

## **The association between heart rate reactivity and driving performance under dual task demands in late middle age drivers**

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**Abstract** - Physiological indices of arousal generally increase when heightened demands are placed on an individual's cognitive resources. As a consequence, measures such as heart rate are frequently used as one method of assessing changes in workload. In a simulation study with young adult (19-23 yrs.) and late middle age (51-66 yrs.) drivers, heart rate responses were compared during a variety of dual task conditions along with driving and task performance data. During two of the tasks in which younger participants showed significant heart rate acceleration, older drivers, as a group, showed little or no change in heart rate. In this paper we present data on a more detailed analysis of the relationship between heart rate change and performance during one of the dual load conditions, a continuous performance task (CPT). The sample was subdivided into individuals who showed a substantive heart rate acceleration response during the task vs. those who showed little change or heart rate deceleration. Of the 18 younger and 15 older adults in the analysis, 56% of the younger and 27% of the older individuals fell into the heart rate acceleration category. Heart rate response did not correlate with performance on the CPT in the younger subjects. In the older subjects, however, the heart rate acceleration group scored significantly higher on the CPT than those who did not exhibit a pattern of heart rate acceleration. In addition to lower performance on the CPT task, older adults in the non-acceleration group showed a significant drop in driving speed, which is generally interpreted as a compensatory response employed to manage total workload. Overall, the late middle aged drivers who showed a heart rate accelerative response during the CPT task performed better on both the primary and secondary tasks than those that did not. The increase in heart rate in the late middle age drivers in this instance could serve as marker for a variety of important performance mediating variables including relative engagement in the task, availability of resources to invest in the dual tasks, attentional style, or overall flexibility of response. The results suggest the potential value of looking at differences in individual patterns of response in driving behavior studies in addition to overall group behavior. The presence of subtypes of heart rate responders, and the observed performance differences between subtypes in this paradigm, illustrate the importance of these considerations. Other heart rate patterning data from the literature is considered and suggestions for future investigation offered.

**Keywords** - *Heart Rate Acceleration / Deceleration, Cognitive Performance, Dual Task, Workload, Attentional Demands, Distraction, Driving Performance, Age*

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## 1. Introduction

The overt physical demands of driving have decreased significantly since the introduction of the early automobiles at the start of last century. Sheltering the driver from the elements in an enclosed cab, the development of automatic transmissions, power steering, power brakes, etc. have in many ways reduced driving to a seemingly leisurely task. In contrast, attentional demands on the driver have increased dramatically with the advent of higher driving speeds, crowded highways, and stimulus dense urban environments. The growing proliferation of in-vehicle devices such as cell phones, multi-function entertainment systems and advanced navigation aids further increases the mental load on drivers [1]. As a consequence, the workload associated with modern driving has shifted significantly from the physical to the mental domain. While these increased demands can be expected to affect everyone, the impact on the older driver is of particular interest since one's capacity for managing multiple tasks simultaneously is known to generally decline with age [2], [3]. Specifically addressing in-vehicle information systems (IVIS), Merat, Anttila and Luoma [4] note that while these systems are intended to increase road safety, the design of such systems generally do not take into account special needs or limitations associated with older drivers. Increasing our understanding of how older individuals deal with the attentional and mental processing challenges of modern driving may contribute to our ability to improve the functionality and safety of this environment as well as having applications in other domains.

Toward this end, we presented younger and older individuals with a range of cognitive performance tasks in a simulated driving environment and compared their behavior under single task (driving only) and dual task (driving plus a secondary cognitive task) conditions [5]. We found that younger and older drivers showed similar performance on easier cognitive tasks while younger drivers performed significantly better on the harder cognitive tasks. Driving speed tended to decrease during dual task conditions for both groups and older drivers drove slower overall. The latter finding is consistent with the position that moderation in driving speed is one strategy for managing workload [6]. As a group, older drivers appear to apply this coping mechanism to the demands of both basic driving and to the additional challenge of a secondary task. This compensatory strategy may be best considered a form of self regulation [7], a general behavior pattern often observed in older adult drivers such as avoiding driving at night to compensate for declining night vision.

In addition to considering vehicle control variables and cognitive task performance, we monitored heart rate. Heart rate has been used as a measure of mental workload in on-road and simulator based driving research [8], [9], [10]. A detailed consideration [11] of one of the cognitive tasks, a simulated cell phone conversation, showed a significant increase in heart rate in younger drivers during the task (mean increase of 4.6 beats per minute) (see Figure 1). This increase is consistent with a state of heightened activation to deal with the elevated workload. Interestingly, mean heart rate for the older driver group did not change during the phone task. A lack of physiological response might indicate a failure to engage in the task. However, performance scores for the task were essentially equal for both younger and older drivers. Given that their performance was equivalent, it seems reasonable to assume that both younger and older subjects were investing mental resources in the task and lack of engagement could not explain the difference in physiological reactivity.

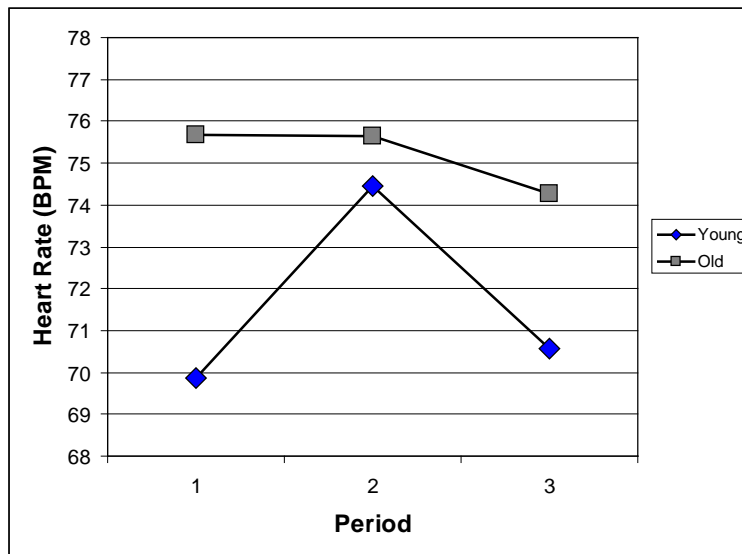
*Differential Heart Rate Reactivity by Age Group*

