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Effect of Electronic Device Use While Driving on Cardiovascular Reactivity

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Introduction

1.0 Motor Vehicle Collisions and Distracted Driving

Motor vehicle collisions (MVCs) are the leading cause of death in people ages 5 to 25 (Centers for Disease Control and Prevention [CDC], 2015). Engaging in secondary tasks while driving is one of the leading contributors to MVCs, with cell phone use as the most popular activity behind the wheel (Centers for Disease Control and Prevention [CDC], 2014). Cell phones, particularly text messaging, are one of the most dangerous forms of secondary tasks because it involves all three levels of distraction: 1) visual—eyes off the road, 2) manual—hands off the wheel, and 3) cognitive—mind off of the road (National Highway Traffic Safety Administration [NHTSA], 2013). Many studies have examined the detrimental effects of secondary task engagement on driving performance via surrogates of safety such as speed control, collision risk, lane control, etc. (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005a; Stavrinos, Garner, et al., 2013). However, few studies have examined the effects of secondary task use while driving on cardiovascular (CV) reactivity.

1.1 Cardiovascular Reactivity and Driving

Many studies have examined how to measure effort-related response via the sympathetic nervous system. The sympathetic nervous system influences CV reactivity, such as heart rate and blood pressure, at times when people are actively engaged in effortful activities, indicating that CV reactivity is a good measure of effort-related response (Obrist, 1976). CV reactivity has been linked to an increase in susceptibility to CV disease, such as heart attack and stroke (Everson et al., 2001; Huang, Webb, Zourdos, & Acevedo, 2013). Therefore, theoretically, the more often one engages in tasks that cause an increase in CV reactivity, the more one increases his risks for CV disease. We hypothesize that secondary tasks such as texting or talking on a cell phone, while driving, may be as dangerous to the CV system as other factors such as stress.

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Few studies have considered the effect of secondary task engagement on CV reactivity. Reimer, Mehler, Coughlin, Roy, and Dusek (2011) conducted a study examining the effect of talking on a hands-free cell phone while driving on heart rate and driving performance, stratified by two age groups – young (19 to 23 years) and older (51 to 66 years). Reimer et al. (2011) found that heart rate increased in young adult drivers when talking on a cell phone while driving, but not in older adults. The authors speculated that older adults may not have had an increase in heart rate when talking on a cell phone while driving due to compensatory behavior as they drove more slowly compared to the young adult drivers.

Stuivera, Brookhuisa, de Waarda, and Mulderb (2014) conducted a study that focused on the effects of mental workload on cardiovascular reactivity. Varying workload conditions were measured using two traffic densities (low and high) with and without fog (used as additional workload demands), and cardiovascular reactivity was measured using heart rate and blood pressure. Stuivera et al. (2014) found that driving in high traffic density conditions (medium-high workload) was associated with an increase in systolic blood pressure and decreased blood pressure variability. On the other hand, driving in foggy, low traffic density conditions (medium-low workload) was associated with a decrease in heart rate and blood pressure variability. It is hypothesized that engaging in a secondary task while driving may affect CV reactivity in a similar manner to driving in these particular traffic conditions.

As used in previous efforts (Stuivera et al., 2014), blood pressure may be a better measure of CV reactivity and effort, particularly systolic blood pressure and diastolic blood pressure; however, due to the restrictive nature of current blood pressure measurement mechanisms, blood pressure is not commonly studied in driving studies, both naturalistic and simulator. The current study is the first to consider blood pressure measurements in addition to heart rate as a means of examining the effects of secondary task use while driving on cardiovascular reactivity. The present study aims to fill in the gaps in the literature on the effects of secondary tasks (cell phone conversation, text messaging, no secondary task) while driving have on CV reactivity as well as including another meaningful measure of CV reactivity (blood pressure).

