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# The impact of a naturalistic hands-free cellular phone task on heart rate and simulated driving performance in two age groups

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ABSTRACT

Heart rate and driving performance were assessed while late middle age (51–66) and younger adults (19–23) engaged in a naturalistic hands free phone task that was designed to place objectively equivalent cognitive demands on all participants. Although heart rate measures have been used in evaluating driver workload, prior studies had not compared responses in late middle age and younger adults with samples of sufficient size to begin to explore possible age relationships. In an evaluation of 37 participants, the two age groups displayed equivalent performance on the cellular telephone task and concurrent decrements in speed control (SD velocity). It was observed that the late middle age subjects drove more slowly overall and, as a group, did not demonstrate heart rate acceleration in response to the phone conversation that was seen in younger drivers. The possibility that age group differences in heart rate response are related to individual differences in attentional focus is raised. While there are significant reasons to discourage all individuals from engaging in phone conversations and other distracting tasks while driving, late middle age adults appeared as capable as young adults of managing the additional workload of a low to moderately demanding cognitive task of the type assessed. The tendency of individuals to adopt self-regulatory behaviors, such as a lower overall driving speed, as a function of age/experience may account for the equivalence in overt performance.



## 1. Introduction

The manner and extent to which cellular phone conversations, text messaging and other cognitive distractions affect driving performance remains an area of great interest. Useful meta-analyses (Caird, Willness, Steel, & Scialfa, 2008; Horrey & Wickens, 2006) and extensive bibliographies and literature reviews (AAA, 2008; Dragutinovic & Twisk, 2005; Goodman, Barker, & Monk, 2005) are available that bring together relevant research on cell phones and driving behavior. It is well established that cellular phone usage adversely impacts safety (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997; Violanti, 1998). Although, as Caird et al. (2008) point out, not all of the work on the dangers of using cell phones while driving is consistent and the extent to which the risks change with age, conversation type, etc. has not been fully characterized. The potential for decline in driving safety with advancing age is of particular concern, as it is known that older adults do not

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perform as well as younger adults when attention is divided between complex cognitive tasks (McDowd & Craik, 1988). However, the age at which declines in cognitive ability begin to impact performance is not well established and is known to vary considerably by individual. The next generation of older adults is expected to drive more frequently than previous cohorts (Bush, 2003; Coughlin, 2005). Since today's younger and middle aged drivers have more exposure to cellular technologies, we believe that with age they are more likely than their predecessors to continue using cellular phones while driving. This is potentially significant since it remains unclear how cellular phone usage impacts driving safety as a function of age.

### 1.1. Background

Results from studies conducted by Beede and Kass (2006), Horrey and Wickens (2006), McKnight and McKnight (1993), Sodhi, Reimer, and Llamazares (2002), and Strayer and Johnston (2001), clearly indicate that distinct components of cellular phone conversations (e.g., dialing and holding a phone, verbal and cognitive thought processes) significantly disrupt driving performance, and handheld and hands-free cellular telephone use has been associated with different degrees of driving impairment (Törnros & Bolling, 2005). Although Törnros and Bolling (2005) report that drivers slowed their forward velocity to compensate for the increase in cognitive workload associated with a cellular phone conversation in both handheld and hands-free conditions, the effect was more pronounced for drivers using a handheld phone. In a recent review, Ishigami and Klein (2009) note that the findings from several studies suggest that drivers tend to compensate for the potentially negative consequences of using handheld phone but fail to do so when using a hands-free cell phone. On the other hand, Patten, Kircher, Östlund, and Nilsson (2004) found that the type of conversation is "far more important" than the handheld/hands-free distinction. Beede and Kass (2006) characterize a significant decrease in driving performance with a simulated cellular phone conversation of a visuo-spatial nature. In a meta-analysis, Horrey and Wickens (2006) conclude that conversational tasks have a greater effect on cognitive or driving performance than information processing tasks. Sodhi, Reimer, and Llamazares (2002) and Amado and Ulupinar (2005) suggest that the type of and difficulty of the conversation may influence effects. Finally, Lesch and Hancock (2004) show that age and gender have different implications on confidence and the associated performance of driving while subjects were being distracted by a simulated cellular phone task.

### 1.2. Cellular phone usage and age

The results of several surveys indicate that cell phone use is lower in older segments of the driving population (McCartt, Hellinga, & Bratiman, 2006). This may, however, simply reflect the overall lower penetration/adoption of cell phone use as a function of age. Clearly it would be of interest to know, that among individuals who have cell phones, how the percentage of usage while driving varies as a function of age. As suggested already, it seems likely that individuals who grow-up using cell phones as part of their daily experience will be more likely to extend that usage into the automotive environment and remain active users as they enter late middle age.

Although several studies have investigated the effect of cellular phone conversations on driving performance of older drivers, the effect on older drivers varies substantially based upon task complexity employed in the research design. For example, using a working memory test, Alm and Nilsson (1995) reported differences in reaction time between older and younger drivers such that older drivers reacted slower with a telephone task and exhibited a large degree of variation in driving performance compared to younger drivers. In contrast, in a simulated car-following task, Strayer and Drews (2004) found an equivalent decrease in driving performance between younger and older drivers during a "naturalistic, casual conversation". McKnight and McKnight (1993), using a more demanding mental arithmetic task found that drivers over the age of fifty were a third more likely not to respond to the telephone distractions. This report is important in suggesting that, when the option is available, late middle age and older drivers may be more likely to make strategically appropriate decisions on attentional priorities.

