **REPEAT SENTENCES**.

The questions consist of a statement, followed by a question. You should **answer the questions as quickly as you can.** Do think about your answer before you respond – don't just guess.

For example, the person talking to you on the cell phone might ask you to answer a question based on other information they give you such as, "Felix is taller than Albert. Who is the shorter of the two?" Think carefully about the answer and respond as quickly (but accurately) as possible.

During the course of your drive you will be asked to **talk about a variety of topics**. If you are unable to talk about the chosen topic you can adapt it, in which case state your changed topic and then talk.

For example, the person talking to you on the cell phone might ask you to say as much as you can about the following topic "A memorable vacation." You would talk as much as you can about this topic by yourself (as a monologue) until your next instruction is given.

You will also be read sentences. You should **repeat these sentences, using as close to the same words as possible**. If you don't recall the sentence exactly, repeat everything that you do recall.

For example, the person talking to you on the cell phone might ask you to repeat the following statement they give to you "The action of the brave cyclist kept the small boy from being hit by the 10-ton truck." Answer quickly, but try to be as accurate in your memory and recitation of the statement.

[DRIVING TASK instructions were inserted here].

In-Vehicle Task Summary

The following instructions were given before the In-Vehicle condition in addition to those instructions given before the Baseline condition:

IN-VEHICLE TASKS

During this session you will be asked to do some in-vehicle tasks. A set amount of time will be allowed to perform each task before moving on to the next. Your ability to perform these tasks will be judged and the data used when analyzing the results, so please do your best.

You will be asked to ADJUST various Climate Control elements and CHANGE the CD Track, as determined by images displayed on the small screen to the right of the wheel. When an image is displayed on the screen, you are to change the setting to match the image

The screen will quickly flash twice when a new instruction image is present. As soon as you see this flashing or see a new image appear on screen, complete the task as soon as possible.

Below are examples of images you may see appear on screen. These tell you to…

Adjust the temperature Climate Control to the hottest setting:

Change the CD to Track 5:

[DRIVING TASK instructions were inserted here].

APPENDIX E – QUESTIONNAIRES

DRIVING HISTORY QUESTIONNAIRE

This questionnaire asks you to indicate some details about your driving history and related information. Please tick one box for each question.

1. Your age: ______________ years

2. Your sex: ☐ Male ☐ Female

3. What is your highest educational level completed?

   ☐ High School / Vocational School
   ☐ Associates Degree
   ☐ Bachelor of Arts / Bachelor of Science
   ☐ Masters
   ☐ PhD

4. Are you currently taking any college level classes?
   ☐ Yes
   ☐ No

5. Please state your occupation:____

6. Please state the year when you obtained your full driving license: 19____

7. About how often do you drive nowadays?

   ☐ ☐ ☐ ☐ ☐
   Never Hardly Sometimes Most Days Every Day

8. Estimate roughly how many miles you personally have driven in the past year:
   ☐ Less than 5,000 miles
   ☐ 5,000-10,000 miles
   ☐ 10,000-15,000 miles
   ☐ 15,000-20,000 miles
   ☐ Over 20,000 miles

9. About how often do you drive to and from your place of work?

   ☐ ☐ ☐ ☐ ☐

Never Hardly Sometimes Most Days Every Day

10. Do you drive frequently on Highways?:

☐ Yes ☐ No

11. Do you drive frequently on Main Roads other than Highways?:
- ☐ Yes
- ☐ No

12. Do you drive frequently on Urban Roads?:
- ☐ Yes
- ☐ No

13. Do you drive frequently on Country Roads?:
- ☐ Yes
- ☐ No

14. During the last three years, how many <u>minor</u> road accidents have you been involved in?

(A minor accident is one in which no one required medical treatment, AND costs of damage to vehicles and property were less than $1,000).

Number of minor accidents ____ (if none, write 0)

15. During the last three years, how many <u>major</u> road accidents have you been involved in?

(A major accident is one in which EITHER someone required medical treatment, OR costs of damage to vehicles and property were greater than $1,000, or both).

Number of major accidents ____ (if none, write 0)

16. During the last three years, have you ever been convicted for:

a. Speeding
- ☐ Yes
- ☐ No

b. Careless or dangerous driving
- ☐ Yes
- ☐ No

c. Driving under the influence of alcohol/drugs
- ☐ Yes
- ☐ No

17. What type of vehicle do you drive most often?
- ☐ Motorcycle
- ☐ Passenger Car

☐ Pick-Up Truck
☐ Sport utility vehicle
☐ Van or Minivan
☐ Other, briefly describe: ______________________________________

SENSATION SEEKING SCALE

SSS

For each of the 13 items circle the choice, A or B, that best describes your likes or dislikes, or the way you feel.

1. A. I would like a job that requires a lot of traveling.
   B. I would prefer a job in one location.

2. A. I am invigorated by a brisk, cold day.
   B. I can't wait to get indoors on a cold day.

3. A. I get bored seeing the same old faces.
   B. I like comfortable familiarity of everyday friends.

4. A. I would prefer living in an ideal society in which everyone is safe, secure, and happy.
   B. I would have preferred living in the unsettled days of our history.

5. A. I sometimes like to do things that are a little frightening.
   B. A sensible person avoids activities that are dangerous.

6. A. I would not like to be hypnotized.
   B. I would like to have the experience of being hypnotized.

7. A. The most important goal of live is to live it to the fullest and experience as much as possible.
   B. The most important goal of life is to find peace and happiness.

8. A. I would like to try parachute-jumping.
   B. I would never want to try jumping out of a plane, with or without a parachute.

9. A. I enter cold water gradually, giving myself time to get used to it.
   B. I like to dive or jump right into the ocean or a cold pool.

10. A. When I go on vacation, I prefer the comfort of a good room and bed.
    B. When I go on vacation, I prefer the change of camping out.

11. A. I prefer people who are emotionally expressive even if they are a bit unstable.
    B. I prefer people who are calm and even-tempered.

12. A. A good painting should shock or jolt the senses.
    B. A good painting should give one a feeling of peace and security.

13. A. People who ride motorcycles must have some kind of unconscious need to hurt themselves.
    B. I would like to drive or ride a motorcycle.

CELLULAR PHONE SURVEY

Please answer the following questions honestly, by putting a tick in the boxes that apply. Only the researchers will see this information and we will not judge you; we just want to find out what drivers really do.