Fig. 1 - Mean heart rate by age group before, during and after a secondary cognitive task (simulated cell phone conversation) [11]

Older individuals are known to generally show somewhat lower physiological reactivity to stressors [12], [13], particularly in heart rate; this is most likely due to diminished dynamic range in the cardiovascular system as a consequence of aging. However, significant heart rate accelerations in response to cognitive challenges are still observed in healthy older adults [14]. It is also established that heart rate generally follows Wilder's [15] *law of initial values* which predicts an inverse relationship between the pre-stimulus level and the magnitude of response to a stimulus. Since the late middle age drivers' heart rates 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. Neither of these considerations, however, seems sufficient to explain a complete absence of a heart rate arousal response to the cell-phone task by the older drivers. In fact, as we reported previously [16], the late middle age driver sample showed a slightly larger increase in heart rate from baseline to the initial single task driving period than the younger group, suggesting that they were capable of comparable cardiac acceleration.

An examination of individual records revealed that, in both the younger and the older groups, there were some subjects who showed a heart rate increase in response to the task, some who showed essentially no change, and others that showed a drop in heart rate during the task [17]. In the case of the older driver sample, the relative distribution of individuals showing each of the three response styles (increase, no change, decrease) essentially cancelled each other out, producing no net change in the group average. In the younger sample, all three response styles were present but the cardiac acceleration pattern appeared in two thirds of the drivers, producing an overall elevation in the group mean. Therefore, what differentiated the younger and older driver samples was not an overall lack of response in the older drivers, but rather a difference in the relative proportion of individuals showing the heart rate increase pattern versus those who showed little change or an actual decrease in heart rate.

This observation raised the question of whether this differential distribution of physiological response styles is merely a reflection of the normal aging process producing a higher percentage of individuals showing a less flexible, less reactive cardiovascular response, or might it highlight particular characteristics of how some older drivers attempt to deal with the demands of multiple tasks while driving? The present paper examines data from an auditory continuous performance task (CPT), presented during the same protocol, to further investigate the value of sub-grouping drivers according to their heart rate response to a dual task condition. There were several reasons for assuming that the CPT component of the study might prove more sensitive for detecting subtle individual differences. First, performance scoring for the cell phone task had a restricted range of values, limiting discrimination. Second, the driving environment where the cell phone task was presented consisted of city blocks where drivers were interpreted by a series of stop signs. These breaks in flow, coupled with a low to moderate speed limit, reduced the variability in driving speed between participants. In contrast, the CPT had a wider range of scores and driving took place in a highway environment that allowed a wider velocity range. It was anticipated that these conditions would allow finer discrimination of the associations between heart rate response patterns and performance measures.

## **2. Methods**

### *2.1. Participants*

Participants were recruited from the community in two age groups, younger drivers between 18 and 25 and late middle age drivers between 50 and 70 years of age. All participants were required to be active drivers with a minimum of one year of driving experience and be able to speak English fluently. Each subject was required to complete an informed consent approved by the local institutional review board.

### *2.2. Apparatus*

The study was completed in the MIT AgeLab driving simulator, "Miss Daisy". The simulator consisted of full cab 2001 Volkswagen Beetle situated in front of a projection screen that provided an approximate 40 degree view of a virtual roadway. The drivers' speed was displayed through the vehicles speedometer and synchronized with the flow of the virtual world. Data was captured at a minimum of 20 samples a second from the original equipment manufacturer brake, accelerator and steering wheel. Data capture devices were connected to a personal computer running STISIM Drive version 2.05 and STISIM Open Module (Systems Technology Inc., Hawthorne, CA) that computed graphical updates of the road geometry. In addition to the visual update, auditory feedback comprised of engine noise, cornering sounds and brake noise was played through the vehicle's sound system. A model SRC-2 pulse oximeter photoelectric plethysmograph sensor (Nellcor Puritan Bennett, Inc., Pleasanton, CA) was attached to participants' left middle finger and connected to an Agilent A1 Patient Monitor to record heart rate every 20 seconds.

### *2.3. Secondary Cognitive Task*

During a portion of the simulation consisting of highway driving, a working memory component of a continuous performance task [18] (CPT) was presented as a secondary task to increase workload. This version of the CPT [19] required subjects to listen to a series of letters presented at approximately one second intervals over the simulator's auditory feedback system. Subjects were to respond to the letter "A" if, and only if, it was preceded by a "Q" separated by 3 letters (e.g. QrctA). If the target "A" appeared in the correct position, they were to respond by saying the word "check". Free standing Q's and A's were periodically inserted into the sequence as distracters, requiring an accurate count to avoid false positives. Participants' responses were recorded for later scoring.

### *2.4. Procedure*

After receiving an overview of the entire procedure and signing an informed consent, subjects completed a questionnaire that measured self-reported health and driving patterns. Subjects were then seated in the driving simulator, asked to adjust the seat for comfort and to familiarize themselves with features of the simulator such as the rear view mirror, the accelerator and brake pedal. Participants were then instructed to drive a six mile (approximate 10 minute) virtual two lane roadway with a gradual increase in speed limit and visual complexity. The habituation period was designed to improve participants comfort in adjusting to unique sensations associated with driving a simulator. Subsequently, subjects were instructed to drive "as they normally would" through a simulation that has been demonstrated to show correspondence between self-reported behaviors and actual driving behaviors [16]. Before beginning a driving segment, participants were reminded that in the case of discomfort they were to immediately alert the research associate.

In addition to receiving \$10 for participating in the study and up to \$20 for travel expenses, participants were informed that up to an additional \$30 would be provided based on their performance. This financial incentive was intended to motivate a more realistic balance of the conflicting requirements of the experiment [16]. Participants were instructed that they would receive a small amount of money for each correct response to a set of secondary tasks up to a total of \$10, would be penalized \$1 out of an allocated \$10 for each minute taken over 45 minutes to complete the simulation, and that additional deductions out of an allocated \$10 would be made as penalties for receiving traffic violations or being involved in a collision.