Performance and judgment are often invoked to describe the balance of driving skills throughout the lifespan (Reimer, D'Ambrosio, & Coughlin, 2007). In novice drivers, driving performance sharply increases with experience (Williams & Ferguson, 2002). Changes in the visual, auditory and cognitive pathways suggest a slow driving performance loss among drivers in their thirties and forties (Llaneras, Swezey, Brock, & Rogers, 1993). Along with declining health, an acceleration of performance declines is observed through the fifties and sixties. This decrease in driving performance becomes apparent with increasing accident statistics observed in the seventies and beyond. On the other hand, the judgment of typical drivers increases through the lifespan. In younger cohorts, impaired judgment is largely associated with excessive speed and alcohol consumption, whereas late middle age drivers are less frequently cited for these infractions (Boyle, Dienstfrey, & Sothoron, 1998). There is evidence that many older drivers recognize deficiencies associated with aging and health status and self-regulate their behavior by limiting their exposure to situations in which they perceive excessive risk, i.e. not traveling on highways, at night or making left turns (Baldock, Mathias, McLean, & Berndt, 2006; Coughlin, Pope, & Leedle, 2006; Donorfio, Mohyde, Coughlin, & D'Ambrosio, 2008). It is also true that such self-regulation with age is not universal or always optimal. Some older drivers do continue to drive past the point when they should stop while others actually restrict their driving prematurely (D'Ambrosio, Donorfio, Coughlin, Mohyde, & Meyer, 2008). The manner and degree to which late middle age drivers self-regulate to mitigate risks are relatively unknown.

The impact of cellular telephone use is often evaluated through complex cognitive tasks. For example, Beede and Kass (2006) found the visual-spatial processes used in their conversation tasks had ‘‘a greater likelihood of competing with the cognitive resources used for driving”. In actuality, these assessment methods fail to consider that typical daily non-emotional conversations are far less taxing than complex cognitive processes. Older drivers often self-regulate by avoiding secondary tasks such as using cell phones while driving (Donorfio, Mohyde, Coughlin, & D'Ambrosio, 2008). However, studies often incorrectly assume that older cohorts would be as likely as younger drivers to partake in a complex secondary task. Although older drivers are known to avoid taxing in-vehicle conversations (Donorfio, Mohyde, Coughlin, & D'Ambrosio, 2008), we believe older drivers will be more willing in the future to participate in less taxing conversations that are typically associated with tasks of daily living. In these less taxing conversations, drivers of all ages are largely unaware of the resulting decrease in driving performance (Lesch & Hancock, 2004). As a result, drivers perceive little risk from the conversation and participate while underway.

Salthouse (1996) proposed that older adults have limited resources to perform complicated cognitive tasks and they may be particularly sensitive to the demands of simultaneous tasks (Brouwer, Waterink, Van Wolffelaar, & Rothengatter, 1991). Application of Salthouse's theory to driving performance tasks would suggest that limited cognitive resources in older adults underlie their poorer performance on multi-factorial cognitive tasks, such as driving coupled with features of a complex cellular telephone conversation. However, as suggested in the research by Strayer and Drews (2004), the workload imposed by less demanding secondary tasks, as might be seen in a more basic cell phone interaction, may well be within the capacity of most drivers across the life span, at least to the extent that the impact on performance is similar. Unfortunately, as noted by Styer and Drews, it was not possible with their protocol to assure that equivalent demands were placed on all subjects. In addition, no assessment of performance on the task was carried out to objectively determine if comparable engagement with the task was obtained in both younger and older age groups.

In this paper, we report on a comparison of driving performance in young adult and late middle age drivers in relation to a cellular telephone task during simulated driving. The task was devised to place equivalent objective demands on all participants and to allow for an assessment of performance. At the same time, it was designed to be a relatively naturalistic, low to moderately demanding cognitive task that imposed a level of workload that could be equated to a time limited, non-emotional cell phone conversation. Under these conditions, it was anticipated that performance of drivers of both age groups would be similar. In addition to assessing the impact of the secondary task on driving performance measures, a physiological index, heart rate, was recorded to provide an additional assessment of workload.

Numerous measurement techniques have been used in on-road, test track, and simulation studies to assess the impact of cognitive distractions on driving. For example, Stutts et al. (2005) used video cameras mounted in volunteers' vehicles to categorize the frequency of different types of distractions. In a field studies, (Harbluk, Noy, Trbovich, & Eizenman, 2007; Reimer, 2009; Reimer, Mehler, Wang, & Coughlin, 2010; Reimer & Sodhi, 2006; Sodhi et al., 2002; Victor, Harbluk, & Engström, 2005) demonstrated that changes in a subject's scan path can be used as a method of quantifying the impact of various cognitive tasks. Lesch and Hancock (2004) used an instrumented vehicle to assess direct measures of driving performance on a test track. McKnight and McKnight (1993) gauged subjects' responses to videotaped driving scenes while completing math operations that the authors equate to an ‘‘intense conversation”. A growing interest in the use of physiological measurements of the driver under different levels of stress or cognitive load is becoming apparent (Collet, Clarion, Morel, Chapon, & Petit, 2009; Collet, Petit, Champely, & Dittmar, 2003; De Warrd, van der Hulst, & Brookhuis, 1999; Haigney, Taylor, & Westerman, 2000; Healey & Picard, 2005; Mehler, Reimer, & Coughlin, 2010; Mehler, Reimer, Coughlin, & Dusek, 2009).

Basic cardiovascular arousal parameters, such as heart rate and blood pressure, have been shown to increase with escalating cognitive demand or workload (Backs & Seljos, 1994; Brookhuis & De Waard, 2001; Kramer, 1991; Roscoe, 1992; Veltman & Gaillard, 1998; Wilson, 2002; Wilson & Enggemier, 1991). In addition, it has been suggested that there are situations in which physiological measures may be more sensitive than traditional performance measures at detecting heightened cognitive load since motivated individuals are likely to invest additional cognitive resources to maintain a given level of performance as demands increase (Lenneman & Backs, 2009; Lenneman, Shelley, & Backs, 2005; Mehler et al., 2009, 2010). If total available cognitive resources decline with age, it might be anticipated that older subjects will be more challenged by a secondary task and consequently show a greater heart rate response. However, the regulation of physiological parameters such as heart rate and blood pressure show less elasticity, increased sympathetic dominance and longer recovery times in response to stimulation with increasing age (Jones et al., 2001; Laitinen, Niskanen, Geelen, Lansimies, & Hartikainen, 2004).