1.2 Purpose

The current study examined the relationship between CV reactivity and secondary task engagement while driving in undergraduate college students. Addressing potential limitations of previous work (e.g., Reimer et al., 2011 & Stuivera et al., 2014), participants operated a virtual driving simulator while engaging in a variety of commonly used secondary tasks ((a) talking on a cell phone, (b) text messaging, or (c) driving with no task) while heart rate and blood pressure measurements were recorded across driving scenarios. It was hypothesized that participants would exhibit the greatest increase in CV reactivity in the texting condition as it is the more effort-demanding task, taking away attention from the cognitive, visual, and manual demands of driving, and CV reactivity being the lowest in the no task condition.

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Method

2.0 Participants

After providing written informed consent, participants were screened for eligibility from a convenience sample of Introductory Psychology students, who would earn research credit for participation in the study. The following protocol was approved by the Institutional Review Board of the University of Alabama at Birmingham.

Inclusion criteria for all participants were: (1) being between 17 and 30 years of age, (2) having a valid driver's license, and (3) owning a cell phone with text messaging capability. Exclusion criteria for all participants included: (1) physical disabilities so severe that they precluded their ability to participate, fully, in any aspect of the experimental protocol, (2) use of beta blockers that could inhibit cardiovascular reactivity, and (3) history of cardiovascular disease, which could affect cardiovascular reactivity.

Of the 152 individuals meeting all eligibility criteria, 64 individuals came in for a laboratory session. The resulting sample of 64 participants was recruited to be half male and half female to have a balance of gender. Two participants developed motion sickness during the simulator drive. There were also technical issues with the simulator and/or the heart rate monitor during two appointments. This resulted in a final sample size of 60 individuals.

2.1 Procedure

Recruitment.—Participants meeting eligibility requirements were contacted by a research assistant who explained the details of the study, and a consent form was e-mailed. If the interested in participating, an appointment was scheduled no sooner than 24 hours after the consent form was received. Initial contact was made with all eligible participants.

Laboratory session.—Participants provided written consent upon arrival to the appointment. Experimental tasks were administered by a team of trained, student research assistants. Standardized protocols were followed in every testing bout. Laboratory sessions took anywhere from 70 to 90 minutes, depending on the driving speed of the participants. Each participants' cell phone number was obtained at the beginning of the session and a test was conducted to ensure that participants were able to receive calls and text messages from research assistants via a Google Voice platform. Then, a test text message and test phone call was sent to the participants' cell phone. Participants were instructed to place the heart rate monitor around their chest. Afterwards, participants were escorted to the simulator room to begin the simulator portion of their session.

Participants were allowed to settle into the driving simulator. Baseline average resting heart rate was first obtained for a five-minute period during which participants read a magazine. At the end of this period the participants' blood pressure was obtained to provide a baseline measurement, as well.

Participants received instruction in the operation and use of the driving simulator during a calibration session prior to actual data collection. Participants drove a brief, standardized simulator scenario without the introduction of a distraction until they achieved stable driving

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performance. This was required, by protocol, to ensure participants could demonstrate a minimum standard of proficiency with regard to basic driving tasks. The familiarization drive entailed driving through a five mile scenario. If participants failed to maintain the required speed (7 miles per hour greater or less than the posted speed limit), a verbal warning was issued, and they were instructed to slow down or speed up accordingly. At the end of the drive, the research assistant totaled the number of verbal warnings that were issued (over 4 warnings – either “too fast” or “too slow” constituted a “fail,” requiring another drive). No participants required a second drive.

