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Distracted driving accounts for a substantial portion of vehicular fatalities and injuries in the United States. The effects of in-vehicle conversations and cell phone usage have been linked to heightened risk for traffic violations and collisions. The divided attention associated with distraction differentially affects age groups, with a potentially greater risk for individuals older than 65 years old. Although drivers may not accurately predict how distraction affects their driving performance, it is possible that their strategic approaches to distractors are influenced by such predictions. Underestimating how a distractor might affect one's ability to drive could lead to decreased adaptation, which may lead to a potentially fatal collision. On the other hand, overestimating the influence of distractors might lead to inefficient driving behaviors, such as driving excessively slow. The current study investigated the relationship between metacognitive predictions and strategic adaptation to distraction in both old adults (ages 60 to 75) and young adults (ages 17 to 30) through the use of concurrent laboratory tasks. The primary task was a visuospatial navigation task and the secondary task was a visual paced serial addition task (PVSAT). Participants completed each task on its own, and then completed two blocks in which the tasks were performed concurrently. The second of the dual task blocks allowed participants to strategically adapt the speed of the navigation task. In general, young adults performed better than older adults, and performance costs due to concurrent task engagement were evident for both age groups. Performance predictions for both young and older adults were reasonably calibrated to PVSAT performance, but not navigation

performance. Both age groups adapted to the multitasking environment via speed selection, but speed selection was not predicted by metacognitive performance predictions.

# METACOGNITIVE PREDICTIONS AND STRATEGIC ADAPTATION TO DISTRACTION

by

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# CHAPTER I

# INTRODUCTION

The impact of multitasking on driving performance has been given an increasing amount of attention over the past few decades. This is unsurprising, as distracted driving accounted for 3,477 fatalities and 391,000 injuries in 2015 alone (National Highway Traffic Safety Administration, 2017). Technological advances resulting in more interactive navigation and entertainment systems in automobiles, as well as a heightened expectation to remain socially connected through personal electronics, place an increasing demand on today's drivers. When attention is diverted from the road, the ability to effectively respond to necessary driving demands is decreased (Cooper & Zheng, 2002; Pashler, 1994). The level of impairment associated with distraction is often augmented for individuals with less executive or attentional control, such as older adults. With the number of older drivers having increased steadily over the past decade (National Highway Traffic Safety Administration, 2015), it is necessary understand factors that might influence their safe driving practices. Few studies have assessed the antecedents of strategic behavior enacted when multitasking and driving. The current study uses a computerized task designed to mimic spatial navigation in conjunction with a visual paced serial addition task to assess whether metacognitive beliefs about one's multitasking abilities influence strategic adaptation to multitasking.

## Age Related Attentional Differences

Normative changes in cognitive processing, such as processing speed (Salthouse, 1991, 1996) and inhibition (Hasher and Zacks, 1988), can alter how an individual selectively attends to and processes information. The effects of these age-related declines are evident in complex tasks involving working memory, decision making, and speed of processing (Park et al., 1996, Cherry & Park, 1993; Zwahr, Park, & Shifren 1999). As proposed by the complexity hypothesis, the magnitude of age related differences in task performance increases proportionally with task complexity (Birren, Woods, & Williams, 1980). Age related deficits in complex task performance have been found in much of the dual-tasking literature (Kramer, Larish, & Strayer, 1995; Verhaeghen et al., 2003). As individuals age they are less able to delegate sufficient attentional resources to concurrent tasks (Craik & Byrd, 1982). Such performance differences are particularly evident when the modality of the concurrent tasks overlap (Kray & Lindenberger, 2000), likely due to age-related differences in response integration (Brouwer et al., 1991). Work in the domain of distraction control has demonstrated that the ability to inhibit the processing of task irrelevant information, otherwise known as the “access function”, may also decline with age (May et al., 1999; Connelly & Hasher, 1993). In daily life, age related attentional deficits may hinder the ability to make sound judgment calls. For example, in a simulated street crossing task, older adults struggled to analyze traffic patterns and took longer to make the decision to initiate crossing than young adults (Neider et al., 2011).

The difference between younger and older adults was even greater when participants were engaged in a concurrent cell phone conversation.

## Attention and Driving

Despite an understanding of the potentially fatal consequences associated with in-vehicle distraction, motorists continue to willingly divert their attention from the road (Rupp, Gentzler, & Smither, 2016). Several states have taken it upon themselves to pass legislation in the effort to discourage drivers from texting and driving (National Highway Traffic Safety Administration, 2017). In-vehicle cell phone usage has been linked to increased reaction times, increased braking distance, and inconsistent speed maintenance (Horrey & Wickens, 2006; Lamble et al., 1999; Hancock, Lesch, & Simmons, 2003). Even when limiting visual and motor distraction through the use of a hands-free device, the amount of time to regain speed after braking by may increase by up to 17% (Strayer & Drews, 2004).

Cognitive factors such as executive function, processing speed, and visual attention have been directly linked to driving performance (Anstey et al, 2012; Hoffman et al., 2005). Age related declines in these abilities have been shown to increase the likelihood of driving errors. For instance, collisions are more common among older drivers than younger drivers in situation requiring heightened levels of executive or attentional processes. Older adults were overrepresented in collisions in intersections or where decisions regarding right of way were necessary (McGwin & Brown, 1999). Furthermore, when under concurrent task load older adults were significantly more likely to misjudge traffic gaps and oncoming vehicle speed than younger adults (Cooper &

Zheng, 2002). Within the population of older drivers, lower working memory capacity and visuospatial attention have been shown to further increase the likelihood of being involved in an accident in an intersection (Owsley & Ball, 1991). Though age related attentional deficits negatively affect driving performance, over 50 million older adults remain registered drivers in the United States (Federal Highway Administration, 2015). Using compensatory driving practices may allow them to avoid or adapt to situations requiring the use of cognitive processes that may have declined with age. It has been shown that older adults drive differently than young adults, with a tendency to self-regulate driving behavior to accommodate visual and cognitive deficits (Ball and Owsley, 2003; Ross, Clay, & Edwards, 2009). It seems plausible that metacognitive processes, or a knowledge of one's own abilities, may influence compensatory driving behavior. For example, if an individual believes that they will experience trouble driving through an intersection, they may be more likely to slow down to allow more time to process relevant information.

**Metacognition**

Metacognition, or cognition about one's own cognition, is essential in regulating behavior to optimize task performance (Hertzog & Hultsch, 2000). For example, if an individual is under-confident in their ability to perform a task they may allocate their resources to help mediate any perceived performance decrements. Indeed, when determining what words to restudy, individuals base their study time allocation on their conceptions of their abilities as a learner as well as environmental limitations (Dunlosky

& Hertzog, 1998; Nelson et al., 1994). Individuals also strategically choose to study more difficult words when provided with longer study times.

The ability to engage in accurate encoding and retrieval monitoring during simple memory tasks is likely spared across the lifespan (Hertzog & Hultsch, 2000), however it remains debated whether there are age differences in the ability to use information gathered when monitoring to formulate effective task strategies (*metacognitive control*). Although previous research has noted that older adults may experience metacognitive control deficits (Hertzog & Hultsch, 2000; Dunlosky & Connor, 1997), a recent body of work has indicated that control processes remain intact well into older adulthood. For example, judgments of learning (JOLs) provided after studying a word have been shown to predict later study time allocation even when controlling for actual performance (Hines, Touron, & Hertzog, 2009). Additionally, older adults are as likely as young adults to report using effective strategies in complex task environments (Touron et al., 2010).