Based on work such as Brookhuis, De Vries, and De Waard (1991) and Haigney et al. (2000), there was the expectation that heart rate would increase in response to the added cognitive challenge of the cell-phone task. Research published subsequent to the initiation of this study (Collet et al., 2009) provides additional data showing an increase in heart rate during a cell-phone task. The mean age of participants in the Haigney et al. (2000) sample was 26.9 (SD = 3.1) and no analysis on the basis of age is reported. Brookhuis et al. (1991) collected data on three age groups (23–35, 35–50, and 50–65) and report no effect of age for any measures. However, their sample consisted of only four subjects in each age group and they state directly that the lack of effects could be attributed to the small sample size. Collet et al. (2009) included subjects ranging in age from 23 to 51 ($M = 35$, SD = 8.1), but their sample was also small ($N = 10$) and no age analysis is reported. Therefore, it was not well established if individuals of differing age stratifications have comparable physiologic responses to the cognitive load associated with cognitively engaging in-vehicle interactions such as cell phone conversations and appeared worthy of investigation.

## 2. Methods

### *2.1. Participants*

Two groups of subjects were recruited for this study. A younger group between the ages of 18 and 25 was recruited from postings around local colleges. The second group of subjects, over the age of 50, was recruited from the community through public postings and newspaper advertisements. All participants were required to speak English, be active drivers, and have a minimum of 1 year of driving experience. Subjects were required to read and sign an informed consent to participate.

### *2.2. Apparatus*

The study was carried out in an instrumented full cab (2001 Volkswagen Beetle) fixed base simulator running STISIM Drive version 2.05 and STISIM Open Module (Systems Technology, Inc., Hawthorne, CA). Driving performance data was captured at 20 samples per second from the original equipment manufacturer brake, accelerator and steering wheel. A front projection screen provided an approximate 40° view of a virtual environment. Force feedback was provided through the steering wheel and auditory feedback consisting of engine noise, cornering sounds and brake noise was played through the vehicle's sound system. Audio tasks and instructions were also provided through the vehicle sound system. A model SRC-2 pulse oximeter photoelectric plethysmograph sensor (Nellcor Puritan Bennett, Inc., Pleasanton, CA) was placed on each subject's left middle finger and connected to an Angilent A1 Patient Monitor to record heart rate every 20 s. A microphone located inside of the cab recorded subjects' responses to secondary tasks.

### *2.3. Procedure*

The cell-phone task that is the focus of this report was the first of four different cognitive challenges presented during the course of a longer protocol. The other tasks consisted of a portion of the Wechsler memory scale, a continuous performance task, and a multiple interference task; the complete protocol and summary results for the other tasks are reported elsewhere (Reimer, Mehler, Pohlmeyer, Coughlin, & Dusek, 2006). A schematic representation of the experimental procedure is presented in Fig. 1. A pre-experiment questionnaire was used to assess subjects' driving history, self-reported health and current medication usage. When sitting in the driving simulator, subjects were trained on how to use a simulated voice activated phone system. Subjects were then familiarized with the driving simulator though a six mile (approximately 10 min) training session designed to reduce the probability of simulator sickness by providing a graded introduction to simulated movement and scene complexity. Following this training segment, subjects were instructed to drive "as they normally would" through a validated simulation protocol (Reimer, D'Ambrosio, Coughlin, Kafrissen, & Biederman, 2006). Incentives were structured to encourage a realistic balancing of attention between the primary task of driving and the secondary tasks that included additional monetary compensation based upon secondary task performance as well as penalties for taking more than 45 min to drive the experimental portion of the simulation, for traffic violations, or being involved in any traffic accidents (Mehler, Reimer, Pohlmeyer, & Coughlin, 2008).

As noted, the components of the protocol relevant to this report are highlighted in Fig. 1 and included three equivalent 1829 m (6000 ft) segments of high stimulus "urban" driving (P1, P2, and P3) and two short 457 m (1500 ft) contiguous separators. The three periods, P1, P2 and P3, represent respectively single task driving before the phone conversation task,

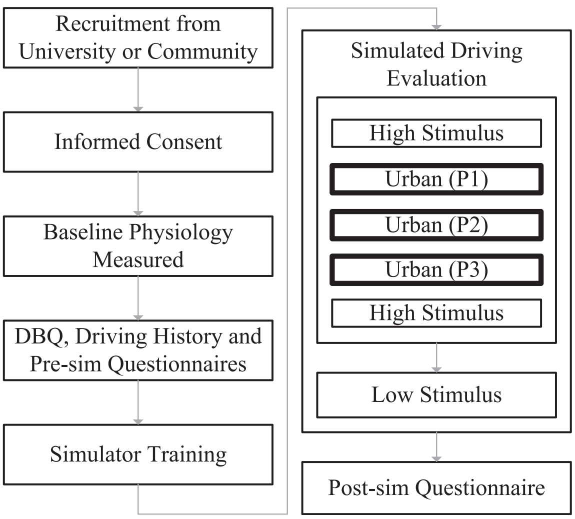


**Fig. 1.** Overview of the simulation protocol including timing of baseline physiology and a detailed view of high stimulus urban driving.

driving with the addition of the conversation task, and single task driving following the conversation task. The urban roadway had a posted speed limit of 40 kph (35 mph). During the second segment, P2, subjects were instructed to make a phone call using the simulator's voice activated phone system. The call was to a 10 digit phone number with the intent of scheduling a new appointment with ''Dr. Jesse for Thursday of next week at 3 pm''. Subjects were first required to initiate the call by saying ''dial'' and the provided number. All task instructions were pre-recorded to provide consistency. After successfully dialing or attempting to dial three times, two sets of three voice messaging prompts provided interference, i.e. ''if you are a physician press or say one'' and ''if you are calling for a referral only press or say two''. Both sets of prompts required the subject to select option three which corresponded to being a ''patient'' and ''scheduling a new appointment''. To further increase interference, the procedure included additional subject instructions to arrive early, bring an insurance card and photo identification, etc. After the three segments of interference, subjects were informed that the office was currently closed, but that appointment requests could be made by leaving ''your first name, a daytime telephone number, the doctor's last name, as well as the date and time of the appointment you are requesting''. Looping of sequences up to three times was allowed for subjects to re-acquire instructions; for example, if they ''dialed'' the wrong number.