Once stable performance was achieved, participants completed three, five mile driving scenarios with the following tasks presented: no task, naturalistic cell phone conversation, and text messaging. Secondary task assignment was counterbalanced so that no particular order of secondary task appeared more often than the others, with participants being randomly assigned a secondary task order. Participants were asked to drive as they normally would on a real road. The use of talking on a cell phone as a secondary task was similar to previous work (Stavrinos, Byington, & Schwebel, 2009, 2011; Stavrinos, Jones, et al., 2013); however, unlike the Reimer study, which featured participants scheduling an appointment during the cell phone task but no text messaging task, the cell phone and text messaging tasks were semi-structured to mimic a typical conversation with unfamiliar individuals (in this case, research assistants whose responsibilities included maintaining a natural conversation flow with participants and asking open ended questions which would require more thought to respond). The tasks matched those used in previous research efforts using simulators (Stavrinos et al., 2009, 2011; Stavrinos, Jones, et al., 2013). Examples of natural flow, conversational questions included items such as, “What is your favorite football team?” and “Tell me about the place you were born.” Each participants’ blood pressure was obtained immediately following each 5 mile driving scenario, and heart rate measurements were recorded continuously for the entire condition.

After the experimental drive, participants completed a questionnaire on demographic information in a private cubicle to protect participants’ privacy. After the simulator drive and questionnaire portion were completed, participants were debriefed. A research assistant provided participants with additional information regarding the study, described the study’s importance to science and public health, and answered any questions participants might have had about the study procedure. Participants were also given a brochure during the debriefing that conveyed the dangers of distracted driving. At the end of the session participants were given a research credit slip as well as a copy of the consent form that they had signed.

2.2 Measures

2.2.1 Driving Simulator.—Participants drove in a computerized driving simulation task to measure cardiovascular reactivity under specified conditions of interest (STISIM Drive, Systems Technology Inc., Hawthorne, CA). The simulation provided a view of the roadway and dashboard instruments, including a speedometer, rotations per minute (rpm) gauge and a letter indicating the vehicle’s gear and was displayed on three, 20” LCD computer monitors (Figure 1). The vehicle was controlled by moving a steering wheel in a typical driving manner and depressing the accelerator and brake pedals accordingly. An on-board stereo

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sound system provided naturalistic engine sounds, external road noise, and sounds of passing traffic.

2.2.2 Driving Scenarios.—Participants completed a brief 5 mile calibration drive with no secondary task introduced and were assessed for stable driving performance (e.g., ability to maintain a particular speed). A verbal warning was presented to the driver when their speed was 7 miles per hour greater or less than the posted speed limit. Research assistants recorded and summed the number of verbal warnings drivers received to determine whether additional practice was needed. Once participants demonstrated stable driving performance in the calibration drive, they were presented with three driving scenarios. Each of the three driving scenarios featured a two-lane, bi-directional 5 mile long road, enhanced by day-time suburban scenery and surrounding simulated vehicles. Speed limits varied between 35mph and 65mph segments within the scenario but remained constant across tasks. Participants were required to navigate through a total of twelve unexpected events that required immediate response (e.g., a lead vehicle braked suddenly, a pedestrian darted into the street, a cyclist swerved into the participants' lane), which were consistent across each scenario. All events appeared across all three scenarios but the order of presentation was randomized to reduce potential practice effects.

2.2.3 Cardiovascular Reactivity Outcome Variables.—Five indicators of cardiovascular reactivity were used. Heart rate and root mean square of successive differences (RMSSD) was measured using a Polar E600 heart rate monitor was used to obtain heart rate. The monitor consisted of recording electrodes and a transmitter, which were attached to participants with an elastic strap, and a receiver and data storage device in the form of a wrist watch. The transmitter was worn around the chest at the level of the xyphoid process, underneath all clothing and in direct contact with the skin. The wrist receiver watch was located in the simulator room, approximately 1 meter away from participants. A button on the heart rate monitor initiated and later terminated recording at the beginning and end of each distraction condition. Average heart rate for that time interval was displayed on the wrist watch and manually recorded by the experimenter at the end of each condition. The average heart rate data were also stored on the watch and were later transferred to a computer. RMSSD was used to measure heart rate variability within time periods of measurement. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) was recorded at the end of each drive, using a Critikon DURA-CUF blood pressure cuff applied to the upper arm and connected to a GE Carescape V100 Vital Signs Monitor. Measurements were electronically completed and results recorded manually. A button on the front panel of the blood pressure monitor started the cuff inflation/deflation cycle, which took approximately 30 seconds to complete. SBP, DBP, and MAP were displayed, and were manually recorded by the experimenter. Previous studies have focused mainly on heart rate (Reimer, Mehler, Coughlin, Roy, & Jusek, 2010), but other CV research gives reason to study systolic and diastolic blood pressure as a better predictor of stress and effort (Obrist, 1976; Richter, Friedrich, & Gendolla, 2008).