**Metacognition and Multitasking**

Prior studies assessing the metacognition of multitasking in both the laboratory (Finley et al., 2014) and during real world driving (Horrey, Lesch, & Garabet, 2008, 2009; Kidd & Horrey, 2010; Lesch & Hancock, 2004) have indicated that individuals are aware of general performance costs associated with multitasking, but are poorly calibrated to the *degree* that engaging in a concurrent task or distraction will negatively affect their performance. Finely et al. (2014) used a computerized multitasking environment consisting of a primary mouse tracking task and a secondary *n-back* task to assess the accuracy of metacognitive predictions of dual task performance. Participants predicted general multitasking costs, but were unaware of how susceptible they were to multitasking costs relative to others (Finley et al., 2014). Individuals who predicted a small decrement were often performing worse than those who predicted a larger decrement. The current study extends on Finley et al. (2014) by assessing the degree to which metacognitive predictions of multitasking performance may influence strategies used to mitigate distraction. When individuals are able to slow down the speed of a primary task, akin to slowing down in a car, are they basing the speed on their perceived ability to multitask?

**Strategic Adaptation**

Despite a poor understanding of the performance costs resulting from distraction, individuals have been shown to alter their driving strategies in accordance with cognitive demand. When engaged in a concurrent secondary task, drivers have been shown to compensate by reducing their speed, increasing the distance between themselves and a lead vehicle, and completing secondary task demands when the vehicle was stationary (Stutts et al., 2005; Liu & Lee, 2005; Strayer & Drews, 2004). The propensity for individuals to utilize these strategies may vary depending on environmental variables such as availability of the technology, social norms, regulations, and productivity pressures (Lee & Strayer, 2004).

Although strategic adaptation to increasing driving demands is apparent across age groups, the degree of adaptation differs. Older adults are less willing to use a cell phone during simultaneous vehicle operation (Pöysti et al., 2005), and tend to limit lane changes during interstate driving (Reimer et al., 2013). In daily driving, older adults opt for longer gaps in oncoming traffic before turning onto a road (Cooper & Zheng, 2002). These effects are evident in the literature regarding more general task switching abilities as well. When coordinating concurrent tasks in a psychological refractory period paradigm (PRP), older adults were subject to greater time costs than young adults due in part to the endorsement of a more cautious coordination strategy (Glass et al., 2000). Though young and older adults often differ in their strategic approach to multitasking, the manner and degree to which these differences are driven by metacognitive processes remains uncertain.

The current study examines the influence of metacognitive predictions on strategic adaptation in a laboratory-based dual task environment. The structure of the current study was similar to Finley et al. (2014), but instead utilized a primary grid mapping task and a secondary paced serial addition task. The primary grid mapping task was chosen as a lab analog for following a GPS navigation aid, while a paced visual serial addition task (PVSAT) (e.g., Patten et al., 2004; Horrey et al., 2009) was chosen to be roughly analogous to engagement with a mobile electronic device. Participants completed a single task version of each task, and then two dual task blocks in which the tasks were presented concurrently. The second of the two dual task blocks allowed participants to strategically select the presentation speed of the navigation task.

The primary goal of the current study was to assess how older and younger adults strategically adapt to a dual task environment consisting of a primary task and a distractor. We also sought to highlight age related differences in metacognitive processes and how they relate to strategic task approach. Prior literature on age related differences in metacognitive processes has mainly utilized simple experimental tasks. The current study seeks to address age related differences in metacognitive monitoring and control in a more complex task environment. The inclusion of an overt measure of strategic adaptation aims to highlight age related differences in metacognitive control that may have been masked in self-report measures. We expect that performance predictions will be associated with strategic adaptation to dual tasking over and above actual performance. Specifically, older and younger adults who predict better dual task performance will select faster speeds than those who predict worse dual task performance. We also expect older adults to endorse a more conservative strategy, which will be evident in their slower speed selections. The results from this study will provide a more detailed view of metacognitive processes and how they relate to strategic choice, and will expand our understanding of the intricacies of metacognitive control across the lifespan. Furthermore, it provides a necessary bridge between metacognitive processes and everyday driving behavior in both old and young adults.

# CHAPTER II

# METHOD

## Participants

One hundred young adults (ages 17-30) recruited from the University of North Carolina at Greensboro and 56 older adults (ages 60 to 75) recruited from the greater Greensboro area participated in this study. Undergraduates received course credit and community volunteers received $20 for participation. Older adults were screened for health conditions that may hinder their ability to effectively use a computer mouse and keyboard. All participants were required to have corrected visual acuity of 20/50 or better to participate in the experiment. Demographic information regarding the participants is provided in Table 1.

## Materials

All experimental tasks were programmed using E-Prime 2.0 software. Testing stations were equipped with desktop computers running Windows OS as well as a standard mouse and keyboard. The screen resolution for each of the computer was set at 1280 x 1024. The primary task was a spatial navigation task, and the secondary task was a paced visual serial addition task.

**Navigation**. The navigation task was designed to roughly resemble everyday route navigation in an automobile. Two 6x6 grids were arranged side-by-side on the computer screen (see Figure 1). The cell width for each grid was calculated as 1/16$^{th}$ of the screen resolution, and the height was calculated as 1/12th of the screen resolution. In the grid on the left a navigation path was displayed, consisting of a 5-pixel wide red line running a continuous path through ten of the thirty-six grid cells. A red dot measuring 15 pixels in circumference was situated at one end of the red line. Each path was only presented once during the experiment. The grid on the right remained blank pending participant response. Participants were asked to match the navigation path from the left grid to the right grid by sequentially clicking each of the cells beginning at the end with the circle. If a cell was selected in the right grid, it turned red. If the entire navigation path was correctly mapped, the right grid turned green.

**PVSAT**. The secondary task was a visual paced serial addition task (PVSAT). Participants were presented with a stream of randomly generated single digit numbers in the center of the computer screen. Each number remained on the screen for 4s. The rate of stimulus presentation in the PVSAT did not vary throughout the experiment. Participants were asked to add the number currently on the screen to the number previously on the screen, and respond with the summation using the number row at the top of the computer keyboard. Participants were instructed to rest their pointer finger, middle finger, and ring finger of their non-dominant hand on the numbers 3, 4, and 5. Summations were constrained to equal either 3, 4 or 5 to eliminate the need for finger reorientation. Prior to the presentation of the first number, a fixation cross was presented to orient participants' eyes to the location of the stimuli. Feedback was provided if accuracy fell below 60% correct via a warning message stating “accuracy has fallen below an acceptable level” at the bottom of the screen.

**Procedure**

Following consent procedures and a brief demographic questionnaire, participants completed a vocabulary test (Ekstrom et al., 1976) and a 60 item pencil and paper version of the Pattern Comparison Test (Salthouse, 1993). Following the pre-task measures, participants completed six task blocks in the following order: *single navigation practice, single navigation test, single PVSAT practice, single PVSAT test, navigation/ PVSAT multitasking, navigation/ PVSAT multitasking strategy*. The single navigation and single PVSAT practice blocks were structurally identical to their corresponding test blocks. After completing each practice block, participants were informed that they would complete the task again and asked to predict their performance. Participants were asked to base their navigation performance prediction on the overall percentage of grids that they believed they would correctly map, and were reminded that grids were only correct if the entire pattern was correctly mapped within the allocated time window. Participants were instructed to base their PVSAT performance prediction on the overall percentage of summations that they would correctly respond to.

The single task block of the navigation task and the first dual-task block were experimenter paced. The presentation speed of the grids, or the amount of time allocated for grid completion, decreased in 1s intervals from 30s on the first grid to 4s on the last grid. When the time allocation had elapsed, a new set of grids were generated and presented. During each trial, the presentation speed was displayed in 22pt font centered at the top of the computer screen. Prior to beginning the task, participants were instructed to pay attention to the presentation speed as they would need the information at a later point in the study.

Following the single task blocks, participants were informed that they would be completing the navigation task and the PVSAT at the same time. Participants were informed that both tasks would be presented in the same location on the screen as they were in the single task block, with PVSAT numbers being situated between the navigation grids in the center of the screen and the navigation presentation speed at the top center of the screen. They were again instructed to attend to the presentation speed as they would need the information later in the study. Additionally, participants were instructed to complete both tasks but to prioritize the navigation task over the PVSAT.