### 2.4. Data analysis

Each subject's conversation was scored on a 10-point Likert scale, with each point associated with correct responses to some component of the conversation, i.e. recalling the phone number, doctor's name, date, etc. Subject responses were independently scored by two research assistants from an audio recording of the task. Differences in scoring between the two coders were evaluated and reconciled by the first author. Age was stratified into two groups corresponding to subjects younger than 25 and subjects older than 50. The mean and standard deviation of the driving speed were computed over a 305 m (1000 ft) uninterrupted interval in each of the periods (P1, P2, P3). Stop sign pause duration was computed for a single non-confounded stop sign that appeared 76 m (250 feet) after the end of each 305 m (1000 ft) period. Unless reported otherwise, a univariate or repeated measures GLM was completed using SPSS version 11.5 considering age as a between subject factor and period as a within-subject factor.

## 3. Results

### 3.1. Demographics

Thirty-seven subjects completed the study. Eighteen were between the ages of 19 and 23 years with an average age of 20.7 years (SD 0.9). Nineteen were between 51 and 66 with an average age of 56.3 years (SD 4.5). Ten of the younger subjects and nine of the late middle age subjects were male. Subjects self-rated their overall health on a five point ranking ranging from ''excellent'' to ''poor''; no significant difference appeared by age $F(1, 35) = 0.713$, $p > .05$. However, five of the older participants (two male) reported taking medication to control high blood pressure.

A baseline comparison of mean heart rate and systolic blood pressure of individuals who reported taking medication for high blood pressure and the remaining late middle age participants was carried out. No significant difference in mean heart rate was observed between the groups $F(1, 17) = 0.143$, $p > .05$ and, at 73.7 (SD 8.8) beats per minute, the mean heart rate for participants with a diagnosis of high blood pressure was nominally lower than the heart rate for participants without (*M* 75.8, SD 11.4). Similarly, no significant difference existed in systolic blood pressure $F(1, 17) = 2.638$, $p > .05$ with mean systolic blood pressure at 143.0 (SD 18.4) mmHg for participants with the high blood pressure diagnosis as compared to 131.4 (SD 11.9) mmHg for participants without. Therefore, high blood pressure was assumed to be under control and not included as an independent variable in subsequent analyses.

Subjects' self-reported driving history revealed that 14 subjects (seven late middle age) had been involved in one or more traffic accidents over the past 5 years. As expected with subjects who were recruited from an urban area, where frequent use of public transportation is common, driving frequently and the number of miles traveled per year increased with age (Kendall's tau-$b = -.574$ and .438, $p < .001$ and $p < .01$, respectively).

### 3.2. Secondary task performance

An analysis of accuracy (on a ten point scale) and response delay on the cell-phone task was carried-out considering the effect of gender, age group and the interaction. Consistent with prior findings (Zelinski, Gilewski, & Schaie, 1993), female participants significantly out-performed male participants with a mean score of 5.4–3.1, $F(1, 33) = 14.113$, $p < .01$. No accuracy differences appeared between age groups $F(1, 33) = 0.002$, $p > 0.05$. On the measure of mean response delay, no differences appear by gender or age, $F(1, 33) = 2.306$, $p > .05$ and $F(1, 33) = 0.264$, $p > .05$ respectively.

### 3.3. Driving performance

Table 1 displays the driving speed, standard deviation of driving speed, and stop sign pauses of the young and late middle age groups during the three testing periods, P1-P3. As observed by Beede and Kass (2006) and Strayer and Drews (2004),

**Table 1**
Mean (and standard deviation) of driving performance variables and heart rate by age group (young = 19–23 and late middle age = 51–66).

| Period | Driving speed in miles per hour and (kph) | | SD of speed in miles per hour and (kph) | | Stop sign pause (s) | | Heart rate (beats per minute) | |
|---|---|---|---|---|---|---|---|---|
| | Young | LMA | Young | LMA | Young | LMA | Young | LMA |
| P1 | 34.55 (4.83) [55.59] | 27.97 (3.40) [45.00] | 2.00 (0.91) [3.22] | 1.82 (0.89) [2.93] | 1.84 (0.61) [*n* = 15] | 2.87 (1.22) [*n* = 16] | 69.87 (9.90) | 75.68 (10.53) |
| P2 | 34.00 (5.97) [54.70] | 27.15 (5.32) [43.68] | 2.68 (1.89) [4.31] | 2.51 (1.82) [4.04] | 2.64 (1.44) [*n* = 15] | 2.58 (1.25) [*n* = 17] | 74.46 (11.88) | 75.65 (10.42) |
| P3 | 34.96 (5.02) [56.25] | 29.36 (6.47) [47.24] | 1.74 (1.02) [2.30] | 1.87 (1.16) [3.01] | 1.65 (0.61) [*n* = 14] | 2.67 (1.12) [*n* = 15] | 70.57 (10.13) [*n* = 17] | 74.27 (9.99) |