1. Do you own or regularly have use of a cell phone? ☐ Yes ☐ No

2. If yes, what make and model do you use?________________________________

3. What is the main use of your cell phone?

☐ Business ☐ Limited for emergencies
☐ Personal ☐ Other use:____________________________

4. How often do you use your cell phone?

☐ More than 10 times a day ☐ Once a week
☐ Every day ☐ Once a month
☐ Several times a week ☐ Rarely

5. Do you think the use of a hand-held cell phone when driving should be banned?

☐ Yes ☐ Depends
☐ No ☐ Don't know

6. Do you think the use of a hands-free cell phone when driving should be banned?

☐ Yes ☐ Depends
☐ No ☐ Don't know

7. What, if anything, do you think the penalty should be if caught driving and using a hand-held cell phone?

☐ Confiscate the phone ☐ A caution/written warning first
☐ A fine ☐ Other:________________________________
☐ Points on license ☐ Don't need a penalty
☐ Ban from driving ☐ Don't Know

8. What, if anything, do you think the penalty should be if caught driving and using a hands-free cell phone?

☐ Confiscate the phone ☐ A caution/written warning first
☐ A fine ☐ Other:________________________________
☐ Points on license ☐ Don't need a penalty
☐ Ban from driving ☐ Don't Know

9. Do you think drivers should pull in to the next safe place and stop if they receive a cell phone call while driving?

☐ Yes ☐ Depends
☐ No ☐ Don't know

10. From your own observations what type of drivers are most likely to use a cell phone while driving?

____
____
____

11. Do you have a hands-free cell phone car kit?

☐ Yes professionally fitted
☐ Ear piece fitted to phone
☐ No

Comments:____
____
____

12. If your cell phone rings while you are driving would you answer it?

☐ Yes, always ☐ Depends on traffic situation
☐ Yes, usually ☐ Not usually
☐ Maybe ☐ Not under any circumstances
☐ Depends on caller ☐ I always have it switched off

Comments:____
____
____

13. If your cell phone indicates that you have a text message while you are driving would you read it?

☐ Yes, always ☐ Depends on traffic situation
☐ Yes, usually ☐ Not usually
☐ Maybe ☐ Not under any circumstances
☐ Depends on caller ☐ I always have it switched off

Comments:____
____
____

14. Would you make a cell phone call while you are driving?

☐ Yes, always ☐ Depends on traffic situation
☐ Yes, usually ☐ Not usually
☐ Maybe ☐ Not under any circumstances
☐ Depends on caller ☐ I always have it switched off

Comments:____

15. If you do talk on the phone while driving; what do you talk about?

☐ Business; complex negotiation ☐ Only light, short conversations
☐ Business; light conversation ☐ Very brief messages, i.e. "I'll be home at.."
☐ Complex conversation with friends

Comments:____

16. If you do talk on the phone while driving; how long is your average conversation?____________Minutes

Comments:____

17. If you do talk on the phone while driving; on average what proportion of the driving time are you in conversation?

☐ 100%, The entire time ☐ 1% to 24% of the time
☐ 75% to 99% of the time ☐ 0%, no conversation (i.e. just listening
☐ 50% to 74% of the time to voicemail, weather, etc.)
☐ 25% to 49% of the time

Comments:____

18. If you do talk on the phone while driving; list all of the conditions or situations where you would not use your phone: (e.g. Heavy Traffic, bad weather, highway, city, etc.)

Comments:____

19. Would you text a message while you are driving?

- ☐ Yes, always
- ☐ Yes, usually
- ☐ Maybe
- ☐ Depends on caller
- ☐ Depends on traffic situation
- ☐ Not usually
- ☐ Not under any circumstances
- ☐ I always have it switched off

Comments:____

17. How often do you use a cell phone while driving

- ☐ Nearly every time you drive
- ☐ Quite often
- ☐ Sometimes
- ☐ Maybe
- ☐ Not usually
- ☐ Not under any circumstances

Comments:____

DISTRACTION SURVEY

Based on your own experience, please Circle a number between 1 and 10, to indicate how distracting you find the following tasks WHEN YOUR ARE DRIVING.

For example, if you thought that opening the glove compartment while driving was really distracting, you might respond as follows:

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10
Not at all Distracting Very Distracting

1. Talking on a cell phone WITHOUT headset or hands-free?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10
Not at all Distracting Very Distracting

2. Talking on a cell phone WITH headset or hands-free?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10
Not at all Distracting Very Distracting

3. Sending a text message?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10
Not at all Distracting Very Distracting

4. Eating (for example, chocolate/sweets)?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10
Not at all Distracting Very Distracting

5. Tuning the car radio?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10

Not at all Distracting Very Distracting

6. Adjusting climate controls?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10

Not at all Distracting Very Distracting

7. Talking with passengers?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10

Not at all Distracting Very Distracting

8. Reading a map?

1---------2--------3---------4---------5--------6---------7--------- 8 --------9--------10

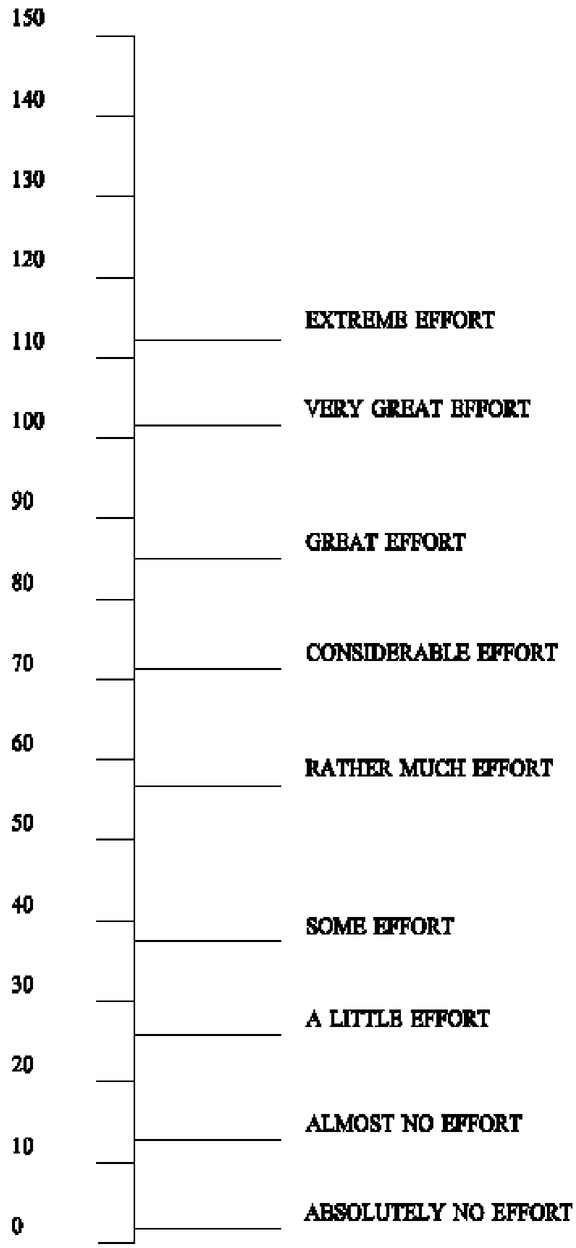
Not at all Distracting Very Distracting

Any Further Comments and suggestions about cell phone use:

RATING SCALE OF MENTAL EFFORT

DRIVING EFFORT SCALE

Please indicate, by marking the vertical axis below, how much effort it took you to ***control the vehicle and interact with traffic*** *in the driving environment you just completed:*



Real World Comparison

How did the effort you applied to this simulated driving scenario compare to how much effort you typically apply during real driving in your own vehicle?