The financial incentives were implemented in order to encourage in the simulation a balancing of demands more in line with those experienced when driving a real vehicle. It is important that the physical safety of a driving in a simulated environment should not encourage participants to drive in a more risky manner than they would outdoors. Therefore, traffic violations (e.g. speeding, passing stop signs) and accidents were penalized financially. It was also recognized that the reduced level of sensory feedback present in a static simulation as compared to that experienced on the road, diminishes sensations associated with changing driving speeds. In some individuals this can potentially result in slower average velocities. By charging \$1 for each additional minute (over 45 min) over the entire simulation, subjects were motivated to pay more attention to maintaining travel near the posted speed limits. In order to ensure secondary task commitment, cognitive task performance was also rewarded with monetary

incentives. Dual-task performance was therefore assumed to be the combined result of an individual's task prioritization and resource allocation among tasks, and not biased toward simply focusing on a financially rewarded driving task.

The driving protocol included a number of different driving environments and secondary tasks, for a complete overview see Reimer, Mehler, Pohlmeier, Coughlin, & Dusek [5]. The focus in this paper is on a section of simulated highway driving that appeared after about 50 minutes of driving (experiment plus training). The visualization presented to the driver was limited to the two travel lanes of the highway. The highway was divided into three approximate two and a half mile segments corresponding to the periods before, during, and after the presentation of the CPT. The length of the CPT was adjusted such that all participants, regardless of driving speed, were engaged in the task for the duration of the a two and a half mile assessment interval. The three segments were separated by a buffer approximately one mile in length that included a construction zone. The speed limit was posted as 65 MPH at the start of each of the three segments.

## *2.5. Data Analysis*

### *2.5.1. Scoring for CPT*

The measure of cognitive performance on the CPT was scored as the percentage of correct responses less false identifications. A percentage calculation was used since the total trials presented varied slightly between individuals depending on their driving speed over testing interval in the simulation.

### *2.5.2. Driving Performance*

Driving performance on the simulated highway segment was assessed in terms of driving speed (velocity) and the variation of speed control. To accommodate for sample size difference in the time domain recordings over a fixed route length, the driving performance measures were averaged over 25 foot segments of roadway before computing summary statistics. In order to control for possible confounding effects arising from participants driving at different velocities, we calculated the coefficient of variation as a measure of variability. This coefficient takes the individual mean into account by normalizing the standard deviation to the mean value. The linear transformation of multiplying the quotient by 100 results in the report of the coefficient as a percentage of absolute variability.

### *2.5.3. Physiological Response Style*

The classification of subjects based on heart rate response to the dual task condition was exploratory in nature and carried out post-hoc. In our analysis of the cell phone task [17], subjects were classified as showing an acceleratory pattern if their mean heart rate increased by at least 2 heart beats per minute (bpm) during the dual task period (driving plus CPT) relative to the preceding single task period (driving only). Dividing the remaining subjects into limited change (less than +/- 2 bpm) and heart rate decrease (drop greater than 2 bpm) categories was useful for examining the relative distribution of response patterns but produced cells that were too small for statistical analysis of possible performance relationships. For purposes of the current analysis, we decided to categorize

all subjects with heart rate responses less than 2 bpm into a single “no acceleration” group.

#### 2.5.4. Data Screening & Subgroup Classification

A total of 38 participants were enrolled in the study. In the original analysis [5], one subject was excluded due to a technical problem that resulted in incomplete driving performance data. One was excluded due to the observation that she failed to engage in some of the secondary tasks. A final individual was excluded due to a technical problem that resulted in missing heart rate values during portions of the protocol. The latter case was added back into the current data set as all relevant heart rate data for the portion under consideration was available. Post-hoc classification of the remaining set of 36 participants based on their heart rate response into the less than 2 bpm (no acceleration) or the 2 bpm or greater (acceleration) categories led to the following distribution: twenty two subjects (8 young and 14 older adults) fit the no acceleration style, while fourteen participants (10 younger, 4 older) fell into the acceleration style.

Given the small sample size and consequently high sensitivity to distortion by extreme values, additional screening was then carried out to identify outliers [20]. The driving and task performance variables were z-transformed. Cases with z-values greater than |3| were classified as outliers and excluded from any further analysis. This resulted in the identification of two older adults with extremely low scores on the cognitive task. The level of performance in these individuals, was essentially at the level of chance and suggested effective non-engagement with the task. Both cases were in the “no acceleration” grouping. An additional older participant differed notably in her driving behavior (extremely reduced velocity and high variability of speed control); she was also in the “no acceleration” category.

The result of the outlier removal was a reduction in 3 cases of late middle aged adults in the non acceleration category. This resulted in a final classification based on heart rate response of nineteen subjects (8 young and 11 older adults) who were categorized as non-accelerators and fourteen participants (10 younger, 4 older) who were categorized as showing a marked increase in heart rate under the dual-task condition (see Table 1). An effect of the outliers on the group heart rate data was evident but relatively modest as can be seen by comparing Figures 2 & 3. Dropping the three cases raised overall heart rate for the late middle age drivers by approximately 1 bpm. Prior to outlier removal, the older drivers showed a mean increase in heart rate from single task driving to the dual task condition of 0.23 bpm (SD= 1.91). In comparison, the mean increase for the younger drivers was 3.14 bpm. When the outliers were removed, the heart rate change for the older drivers increased slightly to 0.61 bpm (SD= 1.77).

#### Heart Rate Response to Dual Task Loading

	No Acceleration	Acceleration
Younger	8	10
Older	11	4

Table 1. - Distribution of individuals classified as showing an acceleration pattern (increase  $\geq 2$  bpm) vs. a nominal change or decrease ( $< 2$  bpm) in heart rate.