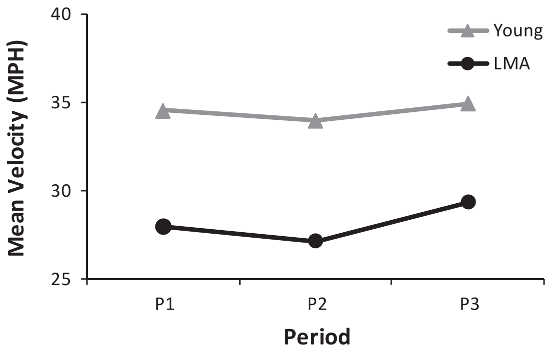


**Fig. 2.** Mean velocity by age group and period where P1 and P2 are single task driving periods and P2 is the cell-phone task.

driving speed (Fig. 2) was not impacted significantly by the secondary task (period) $F(2, 70) = 1.573$, $p > .05$. An examination of the means suggest that the effect is similar to the non-significant decrease in speed associated with the hands free conversation in Törnros and Bolling (2005). Consistent with Strayer and Drews (2004), the older subjects' average speed of 45.4 KPH (28.2 MPH) was slower than the younger participants' average of 55.5 KPH (34.5 MPH), $F(1, 35) = 20.94$, $p < .001$. These results are consistent with the position that late middle age drivers, similar to older drivers, appear to use speed as a method of regulating the demands of the driving task, with the lower speed providing more time to process and deal with unanticipated events.

The standard deviation of speed across both groups appears in Fig. 3. An analysis shows a significant effect for period $F(2, 70) = 5.834$, $p < .01$, but not for age $F(1, 35) = 0.049$, $p > .05$. Post hoc tests computed with a Bonferroni adjustment show a nominal but non-significant increase in the standard deviation of speed from P1 to P2 ($p < .10$) and a significant decrease from P2 to P3 ($p < .05$). Thus, the overall pattern is similar to the findings of Rakauskas, Gugerty, and Ward (2004) with subjects of all ages exhibiting a larger standard deviation of speed, i.e. reduced driving consistency/performance, while participating in the phone task.

As illustrated in Fig. 4, a significant age difference is evident in pause duration at stop signs $F(1, 27) = 4.773$, $p < .05$. The significant effect of period $F(2, 54) = 5.150$, $p < .01$ is best interpreted taking into consideration the significant age by period interaction $F(2, 54) = 5.310$, $p < .01$. The interaction suggests that while older subjects did not very their pauses substantially by period, younger participants paused longer while engaged in the conversation task. This result appears consistent with Beede and Kass (2006) who found an increase in pause time at stop signs for a younger population participating in a conversation. The effect suggests the possibility that younger subjects use pauses as a method of regulating the demands of the conversation on the driving task or, alternately, that they may be more distracted from the resumption of driving as compared to when they are not engaged in a phone conversation.

### 3.4. Heart rate

At baseline, older subjects' heart rate appeared marginally higher than younger subjects', with a mean heart rate of 75.3 (SD 10.6) beats per minute for older subjects versus 69.5 (SD 9.0) for younger subjects, although this difference was not statistically significant ($F(1, 35) = 3.19$, $p = .083$). While heart rate values obtained during maximum exercise clearly decline with age (Lakatta & Levy, 2003), the data on expectations for resting heart rate values are not as consistent. Reviews typically conclude that resting heart rate generally shows a decline (Anderson & McNeilly, 1991; Fox et al., 2007; Palatini et al., 2006)

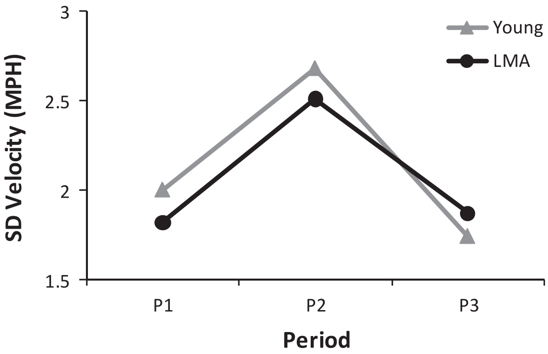


**Fig. 3.** Standard deviation of velocity by age group and period.

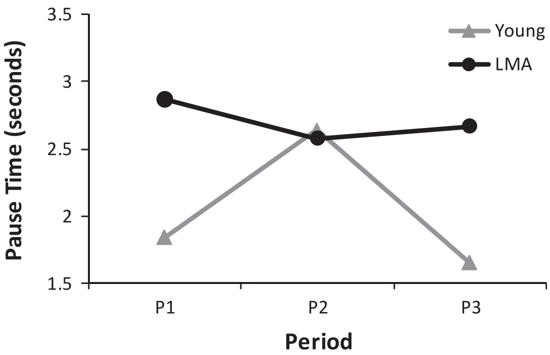


**Fig. 4.** Pause at stop signs by age group and period.

or remains essentially unchanged as a function of age (Lakatta, 1990). However, Fox et al. (2007) point to data presented by Boonemeier et al. (2003) as an example of work not supporting the position that there is a simple decline with age. Boonemeier et al. (2003) grouped subjects into decades (20's, 30's, 40's, 50's, 60's) and conducted a 24-h Holter monitoring of heart rate. Subjects were restricted to individuals who showed no signs of organic disease on the basis of medical history and physical examination. They did not find a linear correlation between age and heart rate and no significant difference in mean heart rate between adjacent decades. In fact, there was the appearance of a slight inverted-U shaped relationship with heart rate being lowest in the 20's and 60's and somewhat higher in the intermediate decades. Given that the mean age of the late middle age subjects in our sample was 56, the non-significant higher mean resting value observed may be a chance finding or may reflect the same pattern seen in Boonemeier et al.'s data.

For the sample as a whole, there was no difference in heart rate between baseline and the single task driving period immediately prior to the phone task (P1) (paired *t*-test $T(37) = -0.439$, $p > .05$). The analysis of heart rate during the three segments (P1–P3) shows a significant main effect of period $F(2, 68) = 10.578$, $p < .01$, and a significant interaction between age and period $F(2, 68) = 6.079$, $p < .01$. The interaction is detailed in Fig. 5 and shows an increase in heart rate for the younger group at P2, i.e. associated with the phone task. In contrast, the older group shows little change in heart rate across the three periods. Conducting the analysis without the five older participants reported taking medication for high blood pressure does not impact the significance of either the main effect or the interaction. Therefore, neither high blood pressure nor associated medications appear responsible for the differences seen in heart rate response between the age groups.