More Difficult ____________________________________ Less Difficult

Comments____

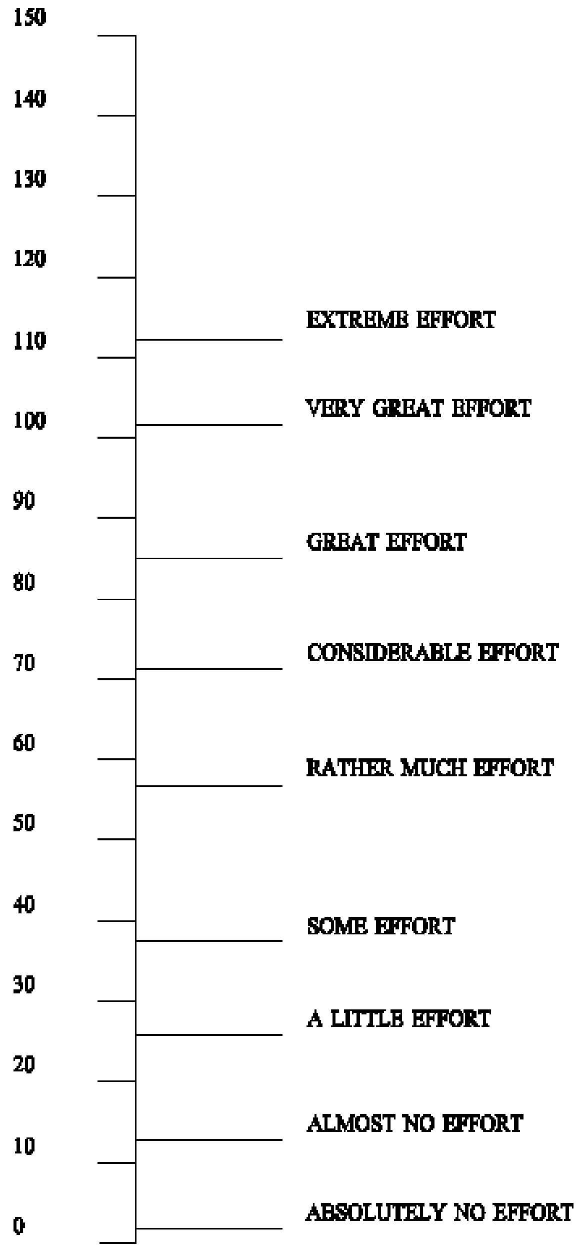
____

RATING SCALE OF MENTAL EFFORT FOR IN-VEHICLE TASK CONDITION

Highlighting was present in the questionnaires during the study.

IN-VEHICLE TASK EFFORT SCALE

Please indicate, by marking the vertical axis below, how much effort it took you to ***complete the in-vehicle task*** *in the driving environment you just completed:*



Real World Comparison

How distracted did you feel completing the in-vehicle tasks in comparison to the amount of distraction you experience completing in-vehicle tasks during a typical trip in the real world?

More Difficult ______________________________ Less Difficult

Comments____

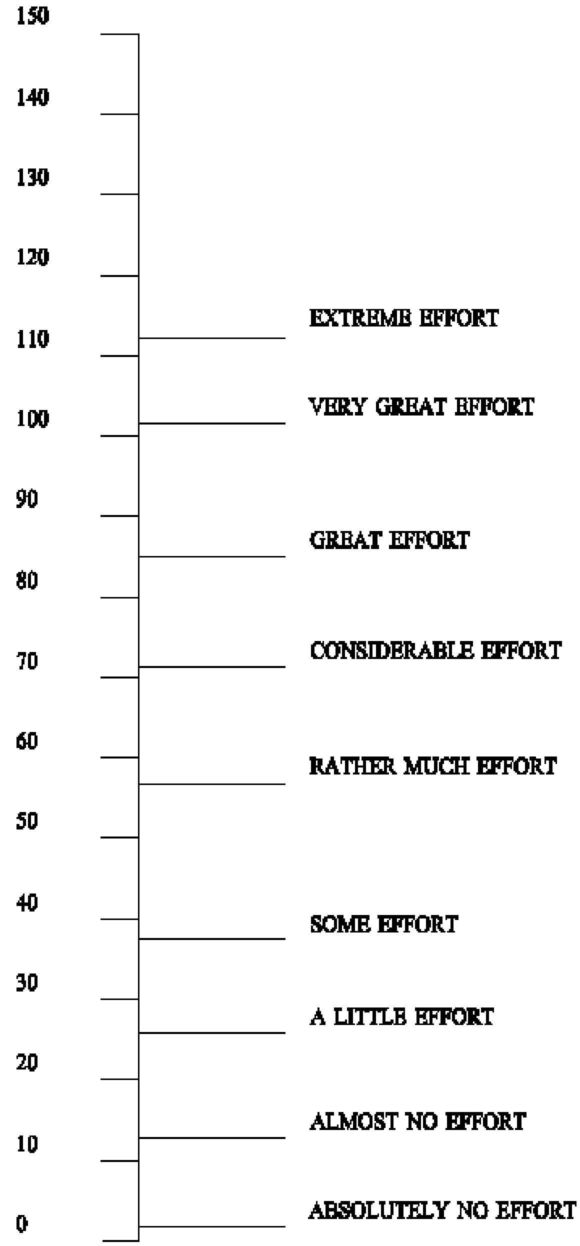
____

Rating Scale of Mental Effort for Cell Phone Task Condition

Highlighting was present in the questionnaires during the study.

CONVERSATION EFFORT SCALE

Please indicate, by marking the vertical axis below, how much effort it took you to ***listen and respond to the conversations*** *presented to you in the driving environment you just completed:*



Real World Comparison

How distracted did you feel responding to the verbal tasks in comparison to the amount of distraction you experience when having (cell phone) conversations during a typical driving trip in the real world?

More Difficult ______________________________________ Less Difficult

Comments____
____

DRIVING CAPABILITY QUESTIONNAIRE

The Driving Capability questionnaire shows the five questions asked at all times, as well as the additional question asking participants to approximate the number of drinks they had consumed, which was only asked during recovery. The questions related to how capable or willing the participants would be to drive at that moment. They were instructed to answer by striking a continuum between "not at all" to "extremely."

During the recovery period, the questionnaire was modified to have participants approximate how many alcoholic drinks they had consumed. These questionnaires were used to establish driver's subjective feeling of being drunk, including any placebo effect for the sober condition.