The final block, referred to here as the strategy block, enabled participants to select their preferred presentation speed. Prior to beginning the strategy block, a screen was presented instructing participants to choose a speed that they believed would allow them to respond as quickly and accurately as possible in the navigation task. Potential speed selections were presented in a 3 x 9 grid beginning with 30s in the top left cell and progressing to 4s in the bottom right cell. Participants were again prompted to select their desired speed after every four navigation grids. Enabling participants to select their speed provided an opportunity for strategic adaptation during the task, and was chosen to be analogous to vehicular speed modulation. Furthermore, it provided an explicit measure of intentional strategic adaptation rather than subjective reports or behavioral inference.

Several computerized questionnaires were administered after the task. The Multitasking Preference Inventory (MPI; Poposki & Oswald, 2010) includes fourteen questions that assesses polychronicity, or an individual's preference for multitasking. Responses are rated from 1 (strongly disagree) to 5 (strongly agree) on a Likert type scale. The MPI was included to assess the degree that self-reported polychronicity was related to speed selection and metacognitive predictions of multitasking.

We also included targeted items from the Driver Behavior Questionnaire (Parker, Reason, Manstead, & Stradling, 1995) to assess whether everyday measures of driving attention were related to metacognition and strategic task approach in the lab. The items were divided by the sub-scale from which they were selected. The included items were twelve questions assessing the propensity to engage in secondary tasks while driving, nine questions assessing an individual's perceived risk of distracted driving, and six questions assessing subjective reports of attentional lapses while driving. We also included a question regarding the general belief that the participant is able to drive safely when engaging in a secondary task, as well as a question regarding the belief that the general public is able to drive safely when engaged in a secondary task.

## CHAPTER III

## RESULTS

### Task Performance

To evaluate differences in performance during the experimenter paced block, mean proportion correct was compared using 2 (age: old, young) x 2 (condition: single, dual) repeated measures ANOVAs for each task. Alpha level for all tests was set to .05. Partial eta-squared and Cohen's *d* were included as measures of effect size.

**Navigation.** A significant main effect of age was observed, $F(1,154)=61.31$, $p<.001$, $\eta_p^2 = .29$, with older adults performing worse than young adults in the navigation task than. A main effect of condition $F(1,154)=255.99$, $p<.001$, $\eta_p^2 = .62$ was also obtained as dual task navigation performance was significantly lower than single task performance. As indicated by the significant interaction between age and condition, $F(1,154)=14.04$, $p<.001$, $\eta_p^2 = .08$, older adults suffered greater performance decrements than young adults when moving from the single task block to the dual task block. Performance decrements between single task and dual task navigation were calculated for both older and younger adults, and were greater for older adults ($M_{old,\ Single\text{-}Dual} =25.73$ than younger adults ($M_{young,\ Single\text{-}Dual} =15.96$), $d= 0.58$, $t(154) = 3.75$, $p < .001$.

**PVSAT.** A significant main effect of age was observed, with older adults performing worse than young adults, $F(1,154)=71.15$, $p<.001$, $\eta_p^2 = .32$. A significant main effect of condition was observed, PVSAT $F(1,154)=870.37$, $p<.001$, $\eta_p^2 = .85$, with lower performance in the dual task PVSAT than in the single PVSAT. As evidenced by a significant interaction between age and condition, older adults suffered greater performance decrements than young adults when moving from the single to the dual task PVSAT, $F(1,154)=90.99$, $p <.001$, $\eta_p^2 = .37$. Performance decrements between single task and dual task were greater for older adults ($M_{old, Single\text{-}Dual}=46.58$) than young adults ($M_{young, Single\text{-}Dual} =23.82$), $d= 1.49$, $t(154) = 9.54$, $p < .001$.

**Binned performance.** To assess differences in navigation performance as the allotted time decreased, the 27 navigation trials were subdivided into 9 bins consisting of 3 trials each. The first bin consisted of the first three trials (30s, 29s, 28s), the second bin consisted of the next three trials (27s, 26s, 25s), etc. Mean proportion correct was calculated for each participant at each bin. These were then submitted to a 2 (Age: old, young) x 9 (Bin: 1-9) repeated measures ANOVA for both the single-task and dual-task navigation blocks. We also ran focused comparisons between age groups at each bin. A Bonferroni correction was used to reduce the likelihood of Type-1 error. The resulting alpha level was .005.

***Single navigation.*** A significant main effect of age was observed supporting the overall lower performance of older adults, $F(1,154)=28.35$, $p <.001$, $\eta_p^2 = .16$. A main effect of bin was observed, $F(8,1232)=191.76$, $p<.001$, $\eta_p^2 = .55$, signifying that performance suffered to a greater degree as the allotted time for navigation grid completion decreased. A significant age x bin interaction, $F(8,1232)=14.80$, $p <.001$, $\eta_p^2 = .09$, supported our prediction that the performance of older adults would degrade earlier in the single navigation task than young adults. Focused comparisons between age groups on bin level performance are presented in Table 2 and illustrated in Figure 3. Older adults performed equally well as young adults when the allotted time was greater than 12s. Age differences were magnified below 12s.

***Dual navigation.*** The main effect of age was significant, $F(1,154)=58.89$, $p < .001$, $\eta_p^2 = .28$, with older adults performing worse than young adults. The main effect of bin was also significant $F(8,1232)=108.92$, $p < .001$, $\eta_p^2 = .41$, as performance degraded as the allotted time decreased. A significant bin x age interaction, $F(8,1232)=6.36$, $p < .001$, $\eta_p^2 = .04$, signified that the navigation performance of older adults degraded earlier on in the dual-task condition than young adults. Bin level comparisons between young and older adults indicated that older adults performed significantly worse than younger adults below 18s (see Table 2 and Figure 3).

**Metacognitive Predictions**

**Navigation.** Prediction data are shown in Figure 4. The main effect of age was non-significant $F(1,154)=2.03$, $p=.156$, $\eta_p^2 = .01$. A significant main effect of condition was observed, $F(1,154)=5.93$, $p=.02$, $\eta_p^2 = .04$, indicating that participants held a general awareness of how dual-tasking may negatively affect their performance. This was further qualified by a significant age x condition interaction, $F(1,154)=4.29$, $p=.04$, $\eta_p^2 = .03$. Older adults ($M_{single} = 69.55$, $M_{dual} = 61.25$) predicted a larger dual task decrement than young adults ($M_{single} = 69.79$, $M_{dual} = 69.12$). In fact, young adults did not predict any multitasking related performance costs in the navigation task, $t(99)= .29$, $p = .77$.

**PVSAT.** A significant main effect of age was observed, $F(1,154)=14.75$, $p<.001$, $\eta_p^2 = .09$, as young adults predicted higher PVSAT performance than older adults. A significant main effect of condition was also observed for PVSAT performance predictions, $F(1,154)=14.08$, $p<.001$, $\eta_p^2 = .084$. Predictions of single task PVSAT performance were higher than predictions of dual task PVSAT performance. Age differences in performance predictions did not vary with condition, $F(1,154)=2.36$, $p = .13$, $\eta_p^2 = .02$.

**Group-level resolution.** To assess the relative accuracy, or group level resolution, of participants, we calculated a between subjects correlation of predictions and performance for each age group. This approach has been used in earlier work on metacognition of multitasking (Finley et al., 2014) and assesses the tendency for high predictors to also have high performance and for low predictors to have low performance. Tables 3 and 4 present the relevant correlation matrices by age group and task. Single task navigation predictions and single task navigation performance were significantly correlated for older adults, $r_{old} = .655$, $p < .001$, but not young adults. Navigation predictions for the first dual task block were not significantly correlated with navigation performance in the first dual task block for either age group ($p > .05$). Single and dual task PVSAT predictions were significantly correlated with their respective PVSAT performance for both young and older adults ($p < .001$ – $p < .05$). Group level resolution of predicted decrements was non-significant for both age groups ($p > .05$), though it should be noted that aggregated performance feedback was *not* provided following the single task block. Without knowledge of single task performance, participants may not have been able to accurately form a reference point for their dual task prediction.