A secondary analysis compares heart rate during the first and second half of each period. As expected, no significant difference in heart rate occurs by half in P1 and P3. However, during the phone task (P2) a significant effect of half ($F(1, 35) = 19.838$, $p < .01$) is associated with heart rates towards the start of the conversation being higher than at the end. A marginal interaction between age and period $F(1, 35) = 3.902$, $p = .056$ suggests that young adults participants recover more quickly from the increase in workload, i.e. dropping from 77.3 (SD 13.5) to 72.2 (SD 11.4) beats per minute as compared to late middle age participants dropping from 76.7 (SD 10.7) to 74.7 (SD 10.4) beats per minute.

### *3.4.1. Heart rate and age – a post hoc consideration of physiological response style*

As described above, the mean heart rate difference between the age groups is consistent across the baseline and initial simulated city driving task (P1) periods, with late middle age drivers showing a 5.8 beats per minute higher average for both periods. However, in response to the cell task, the younger drivers showed a marked increase in heart rate of 4.6 beats per

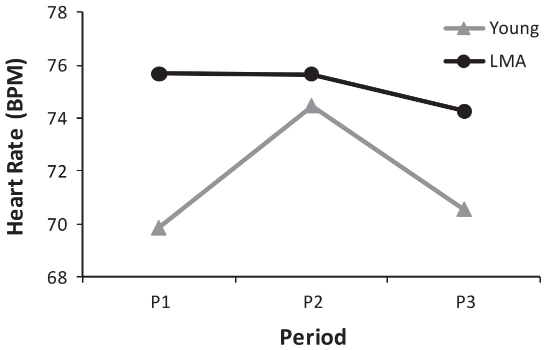


**Fig. 5.** Heart rate for young and late middle age (LMA) subjects where P1 and P2 are single task driving periods and P2 is the cell-phone task.

minute compared with an apparent lack of change in heart rate in the late middle age group (Fig. 5). Several factors seem reasonable to consider in interpreting the lower reactivity. For example, older individuals are known to show somewhat lower physiological reactivity to stressors (Faucheux et al., 1989; Furchtgott & Busemeyer, 1979; Riege, Cohen, & Wallach, 1980), particularly in heart rate, possibly due to diminished dynamic range in the cardiovascular system as a consequence of aging. In addition, heart rate generally follows Wilder's (1967) law of initial values which predicts an inverse relationship between the pre-stimulus level of a physiological parameter and the magnitude of the response to a stimulus. Since the late middle age drivers' heart rates in the sample were already elevated compared to younger drivers, their absolute increase in heart rate in response to an arousal stimulus might be expected to be lower. However, neither of these considerations seems sufficient to explain a complete absence of a heart rate arousal response to the cell-phone task by the late middle age drivers. In fact, as we reported previously (Reimer et al., 2006), the late middle age driver sample showed a slightly larger increase in heart rate than the younger group (2.8 versus 1.2 bpm) from the resting baseline to an initial single task driving period prior to the start of the urban scenario in which the cell-phone task was presented, suggesting that they were capable of cardiac acceleration in the overall experimental environment.

An alternative approach to considering the heart rate data is to set aside a unidirectional arousal model and ask instead if there might be individual patterns of physiological response to the demands of the cell-phone task that are being obscured by simply looking at the mean values obtained by grouping drivers into the younger and older age categories. As noted previously, heart rate generally increases with arousal and workload. However, there are cognitively demanding situations where heart rate may increase or decrease, possibly depending on how attention is directed or allocated. It has been suggested that heart rate deceleration is associated with an attentional state involving the intake of environmental stimuli (a broad ranging external focus) while heart rate acceleration may be related to an attentional style that involves selectively ignoring or rejecting input that may be disruptive or distracting to a focused cognitive task (Lacey & Lacey, 1974; Lacey, Kagan, Lacey, & Moss, 1963). While the Laceys' proposition that these differential cardiac patterns directly modulate central attentional processes has been critically challenged (see Carroll & Anastasiades, 1978; Green, 1980 for reviews), the fundamental observation that decreases in heart rate occur in numerous experimental tasks involving attention to environmental stimuli is well established (McCanne & Lyons, 1990; Sandman & Walker, 1985). In the complex demand environment of driving a car in a stimulus dense city environment and simultaneously engaging in the cell-phone task, it seems reasonable to suggest that individuals may differ in how they direct their attention in managing these competing demands. Such differences in response style may be reflected in different patterns of cardiovascular reactivity.

**Table 2**
Mean heart rate (and standard deviation) by age group and response style.

| | Physiological response style | | | | | |
|---|---|---|---|---|---|---|
| | HR deceleration (Intake) | | No change | | HR acceleration (rejection) | |
| | Young ($n$ = 2) | LMA ($n$ = 2) | Young ($n$ = 4) | LMA ($n$ = 15) | Young ($n$ = 12) | LMA ($n$ = 2) |
| Baseline | 80.2 (4.7) | 84.7 (10.6) | 66.8 (6.7) | 73.8 (10.5) | 68.6 (9.3) | 77.0 (11.8) |
| P1 | 76.5 (5.0) | 83.6 (6.4) | 66.0 (5.2) | 74.2 (10.8) | 70.1 (11.3) | 79.1 (11.6) |
| P2 | 70.3 (0.9) | 80.2 (7.8) | 67.4 (5.6) | 74.1 (10.6) | 77.5 (13.4) | 82.7 (12.3) |
| P3 | 75.9 (5.3) | 79.1 (7.1) | 65.1 (5.2) | 73.3 (10.6) | 71.6[a] (11.6) | 76.9 (10.0) |

[a] *Note*: In this cell $n$ = 11.