Driving Capability Questionnaire

1. How intoxicated do you feel at this moment?

Please strike the line to indicate your feelings

Not at all ________________________________ Extremely

2. How impaired do you feel at this moment in terms of being able to safely drive a vehicle?

Please strike the line to indicate your feelings

Not at all ________________________________ Extremely

3. How willing would you be to operate a motor vehicle for an unimportant though gratifying reason? (e.g. drive friends to a party)

Please strike the line to indicate your feelings

Not at all ________________________________ Extremely

4. How willing would you be to operate a motor vehicle for an important, but avoidable reason? (e.g. driving a friend home, who feels mildly ill, when they could get a taxi)

Please strike the line to indicate your feelings

Not at all ________________________________ Extremely

5. How willing would you be to operate a motor vehicle for an urgent reason? (e.g. driving a sick child to hospital)

Please strike the line to indicate your feelings

Not at all ________________________________ Extremely

6. Approximately how many *alcoholic drinks* do you think you consumed at the beginning of this experiment?

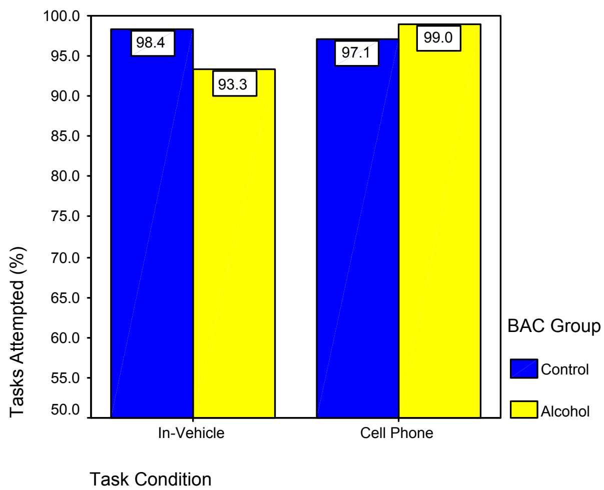
[Note: one “alcoholic drink” is equal to 12oz of beer, or a 5oz glass of wine, or 1.5oz shot of hard liquor.]

APPENDIX F – SECONDARY-TASK VALIDATION

We wanted participants to attempt the same number of tests in the cell phone and in-vehicle task conditions. Otherwise, any secondary-task effects could be due to differences in the number of tasks attempted or differences in intoxication level instead of the conditions themselves.

Percentage of tasks attempted

No participants were excluded from the percentage of attempted task analyses. Results are shown in Figure F-1 along with relevant statistics.



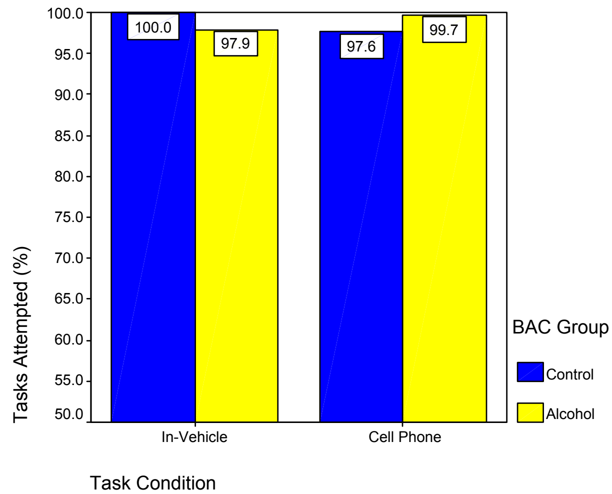
Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(1, 44)= 4.91	.032*	Power= .582 IV-CP: Z_W= 1.61, p= .109
	BAC Group	F(1, 44)= 2.52	.119	Power= .343 (IV* CP')
	ERP Group	F(1, 44)= 0.91	.346	Power= .154
Interactions	Task * BAC	F(1, 44)= 12.4	.001*	Power= .931
	Task * ERP	F(1, 44)= 0.37	.544	Power= .092
	BAC * ERP	F(1, 44)= 0.05	.817	Power= .056
	Task*BAC*ERP	F(1, 44)= <.01	.950	Power= .050
Task by BAC	Control	X^2_F= 1.92	.166	
	Alcohol	X^2_F= 9.00	.003*	

* Significant at the .05 level

Figure F-1 – Percentage of attempted tasks

A significant main effect was present, though the more conservative follow-up did not support the apparent difference in overall mean percentage of attempted tasks between the cell phone (M= 98.04 percent) and in-vehicle (M= 95.85 percent) task conditions. There was also an interaction between task condition and BAC group, revealing that the alcohol group participants had significantly lower percentage of attempted responses during the in-vehicle task condition (M= 99.00 percent) than during the cell phone task condition (M= 93.33 percent). This suggests that intoxicated drivers had missed or ignored more of the in-vehicle tasks than the cell phone tasks.

Percentage of tasks attempted during car-following
No participants were excluded from the analyses of percentage of attempted tasks during the car-following. Results are shown in Figure F-2 along with relevant statistics.



Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(1, 44)= 0.19	.666	Power= .071
	BAC Group	F(1, 44)= <.01	.977	Power= .050 (IV* CP*)
	ERP Group	F(1, 44)= 0.25	.622	Power= .078
Interactions	Task * BAC	F(1, 44)= 8.22	.006*	Power= .801
	Task * ERP	F(1, 44)= 2.18	.147	Power= .303
	BAC * ERP	F(1, 44)= 1.05	.312	Power= .170
	Task*BAC*ERP	F(1, 44)= 0.91	.345	Power= .155
Task by BAC	Control	X^2_F= 6.00	.014*	
	Alcohol	X^2_F= 1.80	.180	

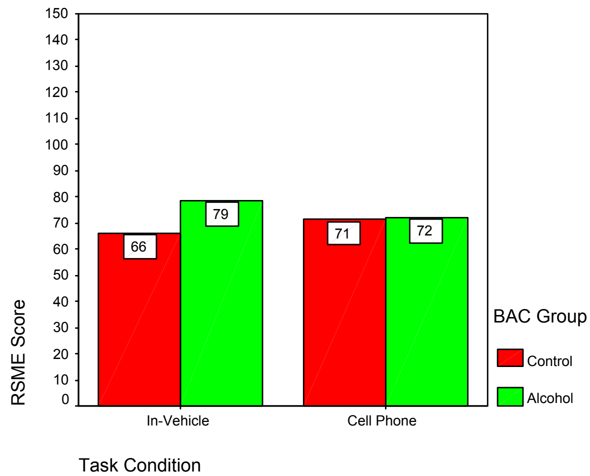
* Significant at the .05 level

Figure F-2 – Percentage of attempted tasks during car-following

No main effects for task condition, BAC group, or ERP group were found for attempted tasks during car-following, as seen in Figure F-2. There was an interaction between Task condition and BAC group, showing that Control group drivers attempted a significantly smaller percentage of cell phone tasks (M= 97.63 percent) than in-vehicle tasks (M= 100 percent). Quite possibly, these sober drivers may have been actively regulating their responses (i.e. not performing the cell phone task) so as to focus their attention on the car-following task and maintaining safe driving performance.