*Heart Rate Reactivity in Original Sample*

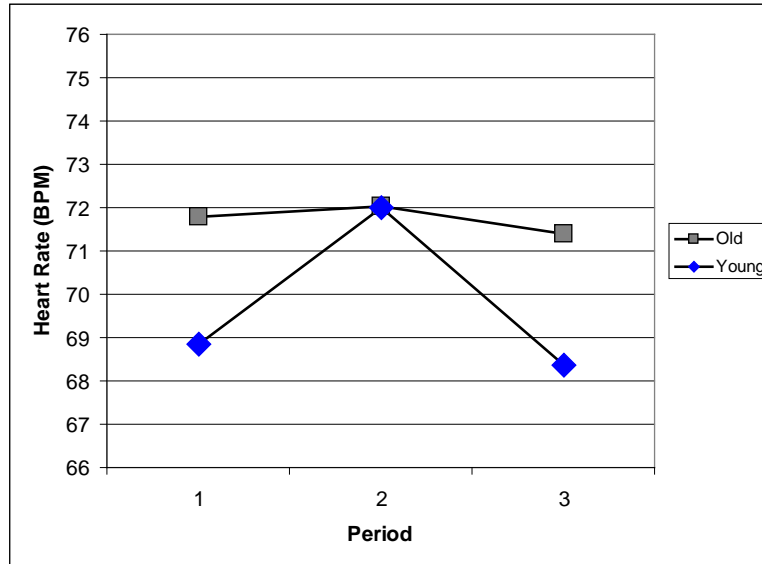


Fig. 2 - Mean heart rate by age group before, during and after the secondary cognitive task (CPT)

*Heart Rate Reactivity in Adjusted Sample*

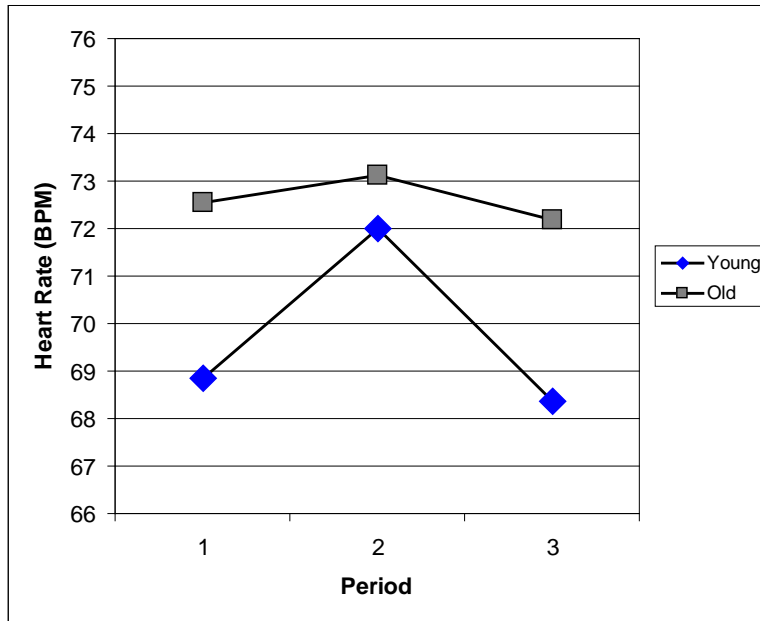


Fig. 3 - Mean heart rate by age following removal of performance outliers.



### 2.5.5. Statistical Analysis

A univariate 2 (age group; under 25 vs. over 50 years) x 2 (response style; no acceleration of heart rate under dual-task vs. acceleration) analyses of variance (ANOVA) was carried out using SPSS version 11.5 [21] for the cognitive measure. For the driving variables, the design was a 2 (age group) x 2 (style) x 3 (period; before, during, and after dual-task) factorial design. Mixed ANOVAs with age group and style as between-subjects factors and period as within-subject factor analyses were performed separately for speed and the coefficient of variation of speed. The alpha level was  $p = .05$ . Partialled eta square values ( $\eta_p^2$ ) are reported as measures of effect size. In situations where the assumption of sphericity was violated, a Greenhouse-Geisser correction was used.

## 3. Results

### 3.3. Sample – Distribution by Age

Of the 33 participants remaining after outlier detection, 18 belonged to the group of ‘young’ adults and 15 late middle aged individuals belonged to the ‘older’ adult group. The younger participants consisted of 8 women and 10 men ( $M_{\text{young}} = 20.67$  years,  $SD_{\text{young}} = .91$  years, range: 19-23 years). The older group consisted of 8 women and 7 men ( $M_{\text{old}} = 57.2$  years,  $SD_{\text{old}} = 4.6$  years, range: 51-66 years). The two age groups did not differ with respect to self-reported health status on a five-point rating scale with ‘1 = excellent’ and ‘5 = poor’ in the pre-testing questionnaire ( $M_{\text{young}} = 1.94$ ,  $SD_{\text{young}} = 0.94$ ,  $M_{\text{old}} = 2.33$ ,  $SD_{\text{old}} = 1.05$ ),  $t(31) = -1.126$ ,  $p = 0.269$ ). The older adults drove more frequently and more miles in the past year than their younger counterparts ( $t(20) = 4.335$ ,  $p < 0.001$  and  $t(28) = -2.775$ ,  $p = 0.01$ , respectively). This difference in driving frequency is expected given the urban period from which the study drew participants

### 3.2. Secondary Task Performance

A 2 (age;  $< 25$  vs.  $> 50$  years) x 2 (heart rate style; no acceleration of HR vs. acceleration of HR) ANOVA was conducted for the cognitive task. Although the mean performance score on the CPT was higher for the younger adult sample ( $M_{\text{young}} = 81.7\%$ ,  $SD_{\text{young}} = 13.1$ ;  $M_{\text{old}} = 75.2\%$ ,  $SD_{\text{old}} = 15.2$ ), this could not be confirmed as being more than a change difference between the age groups ( $F(1, 29) = 0.2$ ,  $p = 0.676$ ,  $\eta_p^2 = 0.006$ ). There was a slightly stronger, but non-significant trend for individuals in the heart rate acceleration category to score higher on the CPT (83.3% vs. 75.4%) ( $F(1, 29) = 3.0$ ,  $p = 0.092$ ,  $\eta_p^2 = 0.095$ ). The age by heart rate response interaction was statistically significant ( $F(1, 29) = 4.4$ ,  $p = 0.044$ ,  $\eta_p^2 = 0.132$ ). A break down of performance on the CPT on the basis of age and heart rate response subgroups is shown in Figure 4. While younger adults’ cognitive performance was independent of heart rate response grouping ( $M_{\text{y\_no\_acc}} = 82.7\%$ , vs.  $M_{\text{y\_acc}} = 80.9\%$ ), older adults belonging to the no acceleration group markedly underperformed relative to the acceleration group of their age cohort ( $M_{\text{o\_no\_acc}} = 70.2\%$ , vs.  $M_{\text{o\_acc}} = 89.2\%$ ).