With this perspective in mind, an examination of the change in heart rate from period P1 (driving) to P2 (driving and cell-phone task) in individual subjects was carried out. This review showed a wide range of individual responses, with heart rate increasing as much as 18 beats per minute (bpm) in one driver and decreasing by 9 bpm in another. Table 2 shows mean heart rate values by age, period, and by sub-grouping drivers by whether they show a decrease in heart rate (a drop of 2 bpm or greater) from P1 to P2, minimal change (less than ±2 bpm), or an increase (2 bpm or greater). For descriptive purposes, the decrease pattern is labeled as an "intake" response style and the increase pattern as a "rejection" response style. When heart rate data by period is categorized in this manner, it can be seen that all three heart rate reaction patterns appear in both the late middle age and younger drivers. The heart rate decrease pattern is present in four participants (2 older and 2 young drivers), minimal change in nineteen (15 older and 4 young), and the heart rate increase pattern in fourteen (2 older and 12 young) participants. Other than having consistently higher heart rates, what differentiates the late middle age and younger drivers is not so much a specific pattern of response to the cell-phone task but the relative distribution of individuals showing each of the three patterns.

## 4. Discussion

This study compared young adult and late middle age individuals on performance variables and a physiological index of arousal (heart rate) during a simulated driving scenario that included a hands-free cellular telephone task involving a level of cognitive workload that could be considered "typical of daily life" activities. Although past research has investigated differences in the effect of cellular phone tasks on younger and older drivers (Alm & Nilsson, 1995; McKnight & McKnight, 1993; Strayer & Drews, 2004), only Strayer & Drews focused on a "naturalistic" conversation that included topics "of interest to the participant". While age differences are well documented in situations involving complex task performance (McDowd & Craik, 1988), an important implication of Strayer & Drews' study was that such performance differences may not be present under less demanding conditions that may characterize many cell phone conversations. However, as they point out, their study design was limited in that subject engagement and performance on the task was not objectively assessed. In addition, they could not confirm that equal demands were placed on all subjects. This study addresses these issues and found that younger and late middle aged subjects did not differ significantly in meeting the performance demands of the cell-phone task either in accuracy or response delay. This confirms our hypothesis that basic performance on a task modeling a non-emotional, naturalistic conversation typical of daily life does not vary with the age groups studied. This finding supports our belief that these more naturalistic tasks do not demand the level of cognitive resource investment associated with tasks typically employed in studies demonstrating age related differences in task performance.

In a manner that is consistent with previously observed age-related changes in driver judgment, late middle aged subjects drove slower overall and, under single task load, paused for longer periods at stop signs than younger participants. As hypothesized, the added demand of the cell-phone task impacted driving performance of both the younger and the late middle age subjects as measured by an increase in the standard deviation in driving speed. In line with Strayer and Drews' findings for younger (ages 18–25) and older (65–74) adults, the impact on this performance measure during simulated driving was equivalent in our subjects for younger (18–23) and late middle age (51–66) drivers. Interestingly, the age by period interaction on stop sign pauses shows only the younger drivers increased their pause time while engaged in the conversation task, bringing them into the same pause range shown by older drivers throughout the driving task. These longer pauses at stop signs appear consistent with results from a study of younger drivers by Beede and Kass (2006). The finding that younger drivers increase their pause times during the conversation period could indicate that the demands of the task cause them to appropriately self-regulate by adopting the longer pause period typical of more experienced drivers. Alternatively, the increased pause period may indicate greater diversion of attention from the overall driving environment during the conversation by the younger drivers. In either case, the impact of the late middle aged subjects' conversations on surrounding traffic congestion due to increased pause time at intersections would be minimal as compared to that of the younger participants.

The impact of a secondary task such as a cell phone conversation on other components of traffic flow appear to be dependent, as would be expected, on the total cognitive load placed on the driver. The traffic density in our scenario was low enough that participants were able to reasonably set their speed of travel at a rate as desired. Under these conditions, both the younger group and the slower driving late middle age drivers, showed a nominal and non-significant compensatory slowing of driving speed during the cell-phone task. Cooper, Vladisavljevic, Strayer, and Martin (2008) simulation study with younger drivers found that a naturalistic hands-free cell-phone task did not significantly impact driving behavior under low density conditions but did result in lower overall mean speed and travel time under medium and high density driving conditions.

Heart rate acceleration can be seen as evidence of an arousal response to increased workload (Backs & Seljos, 1994; Brookhuis & De Waard, 2001; Kramer, 1991; Mehler et al., 2009; Mehler et al. 2010; Reimer, Mehler, Coughlin, Godfrey, and Tan, 2009; Roscoe, 1992; Veltman & Gaillard, 1998; Wilson, 2002). An increase in heart rate might then be reasonably taken as an indicator that an individual's capacity to respond to additional or unexpected events in the driving environment may be compromised or reduced since such arousal suggests that some portion of their remaining spare capacity has already been engaged. Consistent with our second hypothesis, an overall effect of period shows that heart rate increased with the phone conversation task. However, the age by period interaction shows that the heart rate acceleration was limited almost entirely to the younger subject group (Fig. 5). This apparent discrepancy, in which younger subjects show a decrease in speed control, longer pauses at stop signs, and heart rate acceleration in response to the cell-phone task, while the late middle age drivers showed the same decrease in speed control but no significant shift in heart rate or pause time, bears a striking parallel to an observation by Strayer and Drews. They stated that the overall effect of younger drivers' conversations on the cell phone was to make their average reactions equivalent to those of older drivers not engaged in the task. In our study, the added load of the cell-phone task resulted in younger drivers increasing their heart rate and pause time to bring them into the same range as that displayed by late middle aged drivers during both single task driving and during the additional load of the cell-phone task. It is interesting to speculate as to whether the heart rate difference is due to an age related difference in cardiovascular reactivity or if the overall pattern of reactivity (or lack thereof) suggests differences in how attention is being allocated or managed among tasks in the younger versus late middle aged drivers.