Task Effort
It was also important to see that it took a comparable amount of effort to perform the Cell Phone and In-Vehicle tasks. Participants were asked to rate how much effort it took them to complete the in-vehicle and cell phone tasks. These RSME scores were expected to be

equivalent across groups. No participants were excluded from the task effort mental workload analyses. Results are shown in Figure F-3 along with relevant statistics.



Test	Comparison	Significance	p=	
Main Effects	Task Condition	F(1, 44)= .015	.904	Power= .052
	BAC Group	F(1, 44)= 1.44	.237	Power= .217
	ERP Group	F(1, 44)= 2.27	.139	Power= .314
Interactions	Task * BAC	F(1, 44)= 2.15	.150	Power= .300
	Task * ERP	F(1, 44)= 0.07	.790	Power= .058
	BAC * ERP	F(1, 44)= 0.68	.414	Power= .127
	Task*BAC*ERP	F(1, 44)= 0.88	.352	Power= .151

Figure F-3 – RSME subjective mental workload ratings for tasks

The amount of effort participants experienced completing the in-vehicle (M= 72.3) and cell phone (M= 71.8) tasks were comparable as shown in Figure F-3. There were no group effects or interaction effects for BAC or ERP. These findings imply that our two tasks were equally taxing, thus if differential effects between them are obtained in subsequent analyses, then these effects should not be attributed to differences in the amount of task difficulty but rather the specific type of processing resources required.

Participants were also asked for their comments on the tasks they performed; their comments are presented in percentages of the total number of drivers for each condition (24 control, 24 alcohol, 48 total). 13 percent of the alcohol participants reported that there was a lot going on simultaneously and 8 percent reported that the steering was very sensitive. More strongly, 19 percent of all participants (five control, four alcohol) reported that the cell phone task was very difficult and distracting from driving.

In regards to task validity, ten percent of all participants in the in-vehicle condition (three control, two alcohol) reported that they would not adjust the controls as frequently as they were instructed to, and another ten percent (four control, one alcohol) reported they were not completely used to the placement of the controls they were instructed to change.

Likewise, eight percent of all participants (two control, two alcohol) found the questions to be on topics they normally wouldn't be discussing or find interesting. Though not seen as completely ecologically valid by all participants these tasks were meant to be more taxing than normal conditions in order to produce more profound effects on driving performance.

Secondary-task Validation Summary
Overall the in-vehicle and cell phone tasks were found to be equally taxing, thus if differential effects between them are obtained in subsequent analyses, then these effects should not be attributed to differences in the amount of task difficulty but rather the specific type of processing resources required.

Control group drivers attempted a significantly smaller percentage of cell phone tasks than in-vehicle tasks, indicating that these sober drivers may have been actively regulating their responses (i.e., not performing the cell phone task) so as to focus their attention on the car-following task and maintaining safe driving performance. In addition, intoxicated drivers had missed or ignored more of the in-vehicle tasks than the cell phone tasks, suggesting that drinking impairs the driver's ability to attend and respond to information presented in the vehicle.

APPENDIX G – CONVERSATION TASKS

The following are the questions recorded and used for the Cell Phone condition of the experiment. They were taken from Burns et al., 2002, who used questions from the Rosenbaum Verbal Cognitive Test Battery, as used in Waugh et al., 2000.

Types of Question

M = Monologue, e.g. “Tell me as much as you can about ….”
RS = Repeat sentence, e.g. “Repeat the following sentence to me ….
VP = Verbal puzzle, e.g. “Answer the following for me ….”

Note: separate VP files were created if multiple questions followed the statement.

Questions

VP11 Felix is taller than Antoine. Who is the shorter of the two?

RS11 The action of the brave cyclist kept the small boy from being hit by the ten-ton truck.

M11 YOUR BEDROOM

VP12 If you see a circle and it has a rectangle to the right of it and if there is a cross directly below the rectangle. Is the rectangle:
a. Below the cross?
b. To the left of the Circle?
c. Below the circle?

RS12 It was raining this morning so the children wore their boots to school.

VP13 If Daphne walks twice as fast as Margaret and they are the only two people in a race, who is most likely to finish last?

RS13 Annie's dog ran to her for help after it was attacked by a raccoon in the woods.

M12 A MEMORABLE VACATION

VP14 If three chocolate bars cost 93 cents, what is the cost of one chocolate bar?

RS14 The team was playing well until the third quarter, when snow made visibility poor.

VP15 Horse number seven entered the home stretch before Tom, number eight's jockey, could get his horse out of the gate.
a. Which horse was Tom riding?
b. Where was horse seven?

RS15 Police protection was given to Mary after her apartment was broken into by a daring thief.

M13 A FRIEND

VP16 Jack, who was working in Tim's garage, found an old Chevy that belonged to his father.
a. Who did the car belong to?
b. Where was Jack?

RS16 The car lost power trying to accelerate on the slippery hill during a storm in March.

VP17 If a car drove 360 miles in six hours, how fast was the car going in miles per hour?

RS17 The train crept up the mountain slowly as it winded its way through the Rockies.

M14 ROUTE THIS BUILDING TO MALL OF AMERICA

VP18 Who is sicker if Jane is less ill than Sam?

RS18 Jane started dancing at age eight, but didn't give her first recital until she was twenty-three.

VP19 If you see a picture with a cross beneath a rectangle, but to the right of a circle, is the rectangle:
a. Above the circle?
b. To the left of the circle?
c. Right of the cross?

RS19 The perfume was strong, but Jane liked the exotic scent of Jasmine.

M15 ANIMALS BEGINNING B

VP21 If I say Jack stole Ann's ball who is the thief?

RS21 The driver was stopped for driving 67 miles per hour in a 20 mile per hour zone.

M21 THE INTERIOR OF YOUR CAR

VP22 If you see a picture with a diamond, a rectangle, and a circle, and the circle is to the right of the rectangle and directly above the diamond, is the rectangle:
a. Right of the diamond?
b. Above the circle?
c. Left of the circle?

RS22 Undetected by the sleeping dog, the thief broke into Jane's apartment.

VP23 Which girl is taller if Jane is shorter than Kim?

RS23 Mike walked around the block three times before he had the nerve to knock on Carol's door.

M22 YOUR DAILY WORK / ACTIVITIES

VP24 If Jane runs 6 miles in 54 minutes, how long does it take her to run one mile?

RS24 The train left Cleveland an hour early, leaving Sam stranded at the station.

VP25 The man who was an engineer came to the store where Alice worked to buy pastries.
a. Who bought the pastries?
b. Where was Alice?

RS25 The shorter the chapter, the easier it is for students to complete the difficult exercises.

M23 A PAST / PRESENT BOSS

VP26 Because he was working late, Jack left a dinner in his microwave for Jim to heat up when he got home.
a. Who was the dinner for?
b. Who did the Microwave belong to?

RS26 The warm humid weather that occurs in the tropics makes people sleepy by midday.

VP27 A chocolate bar costs 24 cents. What will 3 chocolate bars cost?