Young and older adults' dual strategy performance predictions, which were provided *prior* to being informed that they would be able to select their own speed, were significantly correlated with all previous performance predictions ($p < .001$ - $p < .05$). Dual strategy performance predictions were also correlated with all previous measures of performance for older adults, and all but single navigation performance for younger adults ($p < .001$ - $p < .05$). This pattern suggests that despite having only item level feedback in the navigation task, participants were using information acquired while monitoring to inform later performance predictions.

**Strategic Adaptation**

In each task performance increased from the first dual task block to the dual strategy block. In fact, no significant differences were found between navigation performance in the dual strategy block and navigation performance in the single task block (see Figure 4) for either age group ($p > .05$). PVSAT performance also increased from the first dual task block to the dual strategy block, though performance remained lower than single task PVSAT performance. This pattern is consistent with our instruction to prioritize the navigation task over the PVSAT when dual tasking.

To assess the temporal optimization of navigation grid performance, a temporal residual (TR) was calculated as the difference between a participant's speed selection and the total amount of time required to complete an individual navigation grid. TRs were then averaged on the participant level for each of the 12 sub-trials, and were submitted to a 2 (age: old, young) x 12 (sub-trial: 1-12) ANOVA. A main effect of age was observed, with older adults having larger TRs than young adults ($M_{old}$=12,103.67ms, $M_{young}$=9777.11ms), $F(1,128)=9.03$, $p=.003$, $\eta_p^2 = .07$. The main effect of sub-trial was not significant ($p > .05$). An age x sub-trial interaction was observed, $F(11,1408) = 7.69$, $p <. 001$, $\eta_p^2 = .057$, with older adults increasing their TR from sub-trial 1 to sub-trial 12, $t(48) = -2.26$, $d = -0.32$, $p = .028$, and young adults decreasing their TR from sub-trial 1 to sub-trial 12, $t(95) = 3.57$, $d = 0.37$, $p = .001$. Focused comparisons at each sub-trial are presented in Table 5 and illustrated in Figure 5. To decrease the likelihood of committing a Type-1 error, a Bonferroni correction was applied resulting in an alpha level of .002.

We also assessed the difference between speed selection in the dual strategy block and the speed during optimal navigation performance in the first dual task block. Again, the 27 trials in the first dual task block were subdivided into 9 bins consisting of 3 navigation trials each, and a mean proportion correct was calculated for each participant at each bin. For each participant, the maximum proportion correct of these averages was labeled as peak performance. To assess the speed at which each participant's performance dropped off, we calculated a threshold defined as 67% of their peak performance. We then calculated at which bin performance dropped below the threshold, and did not bounce back over the threshold. The bin immediately preceding the bin in which performance fell below the threshold was labeled as the bin of optimal performance. A difference score, labeled as deviation from optimal speed (DOS), was then calculated between each of the speed selections in the dual strategy block, and the speed associated with the bin of optimal performance in the first dual task block. We submitted DOS to a 2 (age: old, young) x 12 (sub-trial: 1-12) ANOVA. No significant main effect of sub-trial was observed ($p > .05$). A significant main effect of age, $F(1,151) = 4.79$, $p < .05$, $\eta_p^2 = .03$, was further qualified by a significant age x sub-trial interaction, $F(1,151) = 5.87$, $p < .001$, $\eta_p^2 = .04$. Though both age groups were over selecting speeds over 5 seconds greater than the speed during optimal performance in the first dual task block, older adults seemed to be endorsing an even more cautious strategy in their speed selection than young adults. Focused comparisons are presented in Table 5, and are illustrated in Figure 6. To decrease the likelihood of committing a Type-1 error, a Bonferroni correction was applied resulting in an alpha level of .002.

To test the relationship between metacognitive performance predictions and strategic control in the dual strategy block, we conducted a series of multiple linear regressions. In each of the models, mean speed selection was included as the criterion variable. Age was dummy coded with older adults serving as the reference group and included as a categorical variable. Performance predictions and accuracy were included as continuous. Since dual strategy performance was contaminated by speed selection, we chose to only include performance in the first dual task block. Dual strategy predictions were included as participants made these prior to being informed that they would be able to select their own speeds.

Of primary interest was whether performance predictions differentially predicted speed selection in young and older adults. Being that the navigation task was prioritized, we sought to understand whether the simple relationship of navigation predictions and speed selection differed between age groups. Our full model included navigation predictions, age, and the age x navigation prediction interaction, $F(3,152)=32.91$, $p <$ .001, ${}_{adj}R^2 = .38$. A reduced model including only navigation predictions was compared to the full model. The inclusion of age and the age x navigation prediction interaction significantly improved model fit, $\Delta R^2 = .30$, $\Delta F(2,152) = 37.21$, $p < .001$. This was expected, as average speed selection of older adults was greater than that of young adults ($M_{old} = 25693.45$, $M_{young} = 18191.67$), $d = 1.48$, $t(154) = 9.24$, $p < .001$. To further understand the relationship, we tested for equality of slopes between age groups. A reduced model including age and navigation predictions was compared to the full model, but did not improve fit, $\Delta R^2 = .005$, $\Delta F(1,152) = 1.28$, $p = .26$. Though the bi-variate relationship between navigation predictions and selected speed was significant for older adults, $r = -.36$, $p < .01$, and not young adults, $r = -.16$, $p > .05$, the slope of the regression equations did not differ between ages.

We were also interested in whether performance predictions remained a reliable predictor of speed selection over and above task performance. Our full model included age, navigation performance, PVSAT performance, navigation predictions, PVSAT predictions $F(5,150)=20.56$, $p < .001$, ${}_{adj}R^2 = .39$. A reduced model including age, navigation performance, and PVSAT performance was compared to the full model. The inclusion of navigation and PVSAT predictions did not improve model fit, $\Delta R^2 = .005$, $\Delta F(2,150) = .58$, $p = .56$. Age differences in predictions did not predict selected speed when controlling for age differences in performance. We also compared the full model to a model including the interactions of age with navigation performance, PVSAT performance, navigation predictions, PVSAT predictions. The inclusion of the interactions did not improve model fit, $\Delta R^2 = .028$, $\Delta F(4,146) = 1.81$, $p = .13$.

**Post-task Questionnaires**

Means, standard deviations, and age comparisons for all post task measures are presented in Table 1. First, we assessed age differences in self-reported driving behavior. Compared to young adults, older adults reported engaging in less risky driving behavior, $t(153) = -7.40$, $p < .001$, reported fewer attentional lapses, $t(153) = -5.24$, $p < .001$, and reported that they were better at multitasking and driving than their peers, $t(153) = 3.30$, $p = .001$. No significant age differences were observed regarding the perceived riskiness of distracted driving ($p = .99$). Scores on the MPI were compared, though and neither age group showed a greater preference for multitasking ($p = .37$). Bi-variate correlations were calculated between the scores on the DBQ subscales, the MPI, and speed selection, though no significant relationships were found. Postdictions of optimal speed were significantly higher for old adults than younger adults, $t(153) = 6.13$, $p < .001$. Postdictions of optimal speed and average speed selection were not significantly different for either age group ($p > .05$).

Older adults rated the experiment as being more difficult, but less fatiguing than young adults. Older adults were also significantly more motivated to perform well, and maintained a higher level of focus when compared to young adults. Speed selection was significantly correlated with self-rated difficulty ($r_{old} = .32$, $r_{young} = .29$) and fatigue ($r_{old} = .29$, $r_{young} = .30$) for both age groups ($p < .05$).