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2.3 Data Analysis

Data were analyzed in three steps. First, descriptives of the sample was obtained. Second, cardiovascular reactivity, except RMSSD, was analyzed as the difference between "stimulus" periods (driving with no task and driving with the secondary task) and a "baseline" condition, which was a period of inactivity (Manuck, Kasprowicz, Monroe, Larkin, & Kaplan, 1989). Previous studies have focused mainly on average heart rate (Reimer, Mehler, Coughlin, Roy, & Jusek, 2010), rather than comparisons using difference scores, because difference scores makes participants more comparable to one another, using a comparison of a resting state to a stimulus state. RMSSD is a fluctuation of heart rate measurements, which is why a difference score was not used for this variable. A repeated measures analysis of variance (RM ANOVA) using a mixed model approach was used to determine the effect of secondary task (no task, cell phone, texting) on cardiovascular reactivity outcome variables. *P*-values less than 0.05 were considered significant for all analyses. RM ANOVAs were conducted using SPSS version 22 considering secondary task as a within-subject factor.

Results

3.0 Participant Characteristics

Of the 64 participants who were recruited and participated in the study, 4 were excluded due to missing outcome variables, resulting from equipment technical error, or simulator sickness. The resulting sample of 60 participants was used in all analyses. The resulting sample of 60 participants averaged 19 years of age, approximately 71% of whom were Caucasian and 50% were male (Table 1).

3.1 Primary Analyses

Descriptives of mean and mean difference scores of cardiovascular reactivity outcomes stratified by secondary task are found in Table 2. A significant main effect of task was found for four of the five cardiovascular reactivity indicators: heart rate ($F(2, 108) = 19.82$, $p < 0.001$), RMSSD ($F(2, 110) = 5.60$, $p < 0.01$), SBP ($F(2, 116) = 3.52$, $p < 0.05$), and MAP ($F(2, 116) = 6.15$, $p < 0.01$). Pairwise analyses showed that participants had significantly lower heart rate in no task ($p < 0.001$) and texting task ($p < 0.001$) compared to the cell phone task. Participants had significantly lower RMSSD in the texting task ($p = 0.006$) compared to the cell phone task. Participants also had significantly lower SBP in no task compared to the cell phone task ($p = 0.04$) and significantly lower MAP in the no task ($p = 0.004$) compared to the cell phone task.

Discussion

4.0 Discussion of Findings

This study examined the effects of talking on a cell phone and texting during a simulated drive on cardiovascular (CV) reactivity, as measured through blood pressure and heart rate, in young college students. In general, talking on a cell phone while driving elicited the greatest CV response, while texting while driving did not differ significantly from driving with no secondary task.

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Few studies have investigated the effects of hands-free conversation while driving in a simulator on heart rate (Collet, Clarion, Morel, Chapon, & Petit, 2009; Mehler, Reimer, & Coughlin, 2012; Reimer et al., 2011). Previous attempts found results similar to this study's findings: talking on a cell phone increased CV reactivity through means of heart rate. Mehler et al. (2012) found that verbal response tasks while driving increased heart rate as well as skin conductance level, which is another method to measure the effects a task has on the sympathetic nervous system. While Reimer et al. (2011) found some differences in heart rate when driving while talking on a hands-free cell phone, they also found that age may contribute to differences in heart rate in that older adults did not have a significant increase in heart rate when talking on a hands-free device while driving as compared to driving with no task while young adults did have a significant increase in heart rate. Our study was not able to examine the impact that age may have on CV reactivity due to the targeted convenience sample; however, our sample did have the same findings as the Reimer et al. (2011) and the Mehler et al. (2012) samples. In addition to heart rate, there was an increase in systolic blood pressure, mean arterial blood pressure, and heart rate variability (RMSSD). There was not a significant increase in diastolic blood pressure, which may be due to the low mean diastolic blood pressure during each scenario. Both of these studies (Reimer et al., 2011; Mehler et al., 2012) made significant findings on the effects of secondary task engagement while driving on CV reactivity, but they were somewhat limited in that they did not also examine the impact of texting while driving on CV reactivity nor did they include blood pressure as a means to measure CV reactivity.