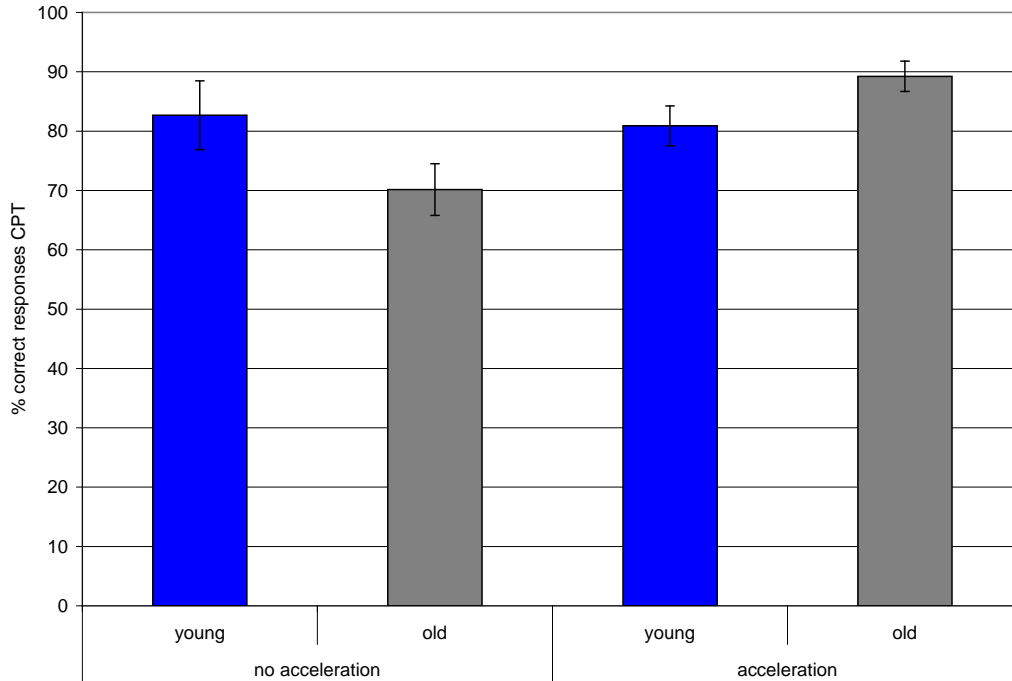
*Performance on Secondary Task (CPT)*

Fig. 4 - Mean percentage and standard errors of correct responses on the cognitive task as a function of age group (young vs. late middle age adults) and response style (no heart rate acceleration under dual-task vs. acceleration)

### 3.3. Driving Performance

#### 3.3.1. Velocity

Figure 5 presents driving speed (velocity) before, during, and after the secondary task across the age and heart rate response sub-groups. In accordance with an expected compensation in driving speed under dual-task load, a 2 (age) x 2 (HR style) x 3 (workload state) mixed ANOVA showed a main within-subject effect of period ( $F(1.5, 44.6) = 8.83, p = 0.001, \eta_p^2 = 0.233$ ). In other words, participants generally reduced their driving speed when concurrently engaged in the working memory task and accelerated again afterwards. This pattern was consistent across the heart rate non-acceleration subjects, whereas the heart rate acceleration subjects as a whole maintained a somewhat higher velocity throughout the entire highway segment. This difference is statistically significant in terms of a heart rate response and period interaction effect ( $F(1.5, 44.6) = 10.48, p = 0.001, \eta_p^2 = 0.265$ ).