# CHAPTER IV

# DISCUSSION

The present research investigated the association of metacognitive performance predictions and strategic adaptation to dual tasking through the use of concurrent laboratory tasks. The results aid in bridging the gap between the literature on metacognition and the literature on multitasking and driving. Our results indicate that the sparing of metacognitive monitoring throughout the lifespan may generalize to more complex task environments such as multitasking. We were unable to find direct evidence of a link between metacognitive predictions and metacognitive control, measured here as strategic speed selection, in either age group, though task approaches did differ between old and young adults.

In general, it seems that individuals were reasonably well calibrated to their raw performance. These findings are consistent with prior laboratory and driving studies (Finley et al., 2014; Horrey, Lesch, & Garabet, 2008). For both age groups, single task and dual task PVSAT performance predictions were significantly correlated with their respective performance. Of the navigation predictions, only single task predictions for older adults were significantly correlated with performance. Interestingly, navigation predictions provided before the strategy block were significantly correlated with performance in the first dual task block. Much as memory for previous test performance may affect judgments of learning (Finn & Metcalfe, 2007; Hertzog, Hines, & Touron, 2013), it seems that participants were monitoring their performance during the first dual task block and using that information when predicting later dual task performance.

Though metacognitive monitoring was reasonably calibrated for both age groups, it appears that neither age group particularly used that information when choosing their speeds. Though a significant bivariate relationship was found between dual strategy navigation predictions and speed selection for older adults ($r = .36$, $p < .01$), much of the variance was shared with prior task performance. Once accounting for prior task performance, predictions were no longer a reliable predictor of speed selection. Although metacognitive predictions did not seem to predict speed selection over and above task performance, young and older adults did approach the task differently when given the opportunity to act strategically. Compared to young adults, older adults had larger deviations from optimal speed and larger temporal residuals. It is possible that older adults were selecting speeds that would ensure accurate responding at the expense of quick responding. Younger adults on the other hand may have been more motivated to complete the task quickly *and* accurately. Prior work has shown similar speed-accuracy biases in young and older adults (Strayer & Kramer, 1994; Hertzog, Vernon, & Rypma, 1993). A second possibility is that older adults may have also been enacting a strategy that allowed them to avoid the concurrent nature of the task for as long as possible. As evidenced by the greater residuals of older adults, they may have been completing the navigation task quickly and using the temporal residual to complete the PVSAT on its own. Strategies such as these have been found in the task switching literature (Glass et al., 2000), and the driving literature (Pöysti, Rajalin, & Summala, 2005; Sutts et al., 2005). If older adults had fewer attentional resources to allocate to completing the tasks concurrently, splitting the tasks may have provided performance benefits.

It is possible that the disassociation between metacognitive monitoring and strategic adaptation was due in part to participants effectively monitoring their performance but failing to monitor speed. The speed during the experimenter paced navigation blocks became faster as the trials progressed, effectively making the task more difficult. It is possible that participants were unable to delegate sufficient attentional resources to completing the task and concurrently monitoring performance and speed. It is also possible that such monitoring deficiencies were exacerbated as the speeds got faster and the task became more difficult. When speed selections were made, it is possible that participants used information gathered during successful monitoring (ie. during slower speeds) rather than when monitoring was impaired. This would corroborate our findings that individuals were selecting speeds that were slower than their speed of optimal performance.

It is also possible that participants were basing their speed selections on macro level beliefs of the task. Previous work has shown that factors such as productivity pressures (Lee & Strayer, 2004) and perceived importance of the concurrent task (Nelson, Atchley, & Little, 2009) can influence distraction mitigation strategies. The results of the current study indicated significant relationships between self-reported task difficulty and fatigue experienced during the task and speed selection. Though the directionality of the relationship is not certain, it may be possible that speed selections were based more on how difficult or fatiguing the task seemed rather than on predictions of performance. This seems even more likely if individuals were unable to monitor speeds effectively during the experimenter paced blocks.

A potential limitation of the current study is that navigation speed was not modulated concurrently with the task. When driving an automobile, individuals are able to continuously modulate speed via throttle or braking input in accordance with road conditions and driving demands. Environmental cues such as perceived lateral acceleration (Reymond et al., 2001) or one's position in relation to points on the road (Beall & Loomis, 1996) have been shown to influence various aspects of driving behavior. For example, the rate that stationary objects pass by the car may cue the driver to slow down or speed up. In the current study, speed modulation was a deliberate act taken out of context of the primary and secondary tasks. Furthermore, participants were provided with few environmental cues to aid in the understanding of how speeds differed from one another - for instance, how 18s *felt* relative to 20s. It is possible that the unfamiliar nature of our index of speed in conjunction with the non-concurrent speed adjustment led participants to underutilize or ineffectively utilize speed modulation. Future work may consider using either simulated or real world driving environments to investigate the influence of metacognitive performance predictions on strategic driving behavior.

The results of the current study propose that knowledge of one's ability to multitask may not have a direct effect on strategies enacted to mitigate multitasking related performance. Prior work has found that metacognitive judgments of multitasking related performance decrements are not well calibrated to actual performance decrements (Finley et al., 2014; Horrey, Lesch, Garabet, 2008). Though some individuals may under-predict the effects of multitasking on their driving performance, the current study suggests that these predictions may not be a significant factor when forming and enacting mitigating strategies. It is possible that individuals rely on environmental stimuli to cue the need to adjust driving behavior. For instance, a driver may be cued to adjust their speed when they perceive uncomfortable lateral forces as they progress through a turn. It may be the case that environmental cues spur the use of in-line metacognitive processes to reappraise driving performance and enact strategic control.

The modern driving experience has become complicated by the inclusion of complex infotainment systems and personal electronic devices. The National Highway Traffic Safety Administration (NHTSA) estimates that on any given day approximately 540,000 drivers engage with a handheld phone (Pickrell et al., 2016). Clearly, drivers are continuing to use cell phones in spite of state level legislation stating otherwise. Understanding the manner in which drivers are adapting their driving to accommodate diverted attention may inform the way in which we design vehicles and implement interventions.

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APPENDIX A

TABLES

*Table 1*

*Descriptive Statistics for Both Age Groups.*

| Variable | Older Adults *M* | Older Adults *SE* | | Young Adults *M* | Young Adults *SE* |
|---|---|---|---|---|---|
| **Demographics** | | | | | |
| Age | 69.52 | 0.57 | | 19.21 | 0.16 |
| Education | 16.57 | 0.32 | * | 12.79 | 0.11 |
| Health | 4.59 | 0.07 | * | 4.22 | 0.07 |
| Medications | 2.37 | 0.21 | * | 0.53 | 0.07 |
| Vocabulary | 24.56 | 0.92 | * | 14.14 | 0.37 |
| Processing Speed | 29.53 | 0.91 | * | 36.99 | 0.78 |
| | | | | | |
| **Post-Task Surveys** | | | | | |
| DBQ Behavior | 57.44 | 1.02 | * | 68.26 | 0.93 |
| DBQ Perceived Risk | 13.05 | .488 | | 13.03 | 0.32 |
| DBQ Lapses | 8.18 | 0.34 | * | 11.41 | 0.42 |
| Relative Ability | 7.02 | 0.29 | * | 5.95 | 0.18 |
| MPI | 40.53 | 1.52 | | 39.60 | 0.88 |
| Post Speed Selection | 26200.00 | 618.68 | * | 19960.00 | 672.84 |
| Difficulty | 3.87 | 0.12 | * | 3.48 | 0.09 |
| Fatigue | 3.15 | 0.13 | * | 3.73 | 0.11 |
| Comprehension | 3.24 | 0.14 | * | 2.77 | 0.11 |
| Motivation | 3.55 | 0.17 | * | 2.88 | 0.12 |
| Stress | 3.25 | 0.14 | | 3.43 | 0.13 |
| Interest | 1.64 | 0.11 | * | 2.83 | 0.11 |
| Effort | 1.53 | 0.09 | * | 1.98 | 0.08 |
| Satisfaction | 3.45 | 0.12 | * | 3.05 | 0.10 |
| Focus | 4.29 | 0.12 | * | 3.30 | 0.13 |
| Subjective Performance | 3.36 | 0.11 | * | 3.06 | 0.10 |