One of the few studies that looked at blood pressure as a measure of effort was one by Stuivera et al. (2014), which focused on the effects of mental workload, rather than secondary task use, on cardiovascular reactivity. Stuivera et al. (2014) found that driving in higher workloads increased systolic blood pressure, while driving in lower workloads decreased heart rate variability and blood pressure variability. In our study, talking on a cell phone evoked the greatest change in CV reactivity, particularly greater than when driving with no secondary task, as was found in multiple other studies (Collet et al., 2009; Mehler et al., 2012; Reimer et al., 2011). This may be due to the human interaction through verbal communication on the cell phone. One study found that talking to someone in the vehicle with participants caused just as much of an increase in heart rate as did talking on a cell phone while driving (Collet et al., 2009). As we suspected, secondary task engagement, particularly talking on a cell phone, while driving increased CV reactivity in the same way that high mental workload traffic environments (i.e., high traffic density and foggy weather conditions) affected CV reactivity. However, texting while driving did not have a significant increase in CV reactivity, which was not expected. CV reactivity, or arousal, associated with text messaging while driving can be difficult to measure due to the lack of continuous communication that is inherent to a text messaging interaction. Texting had unpredictable downtimes between sending and receiving text messages while the cell phone task was a continuous verbal conversation, which may provide one explanation as to why CV reactivity while text messaging did not differ significantly from driving with no secondary task. An alternative, yet plausible explanation for the lack of significant findings within the text messaging task as compared to the cell phone conversation task could be that actually talking to someone may be more emotionally charged and/or stimulating than text messaging and may have be more likely to significantly impact heart rate and blood pressure.

4.1 Strengths and Limitations

There were some notable limitations and strengths in this study. For one, the sample, while sizeable in the number of participants enrolled, was limited to a convenience sample of college students; however, there was a large age range, from 17 years to 30 years of age. Thus, it is difficult to generalize the findings from this to those who are not college students between the ages of 17 and 30 years. Driving exposure, or experience, has significant impacts on driving performance (Crundall & Underwood, 1998; Jackson, Chapman, & Crundall, 2009), especially when introducing secondary tasks (Klauer et al., 2014; Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005b); this may additionally result in differences in CV reactivity based on experience and should be examined in future studies. The heart rate monitor also had a few limitations. Heart rate measurements were taken every 15 seconds. Equipment, such as an EKG, that could analyze beat by beat heart rate and heart rate variability may be a useful assessment approach in future studies. Blood pressure was also only taken directly at the end of each task, so as to ensure that the cuff would not hinder natural, simulated driving performance. This, of course, could have led to a decline in blood pressure as time was taken in attaching the cuff to participants. There was also only one blood pressure reading, which previous studies have looked at blood pressure over time as a more valid approach (Stuivera et al., 2014).