RS27 Old houses are more difficult to maintain, but worth the extra time and effort.

M24 ROUTE FROM YOUR HOME TO I-494

VP28 Which house is smaller if Jim's house is half again as big as Brian's?

RS28 The students needed to complete chapters 9 and 11 and answer the question on page twenty.

VP29 If you see a picture with a circle to the left of a square but on top of a cross, is the cross:
a. Above the square
b. To the left of the circle?
c. Below the circle?

RS29 The weather in March is snowy and cold in many parts of Canada.

M25 NAMES BEGINNING WITH The LETTER A

APPENDIX H – CONTINUOUS PRIMARY TASK MEASURE CALCULATIONS

STEERING REVERSALS

The mean of steering reversals measure is based on published metrics (Verwey and Veltman, 1996) and was measured as the time between successive steering movements. Take for example the steering wheel angle data in Figure H-1, where steering wheel angles above zero reveal times where the center of the wheel is turned to the right, and negative values when the wheel is turned left.

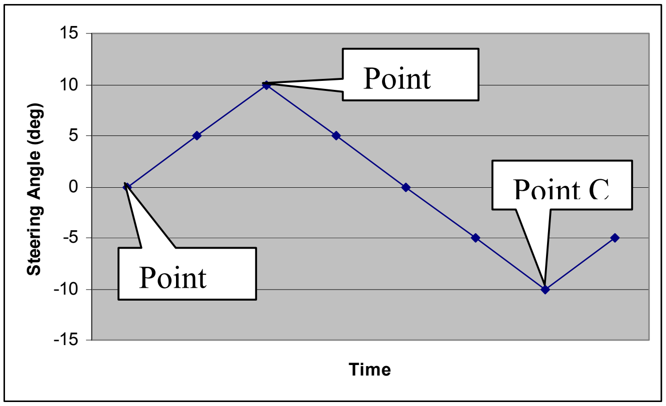


Figure H-1 – Example data to illustrate how steering wheel "reversals" are measured

At "Point A," the steering wheel begins turning to the right, up until "Point B." At "Point B", the wheel stops its steady rotation to the right, and begins turning to the left. By definition, "Point B" and "Point C" are "reversals" since that is when the wheel's angular velocity switches towards the opposite direction. Therefore, in this example, a steering wheel "reversal" is considered to be the period of time between successive inflection points (i.e., the period of time between "Point B" and "Point C"). It has been shown in past studies that steering frequency increases when drivers are put under higher levels of mental workload (Verwey and Veltman 1996).

STEERING ENTROPY

The entropy measures are a variation of steering entropy based on Nakayama et al., (1999; also see Boer, 2000) to measure controllability. With this metric, steering wheel and accelerator pedal position data is recorded for all subjects and is then subjected to a first order low pass Butterworth filter with a cut-off frequency of 3 Hz. As illustrated in Figure H-, the prediction error for this filtered data set is calculated at each point and combined for all subjects during the no-distraction task period (black line). From this, the 90^{th} percentile value is calculated (α) and the frequency distribution is divided into nine bins at -5 α ,-2.5 α , - α , -0.5 α , 0.5 α , α , 2.5 α , 5 α (black dotted lines). This results in the generation of nine standard bins PN1…PN9.

For each subject, the prediction error is then calculated to derive the proportions (PO1-PO9) within each of the standard bins PN1-PN9 for all other conditions. In this example, both the no-distraction (red dotted line) and the distraction task (red dash- dot line) conditions are presented. Using these proportions within the standard bins, the number of bits is calculated for each subject in the task conditions. Note that the bin definitions remain the same for all subjects and conditions.

The number of bits based on this method is calculated using the following formula:

$$H_{\#\,bits} = \sum po_i \, Log(pn_i)$$

Where

po_i is the observed proportion for each subject

pn_i is the proportion calculated using the standard bins for all subjects in baseline condition during the no-distraction period (without MB).

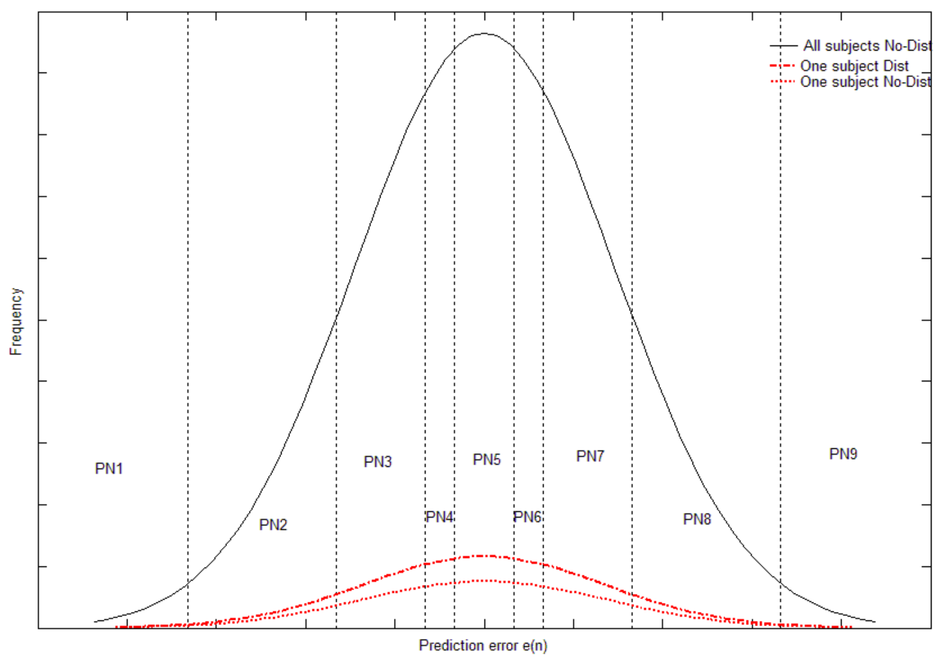


Figure H-2 – Frequency distribution for prediction error.

Frequency distribution for prediction error is shown in Figure H-. Curve is shown for all subjects for no-distraction condition (black) and for a sample subject for both the no-distraction (red dotted) and the distraction condition (red dash-dotted). Vertical dotted lines show the bins based on the 90th percentile of standard prediction error. A larger value indicates that prediction error has greater standard deviation. Higher fluctuations in steering input cause greater variance in the prediction error, which causes an increase in the entropy value.

APPENDIX I – RESULTS FROM DEMOGRAPHIC QUESTIONNAIRES

DRIVING HISTORY QUESTIONNAIRE

These questions pertain to trends in participant driving behavior and attitudes towards driving and driving regulations.