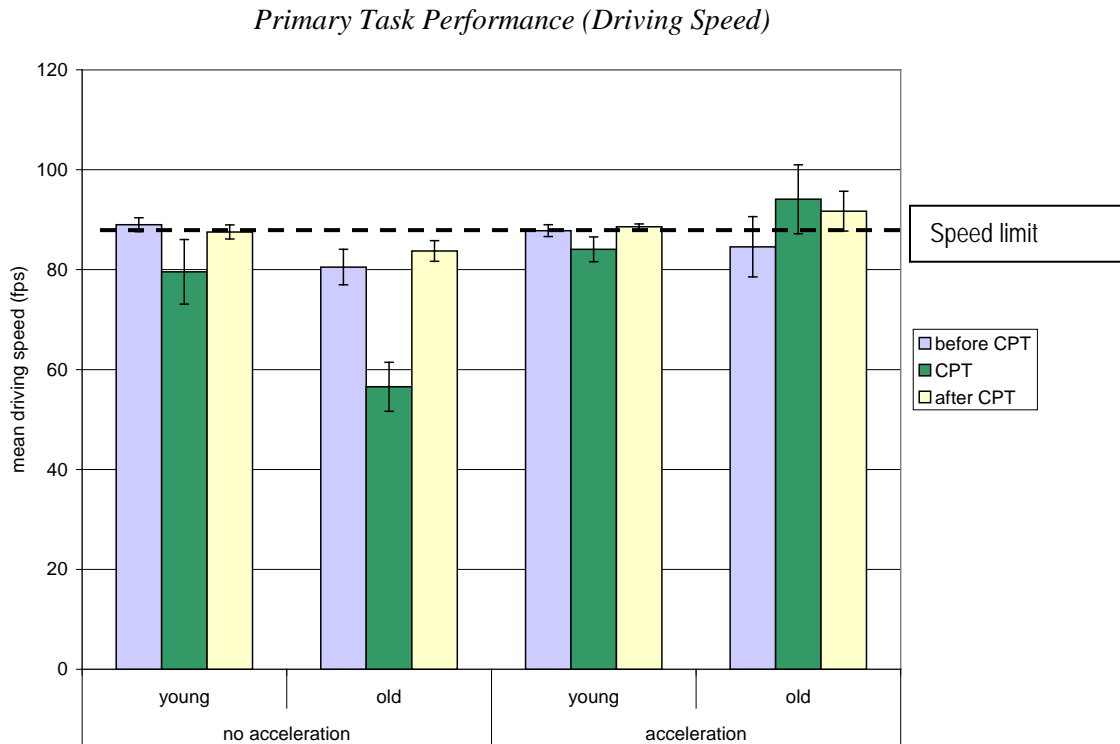


Fig. 5 - Means and standard errors of driving speed as a function of age group (young vs. late middle age adults), response style (no heart rate acceleration under dual-task vs. acceleration), and period (before/ during/ after cognitive task). Posted speed limit was 65 MPH (95.3 FPS)

The main effect of heart rate response on velocity was significant ( $F(1, 29) = 10.71, p = 0.003, \eta_p^2 = 0.27$ ), with the heart rate acceleration group driving faster. There was no main effect of age on velocity. Age does appear to influence velocity when interacting with heart rate response ( $F(1, 29) = 7.55, p = 0.01, \eta_p^2 = 0.207$ ) and in a three way interaction with heart rate response and period ( $F(1.5, 44.6) = 5.73, p = 0.01, \eta_p^2 = 0.165$ ). Again, the two heart rate response groups in the young adults sample did not differ ( $M_{y\_no\_acc} = 85.4$  fps, vs.  $M_{y\_acc} = 86.8$  fps), whereas velocity within the older sample varied with respect to heart rate response. In the older sample, the heart rate acceleration group drove faster ( $M_{o\_no\_acc} = 73.6$  fps, vs.  $M_{o\_acc} = 90.1$  fps). As far as the three-way-interaction is concerned, older adults in the non-acceleration group showed qualitatively the same pattern as the younger drivers except that their reduction in velocity during the dual task was greater.

### 3.3.2. Coefficient of Variation of Velocity

The coefficient of variation of velocity provides an index of consistency in control of driving speed. The means and standard errors for this variable are plotted by heart rate response pattern and by age subgroups across the three periods (before, during and after the cognitive task) in Figure 6. A mixed 2 (age) x 2 (HR response) x 3 (period) ANOVA demonstrated a main effect of period ( $F(1.4, 39.4) = 23.85, p < 0.001, \eta_p^2 =$

0.451), a main effect of age ( $F(1, 29) = 11.26, p = 0.002, \eta_p^2 = 0.28$ ), and a three way interaction of age x heart rate response x period ( $F(1.4, 39.4) = 6.1, p = 0.011, \eta_p^2 = 0.174$ ). The younger participants showed essentially the same pattern in speed control before, during and after the CPT regardless of heart rate response grouping; variability increased markedly during the dual task condition and recovered following the dual task. Thus the divided attention required by the secondary task impacted on performance on the primary driving task. The late middle age drivers showed greater variability in speed control overall compared to the younger drivers. As was the case with velocity, the heart rate response grouping highlighted a marked difference in driving behavior in the older sample. The older drivers in the heart rate acceleration subgroup showed a level of variability of speed control during the cognitive task that was in the same range as the younger drivers under dual task load. The older drivers in the heart rate non-acceleration group, however, showed a dramatic jump in variability of control during the CPT.