While this is speculative, the anecdotal observation can be made that many younger individuals who have grown-up with cell phones show a greater tendency to give precedence to attending to the cell phone over the broad attention demands of the driving situation. Older adults who learned to drive prior to the introduction of cell phones may be more likely to adopt a wider sensory scan during the driving task as opposed to directing their focus primarily on the cell-phone task. A potentially important component of the appointment scheduling phone task used in this study is that it allowed subjects a degree of self-pacing in the initiation of the call, response to the menu selections presented by the task, etc. This means that participants had some leeway in the extent to which they gave precedence to the phone task over driving while still remaining engaged with both. This is a potential contrast to surrogate tasks requiring immediate response to stimuli presented at fixed rates. As described earlier, heart rate deceleration has been associated with generalized sensory intake as opposed to heart rate acceleration which has been associated with selective attention to one task and a blocking out of distracting information from other sources (see also Mehler et al., 2008 for additional background). From this perspective, it may be that the relative absence of the cardiac acceleration response style in the late middle age drivers may reflect a broader sensory intake strategy that is a product of an age related strategy for balancing attention.

As described in the results section, it is striking that the comparison of group means showed an apparent total lack of heart rate response to the cell-phone task in the late middle age group. A more detailed analysis that looks for the presence of individual patterns of response to the cognitive challenge (heart rate increase, no change, decrease), presents a picture that is both more reasonable and potentially more interesting for examining how individual differences and age interact to produce the observed mean group results. The heart rate style analysis shows that there are subgroups of both younger and late middle age participants that react physiologically to the conversation in similar ways. As stated earlier, what differentiates the younger and late middle age drivers is not so much a specific pattern of physiological response to the task but the relative distribution of individuals showing the heart rate increase pattern. If, as suggested by Lacey and Lacey (1974) and others (Sandman & Walker, 1985), heart rate acceleration/deceleration are markers of differences in how individuals are attending to the environment, this is particularly relevant. Unfortunately, the stratification of the current data by style and age (Table 2) results in cell sizes that are too small to examine statistically the relationship between response style and driving performance independent of the association with age. Follow-up with a larger sample is indicated to further investigate the patterns that may appear in response to this task.

### 4.1. Conclusions

In conclusion, if late middle age adults appropriately manage overall demands by self-regulating their behavior, such as driving slower as observed in this study, and by only partaking in low demanding conversations and avoiding complex ones, these results suggest that cellular phone conversations will not impair their performance any more than that seen in younger drivers. Given the parallels between our findings and those of Strayer and Drews, it may well be that the same holds true for healthy older drivers, although additional research with older individuals will be required to establish if this is the case. However, nothing in these findings should detract from the fact that engaging in a secondary task such as a cellular phone conversation does divide attention and drivers of all ages need to be mindful of the conditions under which it might be considered appropriate to utilize a phone while driving and the importance of limiting the level of demand or absorption engendered by a conversation. An unknown percentage of cellular phone conversations are likely to involve higher attentional demands than those studied here, particularly those with significant emotional content. In light of this, the results presented in this work should be balanced with findings from studies involving higher attentional and emotional demands in the development of appropriate policy on the use of cellular and other in-vehicle technologies.

This study illustrates the need for additional research in the area of cognitive distraction of varying levels of demand during driving. Previous studies of cellular telephone conversations and similar cognitive distractions have largely involved complex cognitive tasks with relatively high resource demands. The work considered here suggests that the results of studies based on such tasks may overestimate likely changes in driving performance, particularly for older drivers, as compared to less demanding tasks that may be more typical of many cellular phone conversations. At the same time, it is important to consider that even low to moderately demanding cognitive tasks that do not result in overt decrements in driving performance, such as lane keeping, may still impact critical aspects of visual attention and reaction times (Recarte & Nunes, 2003; Reimer, 2009; Strayer & Drews, 2004). Future efforts may better characterize changes by developing an understanding of how incremental increases in task difficulty and potential attentional absorption impact overt performance as well as more subtle measures of attention and capacity across different age groups (Reimer et al., 2010). We suggest that there is important insight to be gained by all drivers from the observation of those older drivers who appropriately self-regulate their driving behaviors to compensate for declines in functional capacity. At the same time, drivers of all ages may benefit from education about the dangers involved with the attentional demands associated with cellular phone conversations and the importance of regulating their behavior appropriately.

### 4.2. Limitations

A number of limitations should be recognized in this study. First, while the sample size is respectable compared to many simulation studies, it is comprised of a relatively small number of subjects and replication with a larger sample, particularly in the exploratory investigation of response subtypes, is clearly desirable. The younger subjects represent a fairly restricted age range around 21 and were less frequent drivers as compared to the late middle age sample. We did not assess and control for possible differences in experiences and frequency of cellular phone use while driving across the age groups, although the performance of the older drivers on the task indicates that any difference that may have existed did not impact the basic task. Additionally, the study was conducted in a driving simulator; it remains to be established as to the extent to which behavior on this task during driving simulation is a valid model for behavior during on-road driving (Wang et al., 2010) or for actual cell phone use. The Angilent monitor limited us to the collection of averaged heart rate values, thus not supporting individual beat by beat analysis or providing the ability to review records to adjust for artifact beyond the built-in capacities of the unit. Based upon subsequent work with instrumentation providing continuous recorded tracings and simultaneous photoelectric plethysmograph and EKG signals, we have found a distinct advantage in signal quality using the EKG methodology in dealing with movement artifact that can be present in the active driving context. It is also recognized that monitoring heart rate alone limits the ability to make inferences about a subject's state of arousal (Mehler et al., 2008). The lab has since upgraded to instrumentation supporting high resolution EKG recording in combination with electrodermal monitoring to address these latter issues (Mehler et al., 2009; Reimer et al., 2009).

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