Variable	Alcohol		Control		U X^2	p
	Mean N	SD %	Mean N	SD %		
Time licensed (years)	6.6	1.85	6.5	1.76	263.0	.973
How often drive					0.375	.945
Hardly	1	4.3	1	4.2		
Sometimes	5	21.7	7	29.2		
Most days	9	39.1	9	37.5		
Every day	8	34.8	7	29.2		
Miles driven last year					2.604	.626
Less than 5k	2	8.7	5	20.8		
5k – 10k	9	39.1	10	41.7		
10k – 15k	4	17.4	4	16.7		
15k – 20k	5	21.7	2	8.3		
Over 20k	3	13.0	3	12.5		
Often drive to or from work					2.677	.613
Never	4	18.2	4	16.7		
Hardly	4	18.2	2	8.3		
Sometimes	3	13.6	6	25.0		
Most days	5	22.7	8	33.3		
Every day	6	27.3	4	16.7		
Drive frequently highways					1.066	.302
Yes	22	95.7	24	100.0		
No	1	4.3	0	0.0		
Drive frequently: main roads other than highways					N/A	N/A
Yes	23	100.0	23	100.0		
No	0	0.0	0	0.0		
Drive frequently: urban roads					0.000	1.00
Yes	20	87.0	20	87.0		
No	3	13.0	3	13.0		
Drive frequently: country roads					0.451	.502
Yes	5	21.7	7	30.4		
No	18	78.3	16	69.6		

Table I-1 – Results from the Driving History Questionnaire (continued)

Variable	**Alcohol**		**Control**		**U**	**p**
	Mean N	SD %	Mean N	SD %	**X^2**	
How many Minor accidents in past 3 years	0.22	0.42	0.17	0.39	253.0	.713
How many Major accidents in past 3 years	0.00	0.00	0.04	0.21	253.0	.317
Convicted: speeding in past 3 years					0.087	.768
Yes	11	47.8	12	52.2		
No	12	52.2	11	47.8		
Convicted: dangerous driving in past 3 years					1.022	.312
Yes	1	4.3	0	0.0		
No	22	95.7	23	100.0		
Convicted: DUI alcohol or drugs in past 3 years					N/A	N/A
Yes	0	0.0	0	0.0		
No	23	100.0	23	100.0		
Vehicle drive most often					11.859	.018*
Motorcycle	1	4.3	0	0.0		
Passenger car	21	91.3	11	52.4		
Pick-up truck	0	0.0	5	23.8		
Sport utility vehicle	1	4.3	4	19.0		
Van or minivan	0	0.0	1	4.8		

* Significant at the .05 level

Table I-1 – Results from the Driving History Questionnaire (continued)

CELL PHONE SURVEY

This survey provided more information about the participants' usage of cell phone technology. Their responses are presented in Table I-2, listed by the question and forced-choice responses or open-ended responses. The number of responses for each choice ("Count, n=") is listed followed by the percentage of valid responses.

For questions indicated with an "£", participants may have indicated more than one valid response. In these cases all responses were noted in the Count column. For all questions, the Percentage was taken out of 44 or 48 total participants, based on these criterion:

- When indicated with "¥", the question deals with owning a cell phone and 44 was used since this many participants reported regularly having or using a cell phone.
- The remaining questions pertain to all participants and so 48, the total number of participants, was used.

Variable	Response	Count	Percentage
Own or regularly have use of a cell phone.	Yes No	44 4	91.7 8.3
If you own or regularly have use of a cell phone, what make and model (open ended). ¥	Audiovox Motorola LG (Verizon) Nokia Panasonic Samsung Sanyo Siemens Sony (Sprint) (Verizon) Not sure	1 7 1 17 1 4 3 1 1 6 1 1	2.3 15.9 2.3 38.6 2.3 9.1 6.8 2.3 2.3 13.6 2.3 2.3
If you do talk on the phone while driving, how long is your average conversation (open ended).	Range Low = 1 minute High =15 minutes	Mean 3.6 minutes	SD 3.24
Comments on last question (open ended).	Usually a short conversation to get needed info (3). Call to tell customers when I'll be there (pizza delivery)		
What is the main use of your cell phone. ¥	Business Personal Limited for emergencies Other use	1 38 0 0	2.3 86.4
How often do you use your cell phone. ¥	More than 10 times a day Every day Several times a week Once a week Once a month Rarely	11 26 6 1 0 0	25.0 59.1 13.6 2.3
Do you have a hands-free cell phone car kit. ¥	Yes, professionally fitted Ear piece fitted to phone No	1 16 27	2.3 36.4 61.4
Comments on last question (open ended).	I don't use it enough to use it in the car (2). I'm cautious when talking and driving. I usually drive with one hand anyway and I tend to talk on my phone only when I am not in traffic or urban areas. So it usually does not interrupt my driving. Normally used an ear piece but I lost it.		

Table I-2 – Results from the Cell Phone Survey (continued)

Variable	Response	Count	Percentage
Do you think the use of a hand-held cell phone when driving should be banned.	Yes	8	16.7
	No	25	52.1
	Depends	14	29.2
	Don't know	0	
What, if anything, do you think the penalty should be if caught driving and using a hand-held cell phone. £	Confiscate the phone	0	
	A fine	10	20.8
	Points on license	5	10.4
	Ban from driving	0	
	Caution/written warning 1st	15	31.3
	Other	0	
	Don't need a penalty	20	41.7
	Don't know	1	2.1
Do you think the use of a hands-free cell phone when driving should be banned.	Yes	2	4.2
	No	40	83.3
	Depends	6	12.5
	Don't know	0	
What, if anything, do you think the penalty should be if caught driving and using a hands-free cell phone. £	Confiscate the phone	0	
	A fine	3	6.3
	Points on license	3	6.3
	Ban from driving	0	
	Caution/written warning 1st	5	10.4
	Other	1	2.1
	Don't need a penalty	36	75.0
	Don't know	1	2.1
From your own observations, what types of drivers are most likely to use a cell phone while driving (open ended). £	Almost anyone/everyone	8	16.7
	Bad/careless/wild drivers	4	8.3
	Professional business people	21	43.8
	Commuters with long drives	1	2.1
	Drivers of nice cars	1	2.1
	Girls/Women	4	8.3
	Mothers	5	10.4
	People that feel comfortable driving and talking	2	4.2
	People who drive for work (pizza delivery, real est.)	5	10.4
	College students	4	8.3
	Talkers ("people that can't deal with silence")	2	4.2
	Teenagers/HS students	13	27.1
	Don't know	2	4.2

Table I-2 – Results from the Cell Phone Survey (continued)

Variable	Response	Count	Percentage
Do you think drivers should pull into the next safe place and stop if they receive a cell phone call while driving.	Yes	9	18.8
	No	18	37.5
	Depends	20	41.7
	Don't know	1	2.1
How often do you use a cell phone while driving.	Nearly every time you drive	5	10.4
	Quite often	7	14.6
	Sometimes	20	41.7
	Maybe	2	4.2
	Not usually	11	22.9
	Not under any circumstances	1	2.1
Comments on last question (open ended).	Rarely; only when important (2). Typically only when working/for business (2). 1/3 of every drive. Just on long trips to tell people how it is going. I am usually only checking voicemail or letting someone know I am on my way home.		
If your cell phone rings while you are driving would you answer it. £	Yes, always	12	25.0
	Yes, usually	13	27.1
	Maybe	2	4.2
	Depends on caller	10	20.8
	Depends on traffic situation	10	20.8
	Not usually	0	
	Not under any circumstances	1	2.1
	I always have it switched off	0	
Comments on last question (open ended).	If I thought it was important enough (3). I usually only answer when it will not distract me; I won't if I really need to pay full attention, if traffic or weather is bad (3). I think most problems are with dialing or answering not necessarily talking. I almost never talk on the phone while driving on the highway/freeway. If I hear it. It doesn't cause me to take my eyes off the road. Only if my hands-free is connected. I'm obligated to as a condition of employment.		