*Primary Task Performance (Variability of Speed Control)*

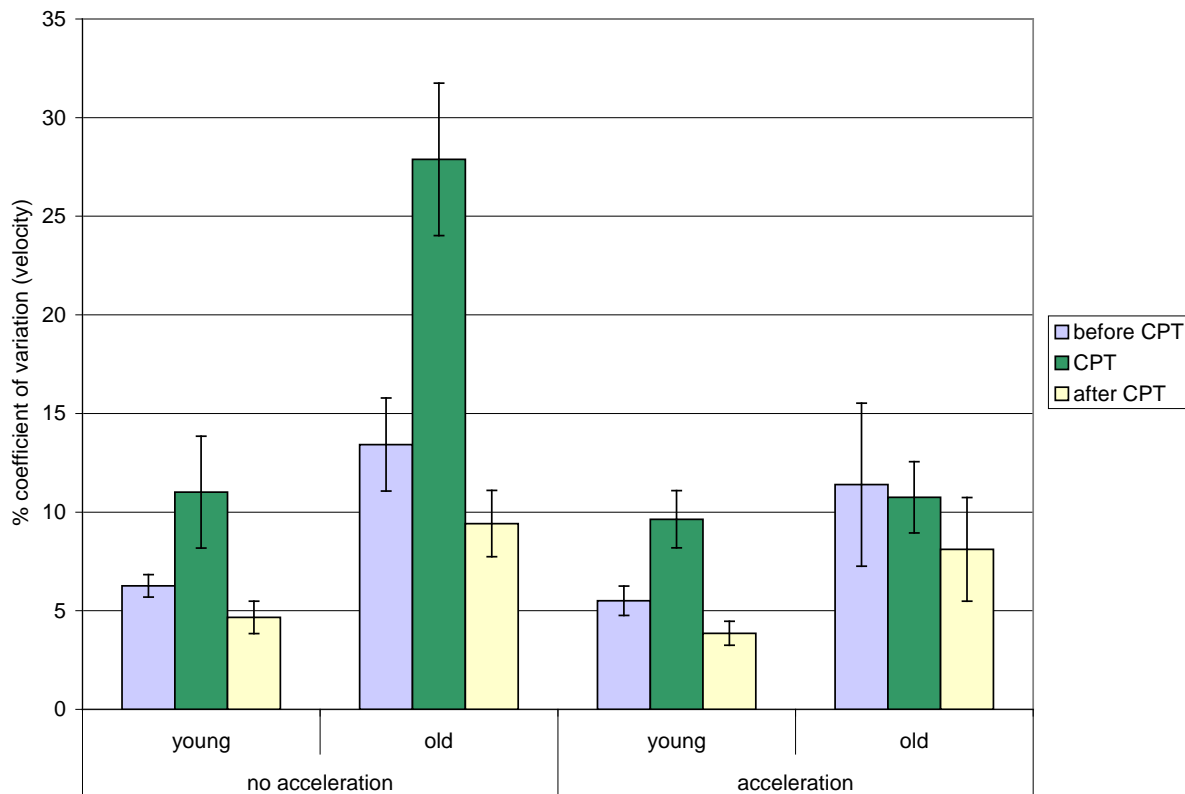


Fig. 6 - Means and standard errors of within-subject variability (coefficient of variation: (standard deviation/mean)\*100) of driving speed as a function of age group (young vs. late middle age adults), response style (no heart rate acceleration under dual-task vs. acceleration), and period (before/ during/ after cognitive task).

#### 4. Discussion

Classifying participants on the basis of their heart rate response to the CPT task revealed patterns similar to those seen with the cell phone task [17]. Although younger drivers were more likely to show heart rate acceleration under the added load of the secondary task, some older drivers also showed a marked increase. In addition, a number of younger drivers showed little change, or an actual drop in heart rate, similar to the patterns displayed by the majority of the older drivers. An assessment based solely on the group means would conclude that younger individuals show a pronounced cardiovascular response to increased cognitive demand while older drivers do not. However, this overlooks a continuum of response styles that is present in both age groups. Inspection of the individual records clearly indicates that what differentiates the younger and older driver samples is not a unitary behavioral response but rather the relative distribution of individuals showing a particular pattern of physiological reactivity.

As was the case with the cell phone data, the differential distribution of heart rate response by age could be seen as simply reflecting normal constitutional changes in cardiovascular reactivity. This is likely part of the story. It is also possible that the differential patterns of response may point to something informative about how older drivers respond to the added cognitive demand of the secondary task. In the younger drivers, heart rate response was not associated with either primary task performance (driving speed or variability of speed control) or with secondary task performance on the CPT. In the case of the late middle age drivers, however, individuals who showed a marked heart rate acceleration during the secondary task scored significantly higher on the CPT. They also drove faster (and closer to the posted speed limit) and showed a more stable velocity control (a lower coefficient of variation). Consistent with a drop in driving speed that is often reported during secondary tasks [22], the older drivers who exhibited a lack of heart rate acceleration slowed significantly while completing trials of the CPT. This can be seen as compensatory response to reduce or manage overall workload. At the same time, drivers in the non-acceleration group also showed greater variability in speed control (i.e. lower driving performance) and lower performance on the CPT task. It appears that overall performance of those late middle age drivers who showed the non-acceleratory heart rate pattern was impacted to a greater extent by the multiple demands than was the case for those who showed heart rate acceleration. In other words, it appears that older drivers who did not show a meaningful heart rate increase tended to do less well on both the primary and secondary tasks. In this instance, a drop in speed was associated not only with attempted compensation but also impaired performance.

An examination of heart rate response patterns clearly differentiated older drivers in an interesting manner as regards overall performance in this sample. However, it is quite reasonable to question whether this is simply a chance finding as opposed to an indication of what might possibly be a broader phenomenon. In a study looking at anxiety and memory in older adults, Pearman & Lachman [23] present data on the relationship between cardiovascular reactivity and cognitive performance. They compared younger and older subjects (18-23 and 60-85 years, respectively) who were presented with a series of cognitive tasks under single task conditions (i.e. not while driving). Based on overall performance scores, each age group was split into a high performance and a low performance group. Heart rate during the tasks was then compared. In findings paralleling those presented here, they observed that there was no significant association between heart rate and performance in the younger group. However, in the older adults, those in the high performance subgroup had significantly higher heart rates than those in the lower performance subgroup.

What might underlie this apparent relationship between greater heart rate reactivity and performance in the older age group? A number of possible mediating factors seem worthy of consideration. Lower heart rate reactivity might be related to lack of engagement with the task, lack of additional cognitive resources to invest in multiple task management, lower flexibility in both the physical and cognitive domains associated with age related deconditioning,, or it might serve as a marker of a different style or coping strategy for attempting to deal with multi-dimensional workload.

As noted previously, heart rate acceleration is generally associated with arousal, stress, or workload [24], [25], [26] and has been observed under these conditions in driving research [8], [9], [27], [10]. A lack of an increase in heart rate in response to a secondary task demand might indicate a lack of engagement with the secondary task. If heart rate is used as an index of additional cognitive resources being invested to deal with increased demand, then a nominal change in heart rate may indicate that an individual is not investing energy into the task. Lack of engagement does not seem likely in the case of the cell phone task, since performance was similar for both the younger and older subjects. In the case of the CPT task, the issue of engagement or, perhaps more appropriately, capacity for engagement, is more open to question. Those older participants who did show a marked increase in heart rate performed better on both tasks. Thus, their heart rate increase may be an accurate index of availability and successful investment of cognitive resources into the concurrent tasks. Those older participants who did not show a significant change in heart rate may have already been operating at capacity and therefore did not have additional resources left to invest. As a result, heart rate did not increase. In this instance, increasing the total demand resulted in a drop in the primary task performance of driving (speed control) as available resources were divided between tasks. As described previously, the outlier removal procedure identified one subject who drove markedly slower and with greater variability of speed control than the rest of the sample and two other subjects whose extreme low scores were near the level of chance performance on the CPT. While these subjects were excluded from the statistical analysis, all three fell in the heart rate non-acceleration grouping. This may provide additional support for the position that heart rate acceleration (or lack thereof) may in fact be a useful marker of older individuals' capacity and / or willingness to invest additional resources in response to the dual task demands.