Strengths of the study include the use of the chest strap heart rate monitor, use of naturalistic conversational questions balanced for both the cell phone and texting tasks, and use of a driving simulator. The heart rate monitor has been used in numerous fitness and cardiovascular studies (Miller et al., 2014), many of which validated the use of the equipment by using ECG as a comparator. The questions used for the cell phone and texting tasks were designed to be conversational so as to mimic what could happen in the real world which increased external validity and were balanced across both secondary tasks in topics discussed (e.g., family, friends, academics/school) and expected level of detail of responses (e.g., numeric – “how old are you?”, one word – “what is your favorite color?”, detailed, “tell me about your family”). We also used a virtual driving simulator that provided for data collection in a safe environment. Simulators have been validated as an acceptable measure of driving performance in research (Mayhew et al., 2011). We chose to use a driving simulator because it provided us with an inexpensive means with great experimental control to conduct this study. Experimental control was essential in lending strength to our study in that participants experienced the same driving conditions regarding speed limits, unexpected events, etc. so as to reduce noise that can contribute to influencing driving performance in the real world. It would be important for future research to consider whether increased cardiovascular reactivity during distracted driving increases likelihood of negative driving outcomes. Even the most technically sophisticated simulator is incapable of completely reproducing “the real world” driving experience, so the generalizability of these results may be limited. Thus, it is our recommendation that future studies include those with a naturalistic setting so as to document “real world” driving during a routine day, under actual roadway conditions.

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Conclusions

5.0 Conclusions and Future Impacts

Cardiovascular reactivity is a well-used method of measuring effort via the sympathetic nervous system. Secondary task use, particularly talking on a cell phone, while driving increases cardiovascular reactivity as measured by heart rate and blood pressure. This study demonstrates the need for more research, particularly on the long term effects of secondary tasks while driving on cardiovascular reactivity. While cardiovascular reactivity is a good measurement of effort, these findings have implications that secondary task use while driving can also, in turn, increase risk of cardiovascular disease and stroke. Future studies could use EKGs to gather beat by beat heart rate information as well as an average of numerous measurements of blood pressure, since blood pressure can fluctuate. At the same time, these studies could assess the risk associated with secondary task use while driving on developing cardiovascular disease or stroke by considering driving exposure, particularly with an older adult population that might be at greatest risk of negative cardiovascular outcomes. Education on how secondary task use while driving affects the cardiovascular system could benefit drivers of all ages and potentially help reduce the incidence of cardiovascular reactivity-related diseases.

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Figure 1.
Photograph of the STISM driving simulator

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Table 1.

Demographic characteristics of sample

	M	*SD*
Age	19.74	2.40
Years Since Driver's License	3.16	2.34
Number of Driving Days per Week	4.13	2.15
	N	%
Gender		
Female	30	50.0
Male	30	50.0
Ethnicity		
White	43	71.7
Black	14	23.3
Other	3	5.0

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Table 2.

Main effect of task of cardiovascular outcomes

	Mean	Mean Difference ± SD*
Heart rate		
No task	*82.69 ± 14.54*	*−0.58 ± 6.14*
Cell phone	*86.90 ± 15.43*	*3.13 ± 6.89*
Texting	*84.39 ± 16.67*	*0.50 ± 6.63*
Resting	*83.11 ± 14.59*	-
SBP		
No task	**116.22 ± 12.54**	**0.93 ± 8.20**
Cell phone	**118.93 ± 11.89**	**3.53 ± 8.41**
Texting	**116.83 ± 12.35**	**1.27 ± 8.21**
Resting	**115.35 ± 10.51**	-
DBP		
No task	65.30 ± 8.43	−0.27 ± 6.40
Cell phone	66.81 ± 9.15	0.97 ± 6.70
Texting	66.22 ± 8.05	0.47 ± 6.36
Resting	65.60 ± 8.39	-
MAP		
No task	*84.18 ± 9.34*	*−0.05 ± 5.65*
Cell phone	*86.58 ± 9.15*	*2.10 ± 5.52*
Texting	*85.18 ± 9.15*	*0.69 ± 6.00*
Resting	*84.28 ± 8.20*	-
RMSSD		
No task	*4.68 ± 1.96*	-
Cell phone	*5.15 ± 1.72*	-
Texting	*4.31 ± 1.35*	-
Resting	*4.18 ± 1.75*	-

Note.

*Calculated as resting – task. **Bold** is $p < 0.05$; *Italics* is $p < 0.01$