*Note:* *. T-test is significant at the 0.05 level (2-tailed), Age = Current age in years, Education = total years of education, Health = 1-4 self-report with low being better, Medications = number of medications taken daily, Vocabulary = Score on the Advanced Vocabulary Test (Ekstrom et al., 1976), Processing Speed = number correct out of 60 on the Pattern Comparison Test, DBQ Behavior = self-reported engagement in risky driving behavior (*out of 5 with 0 = very rarely and 5 = very often*), DBQ Perceived Risk = self-perceived risk of distracted driving (*out of 5 with 0 = extremely dangerous and 5 = not at all dangerous*), DBQ Lapses = self-reported frequency of attentional lapses while driving (*out of 5 with 0 = very rarely and 5 = very often*), Relative Ability = self-reported ability to drive safely when multitasking compared to one's peers (*out of 5 with higher scores indicating participants viewed themselves as better drivers.*, MPI = score on the Multitasking Preference Inventory (*out of 5 with higher scores being more indicative of a preference for multitasking*), Post Speed Selection = Postdiction of the speed at which one believed they performed as quickly and accurately as possible in the navigation task, Selected Speed = Mean selected speed in the strategy block, Difficulty = self-rated difficulty of the experiment, Fatigue = self-rating of fatigue experienced during the experiment, Comprehension = self-rated ability to understand instructions during the experiment, Motivation = self-rated motivation to do well in the experiment, Stress = self-rated stress experienced during the experiment, Interest = self-rated interest in the experiment, Effort = self-rating of the ability to do better with more effort invested, Satisfaction = self-rating of how satisfied one was with their performance, Focus = self-rating of the ability to maintain focus during the experiment, Subjective Performance = self-rating of overall performance during the experiment.

*Table 2*

*Age Comparisons of Binned Performance.*

| | Single Navigation | | | Dual Navigation | | |
|---|---|---|---|---|---|---|
| | *t* | *df* | *Sig.* | *t* | *df* | *Sig.* |
| 30-28s | -1.993 | 154 | .048* | -2.495 | 154 | .014* |
| 27-25s | .555 | 154 | .580 | -3.439 | 154 | .001** |
| 24-22s | -.317 | 154 | .752 | -2.364 | 154 | .019* |
| 21-19s | .304 | 154 | .762 | -2.872 | 154 | .005** |
| 18-16s | -2.768 | 154 | .006** | -4.021 | 154 | .000** |
| 15-13s | -1.487 | 154 | .141 | -5.257 | 154 | .000** |
| 12-10s | -3.806 | 154 | .000** | -7.018 | 154 | .000** |
| 9-7s | -7.797 | 154 | .000** | -7.324 | 154 | .000** |
| 6-4s | -6.780 | 154 | .000** | -3.814 | 154 | .000** |

Note: Independent samples t-test between age groups at each bin of the navigation trial. *. T-test is significant at the .05 level (2-tailed). **. T-test is significant at the .005 level (2-tailed w/ Bonferroni correction).

*Table 3*

*Older Adult Predicted vs. Actual Performance Correlation Matrix.*

| | Single Prediction | Single Performance | Dual Task Prediction | Dual Task Performance |
|---|---|---|---|---|
| | | Navigation | | |
| Single Performance | .655** | | | |
| Dual Task Prediction | .520** | .333* | | |
| Dual Task Performance | .328* | .528** | .222 | |
| Dual Strategy Prediction | .428** | .431** | .627** | .489** |
| | | PVSAT | | |
| Single Performance | .593** | | | |
| Dual Task Prediction | .782** | .550** | | |
| Dual Task Performance | .571** | .413** | .453** | |
| Dual Strategy Prediction | .587** | .390** | .732** | .492** |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

*Table 4*

*Young Adult Predicted vs. Actual Performance Correlation Matrix.*

| | Single Prediction | Single Performance | Dual Task Prediction | Dual Task Performance |
|---|---|---|---|---|
| | | Navigation | | |
| Single Performance | .163 | | | |
| Dual Task Prediction | .348** | .117 | | |
| Dual Task Performance | .139 | .351** | .108 | |
| Dual Strategy Prediction | .252* | .181 | .457** | .559** |
| | | PVSAT | | |
| Single Performance | .205* | | | |
| Dual Task Prediction | .581** | .125 | | |
| Dual Task Performance | .343** | .479** | .271** | |
| Dual Strategy Prediction | .471** | .203* | .527** | .511** |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

*Table 5*

*Means and Standard Errors for TR and DOS by Sub-trial.*

| | TR | | | | | DOS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Older Adults | | | Younger Adults | | Older Adults | | | Younger Adults | |
| Sub-trial | *M* | *SE* | | *M* | *SE* | *M* | *SE* | | *M* | *SE* |
| 1 | 10473.67 | 663.13 | | 11863.03 | 580.84 | 5611.11 | 640.70 | | 7404.04 | 610.31 |
| 2 | 11490.72 | 682.76 | | 11553.55 | 534.32 | 6925.93 | 670.77 | | 6929.29 | 569.12 |
| 3 | 12422.04 | 700.84 | ** | 9725.89 | 528.74 | 8018.52 | 686.54 | * | 5848.48 | 532.66 |
| 4 | 11938.10 | 740.82 | * | 9808.08 | 553.01 | 8277.78 | 716.88 | * | 6111.11 | 515.06 |
| 5 | 11643.61 | 766.73 | * | 9305.45 | 543.27 | 8018.52 | 740.88 | * | 5979.80 | 510.45 |
| 6 | 11988.86 | 746.21 | * | 9373.48 | 550.26 | 8240.74 | 741.09 | * | 6383.84 | 499.37 |
| 7 | 12684.22 | 733.33 | ** | 8979.93 | 525.06 | 8537.04 | 732.45 | * | 6111.11 | 524.97 |
| 8 | 12260.28 | 727.54 | ** | 9067.28 | 549.87 | 8351.85 | 732.66 | * | 6434.34 | 516.31 |
| 9 | 12570.37 | 696.60 | ** | 9530.63 | 552.28 | 8425.93 | 739.99 | * | 6414.14 | 525.19 |
| 10 | 11234.24 | 733.60 | ** | 9695.27 | 572.05 | 8462.96 | 710.17 | * | 6323.23 | 553.81 |
| 11 | 12164.89 | 709.49 | ** | 9288.56 | 577.13 | 8351.85 | 719.19 | * | 6010.10 | 535.00 |
| 12 | 12300.64 | 734.51 | ** | 9211.72 | 565.39 | 8203.70 | 730.86 | * | 5838.38 | 530.59 |

Note: Independent samples t-test for Temporal Residuals (TR) and Deviation from Optimal Speed (DOS) between age groups at each sub-trial of the dual strategy block. *. T-test is significant at the 0.05 level (2-tailed). **. T-test is significant at the .004 level (2-tailed w/ Bonferroni correction).