Table I-2 – Results from the Cell Phone Survey (continued)

Variable	Response	Count	Percentage
Would you make a cell phone call while you are driving. £	Yes, always	11	22.9
	Yes, usually	10	20.8
	Maybe	6	12.5
	Depends on caller	4	8.3
	Depends on traffic situation	14	29.2
	Not usually	4	8.3
	Not under any circumstances	1	2.1
	I always have it switched off	0	
Comments on last question (open ended).	Depends on traffic and weather conditions (3). Not unless I had to/sometimes it is necessary (2). I like to talk while I drive (2). Not likely to do so while on the highway/freeway I usually wait until highways since I drive a manual, requires use of a hand in urban stop-and-go. Problem is with the difficulty of driving and dialing. Only if hands-free is connected. I'm obligated to as a condition of employment.		
If you do talk on the phone while driving, list all the conditions or situations where you would not use your phone (open ended). £	Bad weather	40	83.3
	City/Urban Areas	4	8.3
	Construction zones	2	4.2
	When Lost	6	12.5
	Emergency	1	2.1
	Faster city streets	1	2.1
	Heavy traffic	31	64.6
	Highways	3	6.3
	If could easily talk later	1	2.1
	Manual shift car	1	2.1
	Night time	1	2.1
	Other distractions	4	8.3
	People talking in car	3	6.3
	Winding roads	2	4.2
	None (would use in any condition)	1	2.1

Table I-2 – Results from the Cell Phone Survey (continued)

Variable	Response	Count	Percentage
If you do talk on the phone while driving, on average what proportion of the driving time are you in conversation.	100%, the entire time	0	
	75% to 99% of the time	1	2.1
	50% to 74% of the time	3	6.3
	25% to 49% of the time	7	14.6
	1% to 24% of the time	33	68.8
	0%, no conversation (i.e. just listening to voicemail, weather, etc.)	0	
Comments on last question (open ended).	I make short calls; I make quick conversations since I'm usually driving in traffic during rush hour (2). I'm a talker.		
If you do talk on the phone while driving, what do you talk about. £	Business; complex negotiation	0	
	Business; light conversation	8	16.7
	Complex conversation with friends	7	14.6
	Only light, short conversations		
	Very brief messages; i.e. "I'll be home at…"	31	64.6
		11	22.9
Comments on last question (open ended).	Not very often/don't usually get text messages (3). It can be quickly read by glancing at it; same as changing radio station or temperature setting, so I don't feel it is very dangerous (2). I have never used/don't like text messaging (2). I wouldn't read it. Usually not important. Depends on the traffic situation.		
Would you text a message while you are driving.	Yes, always	2	4.2
	Yes, usually	3	6.3
	Maybe	2	4.2
	Depends on caller	0	
	Depends on traffic situation	1	2.1
	Not usually	25	52.1
	Not under any circumstances	14	29.2
	I always have it switched off	0	
Comments on last question (open ended).	To write a text message is very distracting (4). Don't text much (2). Never done this in a car. Only if it was urgent. If I was familiar with my phone: yes. I text often, but have the pin pad memorized.		

Table I-2 – Results from the Cell Phone Survey (continued)

APPENDIX J – MENTAL WORKLOAD/DRIVING CAPABILITY CORRELATIONS

Results from the RSME mental workload and driving capability questionnaires were correlated by Task condition using Pearson Correlations (R). This was done in order to determine if they are measuring similar aspects of the participants' experience instead of mental workload and driving capability separately. Significant correlations indicate that the measures are related and therefore measuring similar aspects of the drivers' experience.

How intoxicated do you feel at this moment?

Task Condition	R=	p=
Baseline	.526	<.001*
In-Vehicle	.432	<.001*
Cell Phone	.420	.003*

* Significant at the .05 level

Mental effort was positively correlated with participants' intoxication rating, indicating that participants who gave high effort ratings also gave high intoxication ratings.

How impaired do you feel at this moment in terms of being able to safely drive a vehicle?

Task Condition	R=	p=
Baseline	.276	.058
In-Vehicle	.273	.060
Cell Phone	.257	.078

Mental effort was not correlated with participants' impairment rating, indicating that participants may not have related these two measures. This also indicates that the impairment rating may be more valid as a measure of driver intoxication or impairment than the other measures reporting a significant correlation with mental workload.

How willing would you be to operate a motor vehicle for an unimportant though gratifying reason (e.g. drive friends to a party)?

Task Condition	R=	p=
Baseline	-.333	.021*
In-Vehicle	-.413	.004*
Cell Phone	-.298	.040*

* Significant at the .05 level

Mental effort was negatively correlated with participants' willingness to operate a vehicle for unimportant reasons. This indicates that participants who gave high effort ratings also gave low willingness ratings for this capability measure.

How willing would you be to operate a motor vehicle for an important, but avoidable reason (e.g. driving a friend home who feels mildly ill, when they could get a taxi)?

Task Condition	R=	p=
Baseline	-.398	.006*
In-Vehicle	-.412	.004*
Cell Phone	-.370	.010*

* Significant at the .05 level

Mental effort was negatively correlated with participants' willingness to operate a vehicle for important but avoidable reasons. This indicates that participants who gave high effort ratings also gave low willingness ratings for this capability measure.

How willing would you be to operate a motor vehicle for an urgent reason (e.g. driving a sick child to the hospital)?

Task Condition	R=	p=
Baseline	-.399	.005*
In-Vehicle	-.321	.026*
Cell Phone	-.338	.019*

* Significant at the .05 level

Mental effort was negatively correlated with participants' willingness to operate a vehicle for an urgent reason. This indicates that participants who gave high effort ratings gave low willingness ratings for this capability measure.

[1] Larger, safer safety margins are equivalent to smaller inverse TTC (TTC^{-1})
[1] Participants number 3 and 28; psychology subject numbers s1006 and s1008, respectively
[1] This figure has been displayed in congruence with the other graphs in this report, however when analyzed the order was changed to make the quadratic contrast comparison of Baseline performance to both In-Vehicle and Cell Phone performances.
[1] Aside from showing more steering entropy, a higher number of steering reversals, and increasing lane position variability during the in-vehicle task.