It is worth noting that eleven (33%) of the subjects showed an actual decline in heart rate in response to the CPT task. The drop in heart rate in these subjects ranged from 0.56 to 2.38 bpm. One explanation for the drop in heart rate is to assume that some drivers slowed their speed sufficiently during the dual task period to lower their total workload slightly below that experienced during single task driving. As mentioned previously, decreasing driving speed to manage workload is generally thought of as a positive, self adaptive response. In the case of the late middle age drivers, however, this pattern is also associated with a drop in both primary and secondary task performance. In this instance, a drop in driving speed seems to be an indicator of difficulty managing workload as much as it is evidence of attempted adaptive behavior.

At the same time, there is an important point that must be taken into consideration when using heart rate, in isolation, as an index of arousal. Regulation of heart rate is governed by direct innervation of the heart by both sympathetic and parasympathetic branches of the autonomic nervous system and by hormonal influences. While sympathetic input speeds the heart, parasympathetic stimulation through the vegas nerve actively slows heart rate. Thus heart rate can decrease because of a reduction in sympathetic activity but also from an increase in parasympathetic activity. There are

known to be conditions of general arousal under which heart rate can be found to drop. It has been suggested [28], [29] that heart rate deceleration in selected situations is associated with an otherwise activated attentional state (increased electrodermal and brain wave activity) that is directed at a broad intake of external sensory information. This is contrasted with a focused attentional pattern in which heart rate acceleration is present that involves selectively ignoring or rejecting input that may be disruptive or distracting to a specific cognitive task. Heart rate deceleration associated with an otherwise heightened arousal state is also found in Soklov's [30] description of the orienting response. While the Lacey proposition that these differential cardiac patterns directly modulate central attentional processes has been critically challenged (see [31], [32] for reviews), the fundamental observation that decreases in heart rate occur in numerous experimental tasks involving attention to environmental stimuli is well established [33], [34]. In the complex demand environment of driving a car and simultaneously engaging in a secondary cognitive 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.

The possibility that differential heart rate responses might be a cue to how attention is being managed has been raised in the context of driving in observations by Richter, Wagner, Heger & Weise [34] in an on-road study and by Backs, Lenneman, Wetzel & Green [36] in simulator based research. Both studies found that heart rate increased when drivers negotiated curves of low to moderate curvature but decreased when dealing with the demands of high curvature roadway. Both groups cited Lacey's work and suggested that the explanation for the heart rate drop might lie in the intense sensory intake, in other words, by the perceptual processing demands required to negotiate the high radius curves. Presumably the sensory processing demands during the low to moderate curves were modest enough that the general arousal aspect of the task predominated over attentional requirements, resulting in higher heart rates. In negotiating the high radius curves, the high perceptual (visual) processing demands of the task may have pulled for an attentional focus akin to that described by Lacey and colleagues, resulting in lower heart rates in the presence of high workload.

In the context of our older driver sample, it is interesting to speculate as to whether the higher performance scores in those individuals who showed the cardiac acceleration pattern was in part a function of their ability to successfully ignore extraneous stimuli, engage in rigid control over velocity, and direct focused attention to the auditory CPT task. In contrast, one might question whether some of the cardiac deceleration observed in the older drivers should be associated with an attempt to manage attentional demands through a broad sensory intake mode. If so, the attempt to distribute attention widely may have resulted in lower success in managing each of the tasks due to the limited resources available. Further investigation of these questions would be facilitated by the addition of a physiological measure, such as electrodermal activity, that is predominantly under sympathetic control and does not show the complex patterning that can underlie heart rate. Combining both measures would allow for an assessment of to what extent the intriguing performance differences between the high and low heart rate responders reflects overall arousal differences, attentional style, or an interaction of factors. If the heart rate non-responders also were to show a drop in electrodermal activity, then this would tend to argue in favor of a reduced engagement or resource ceiling interpretation of their behavior. If the limited change or actual drop in heart rate in these individuals was associated with an increase in electrodermal activity, then this

would lend some credence to the possibility that these individuals were attempting to manage their attentional focus differently than the heart rate responders, perhaps along the lines of the sensory intake vs. sensory rejection construct.

## **5. Conclusions**

Young and late middle age drivers differed substantially in heart rate reactivity in response to dual task loading on the CPT when considered at the group level. The analysis presented in this paper argues for the utility, at least in the late middle age drivers, of looking in more depth at individual patterns of heart rate response in addition to overall group behavior. In the late middle age drivers, heart rate acceleration was associated with more consistent velocity control and higher secondary task performance on the CPT; nominal heart rate change or decrease was associated with less consistent velocity control, a marked drop in driving speed, and lower scores on the CPT. It remains to be determined what variables or processes underlie the associations observed between heart rate response and task performance in the late middle age drivers. In light of other findings on cognitive task performance, such as those reported by Pearman and Lachman [23], it does appear that physiological reactivity is associated with differential performance in some manner in older individuals. As discussed, the absence of a heart rate response, or an actual drop in heart rate, could indicate a lower availability of resources to invest, diminished physical capacity or psychological willingness for multi-task engagement, a differential strategy or style of responding to the attentional demands of the situation, or a combination of these or other factors. It does appear clear, however, that research looking at physiological indices, workload, and performance may benefit by considering the role of age and individual differences in examining these relationships.

## **Limitations**

Sample size is a frequent limitation and particularly so when sub-dividing groups post-hoc to look at differences in response patterns; replication with a larger sample is clearly desirable. The heart rate monitoring instrumentation employed did not support individual beat by beat analysis and the finger based plethysmograph sensor was susceptible to movement artifact in the active driving context. As discussed, monitoring heart rate alone limits the ability to make inferences about an individual's state of arousal and the inclusion of additional physiological indices is to be recommended. We are currently following-up this work using instrumentation that supports individual beat by beat heart rate analysis and simultaneous monitoring of skin conductance and respiration rate. Finally, as with all simulation research, there is the question of the extent to which the patterns observed model behavior during actual driving.

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