APPENDIX B

FIGURES

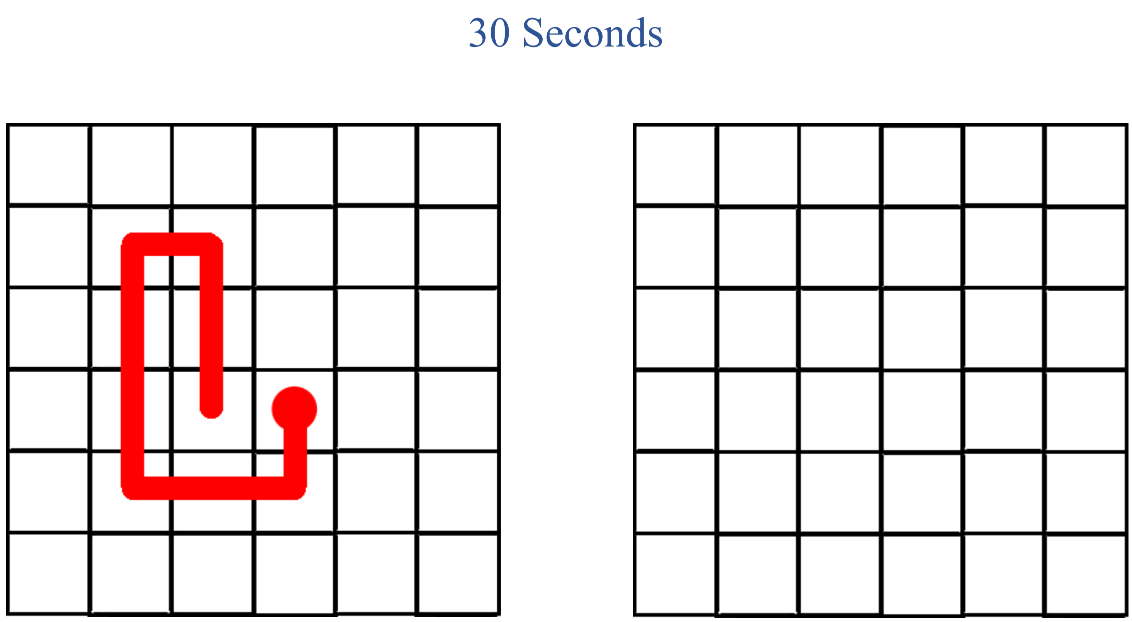


*Figure 1*

*Example of Navigation Task.* Participants were to copy the navigation path displayed in the left grid to the empty grid on the right. They were asked to begin at the end with the circle, and use the mouse to click sequentially through the end of the path. Cells in the right grid would turn red upon selection. If the pattern was correctly copied in order, the right grid would turn green. The amount of time allocated for the completion of each navigation grid was displayed at the top of the screen.

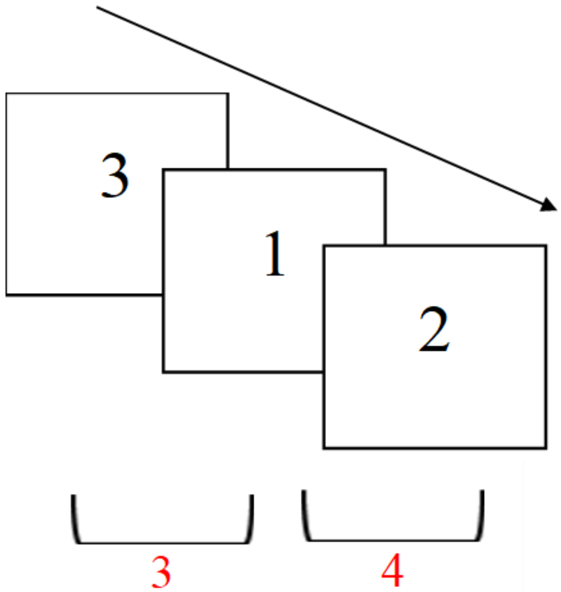


*Figure 2*

*Example of PVSAT.* The PVSAT required participants to add the number currently on the screen to the number previously presented on the screen. In this example, the correct response after the second number would be "4" and the correct response after the third number would be "3". The stimulus presentation rate was held constant at 4s for the entirety of the experiment.

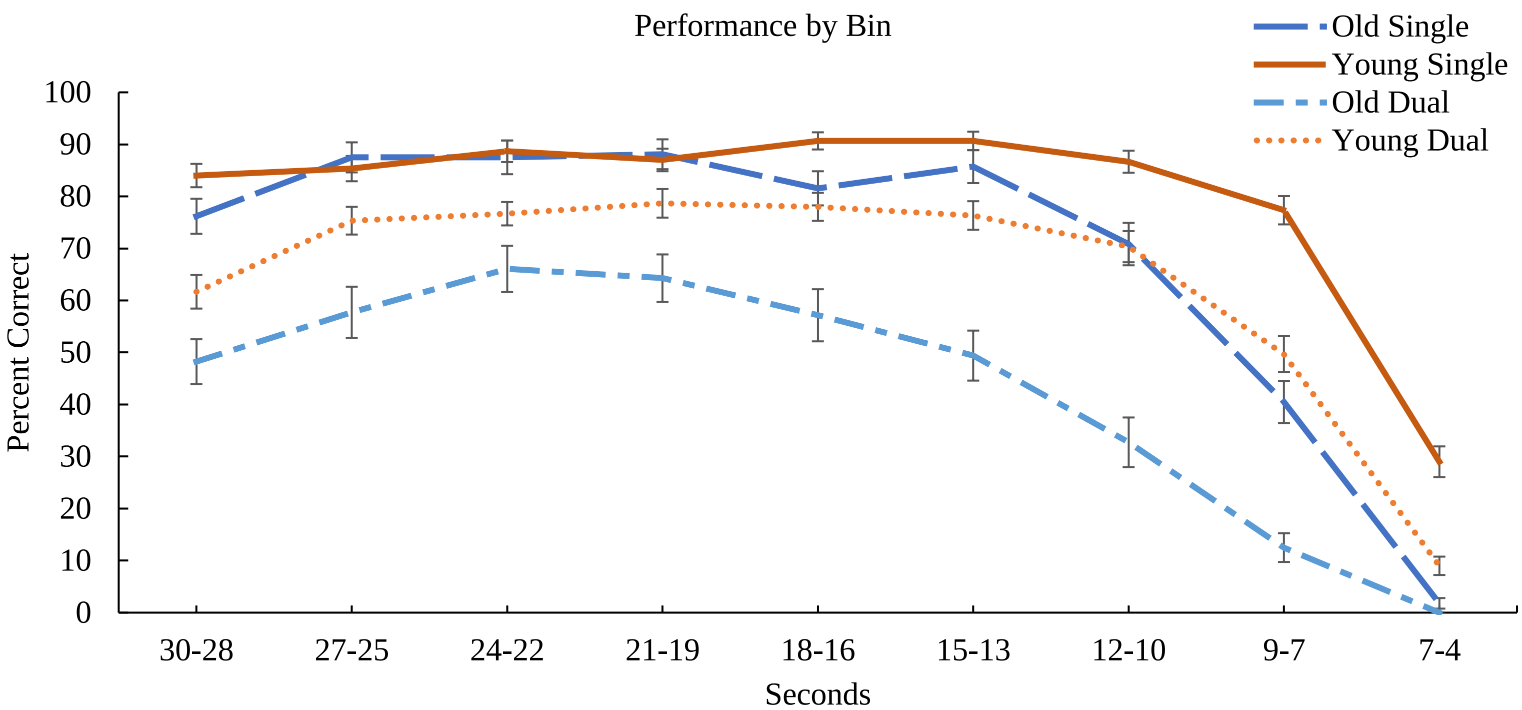


*Figure 3*

*Age Comparisons of Navigation Performance by Bin.* Bars signify standard error of the mean.

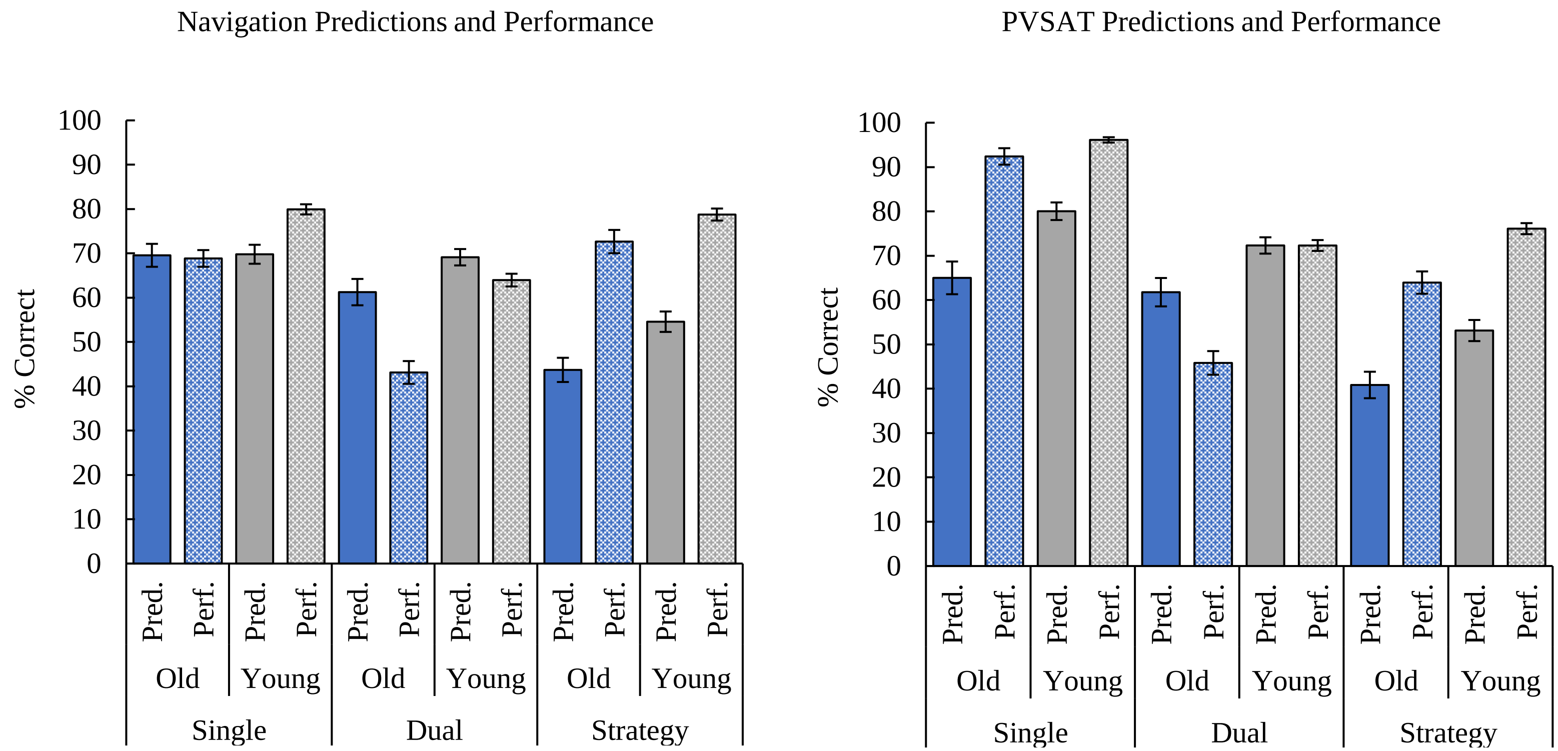


*Figure 4*

*Predictions and Performance by Age, Condition, and Task.* Single = Single-task, Dual = Dual-task, Strategy = Dual-task strategy block, Pred. = Prediction, Perf. = Accuracy. Bars signify standard error of the mean.

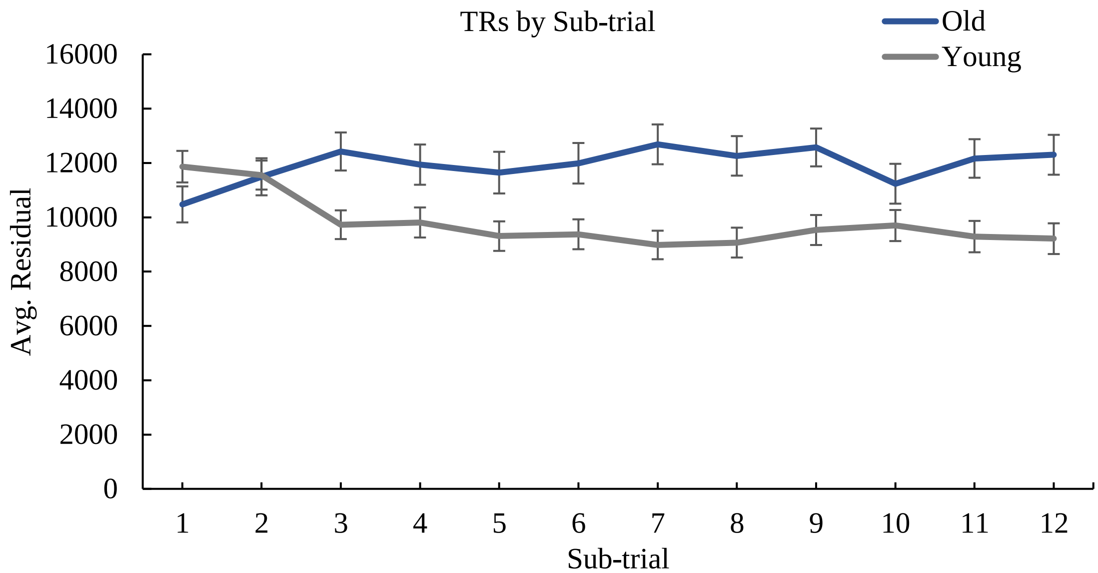


*Figure 5*

*Temporal Residuals (TR) by Sub-trial*. Each sub-trial consists of 4 navigation grids. Bars signify standard error of the mean.

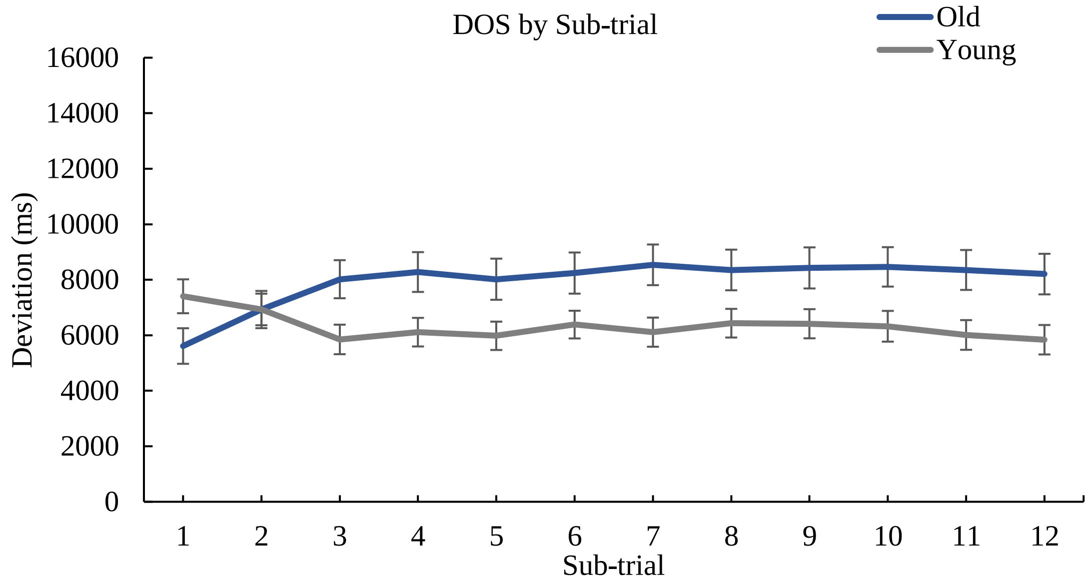


*Figure 6*

*Deviation from Optimal Speed (DOS) by Sub-trial.* Each sub-trial consists of 4 navigation grids. Bars signify standard error of the mean.