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The Neuropsychological Functioning of Older Adults Pre- and Post-Cognitive Training with a Brain Plasticity-Based Computerized Training Program

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THE NEUROPSYCHOLOGICAL FUNCTIONING OF OLDER ADULTS PRE- AND POST-COGNITIVE TRAINING WITH A BRAIN PLASTICITY-BASED COMPUTERIZED TRAINING PROGRAM

A Thesis Presented

by

SHANNON M. SORENSON

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ABSTRACT

THE NEUROPSYCHOLOGICAL FUNCTIONING OF OLDER ADULTS PRE- AND POST-COGNITIVE TRAINING WITH A BRAIN PLASTICITY-BASED COMPUTERIZED TRAINING PROGRAM

December 2012

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The present study evaluates the effectiveness of Posit Science Cortex™ with Insight Drive Sharp™ as a tool for improving neuropsychological functioning in a normal aging sample. The purpose of the DriveSharp™ training program is to help an individual improve his or her visual attention and useful field of view. Each exercise continually adapts to the individual's performance so that the training is always at an appropriate level for that specific person. Thirty-two healthy older adult participants were randomly assigned to either the active intervention group (DriveSharp™) or a waitlist control group. Participants in the intervention group were required to engage in training at its recommended dosing (60 min/day, 5 days/week, 2 weeks). All participants were given identical neuropsychological assessments to measure change in various realms of cognitive functioning. The Trail Making Test (Reitan, 1986) and the Useful Field of View test (UFOV; Edwards, Vance, et al., 2005) were used to assess the areas of cognition that DriveSharp™ was designed to train (visual attention and information processing), and the Raven's Progressive Matrices test (Raven, 1962) was used to measure area of cognition that is not directly trained by the program: fluid intelligence. It was hypothesized that participants undergoing the intervention would experience improvement in both the trained and untrained neuropsychological measures, and that the performance gain on the measure of fluid intelligence would be the result of the variance shared between fluid intelligence and the more fundamental, directly-trained cognitive abilities. Results revealed a statistically significant improvement on Trail Making Test A/C and the UFOV Selective Attention subtest for the total sample that received training. There was also evidence of a training effect on the UFOV Divided Attention subtest, though this improvement was not statistically significant. These results indicate that the DriveSharp™ program may improve specific aspects of visual attention related to selective attention and inhibition of irrelevant information. No significant change in performance was seen on the UFOV Processing Speed subtest (a measure of a cognitive area claimed to be directly trained by the DriveSharp™ program). Additionally, there was no significant improvement in performance on the Raven's Progressive Matrices, indicating no improvement due to training in more complex abilities, such as fluid intelligence.

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CHAPTER 1

INTRODUCTION

Over the past decade, there has been an increasing scientific and popular interest in the question of whether mental exercises can improve cognition (e.g., Restak & Kim, 2010). This area of research is especially important for older adults who are at significant risk for cognitive decline. Elderly adults (65 and older) make up the fastest growing age group in the country, expected to grow to be 19% of the population by 2030 (US Census Bureau, 2010). As this large proportion of individuals reach the age where cognitive changes can limit their functional capacity, it will be important to develop useful interventions that can prevent, slow, or even reverse their cognitive decline.

1.1 Specific Aims

Using a randomized, controlled study, the effects of a computerized cognitive training software program on neuropsychological test performance were evaluated. The software used, Posit Science Cortex™ with Insight Drive Sharp™ (henceforth called DriveSharp™), was designed to improve visual attention and processing speed. The specific aims of this study were as follows:

1. **To use a randomized controlled design to examine the effects of Drive Sharp™ on basic aspects of visual attention, including processing speed,**

scanning, and shifting set evaluated by the Trail Making Test in a healthy aging sample.

Older adults are often slower and less accurate than younger adults in performing visual-search tasks, suggesting an age-related decline in attentional functioning (e.g., Craik & Byrd, 1982). Computerized cognitive training has been shown to improve functioning in cognitive realms that are directly trained, such as attention (Ball et al., 2002; Smith et al., 2009; Willis et al., 2006). The Trail Making Test is a neuropsychological test of visual attention that requires participants to draw a line to connect 25 consecutive targets on a sheet of paper. This study used two versions of the Trail Making Test. Trail Making Test A (or C, as the alternate version) requires connecting dots in numerical order—a measure of processing speed and visual scanning. Trail Making Test B (or D, the alternate version) requires switching between ascending numbers and letters (a measure of executive functioning and set-shifting). The primary measure of performance on these tests is the time to completion. The test was given to a community sample of healthy, older adult participants (ages 60-75) who were of normal cognitive aging (Mini-Mental Status Examination [MMSE] greater than 26). The participants were assigned to either the training condition or a waitlist control condition to determine the efficacy of the DriveSharp™ training program on performance on this measure of visual attention. *Hypothesis:* Performance on Trail Making Tests A/C and B/D, measures representing cognitive realms thought to be directly trained by the DriveSharp™ program (visual attention, visual processing speed, and divided attention) would improve after the two-week training period.

2. **To use a randomized controlled design to examine the effects of Drive Sharp™ on basic aspects of visual information processing related to attention, orienting, and control evaluated by the UFOV test in a healthy aging sample.**

The Useful Field of View (UFOV) is defined as the region of the visual field from which an observer can extract information at any given time (Ball, 2003). The Useful Field of View test is a computerized task that measures the speed at which one can rapidly process multiple stimuli across the visual field. Three subtests are administered (a test of processing speed, a test of divided attention, and a test of selective attention). Each subtest requires accurately identifying targets presented at varying durations (16.67-500 ms). The three subtests were given to a community sample of healthy, older adult participants (ages 60-75) who were of normal cognitive aging (MMSE greater than 26). The participants were assigned to either the training condition or a waitlist control condition to determine the efficacy of the DriveSharp™ training program on performance on this measure of visual attention. *Hypothesis:* Performance on the UFOV, a measure of visual attention (a cognitive realm thought to be directly trained by the DriveSharp™ program), would improve after the two-week training period.

3. To use a randomized controlled design to examine the effects of Drive Sharp™ on fluid intelligence evaluated by the Raven's Progressive Matrices test in a healthy aging sample.

Fluid intelligence is a higher-level cognitive ability that allows us to solve novel problems, independent of our previously acquired knowledge (e.g., Bors & Forrin, 1995). Fluid abilities such as problem-solving, learning, and pattern recognition have been shown to rapidly decline with age (Maitland, Intrieri, Schaie, & Willis, 2000). A recent study provided evidence that training more fundamental cognitive realm could produce a transfer effect, improving complex, higher-level areas of mental ability that were not directly trained (e.g., fluid intelligence; Jaeggi, Buschkuehl, Jonides & Perrig, 2008). This study used the Raven's Standard Progressive Matrices test, a measure of fluid intelligence requiring analytic and reasoning processes to understand visual analogies and solve multiple choice matrix problems. The test was given to a community sample of healthy, older adult participants (ages 60-75) who were of normal cognitive aging (MMSE greater than 26). The participants were assigned to either the training condition or a waitlist control condition to determine the efficacy of the DriveSharp™ training program on performance on this measure of fluid intelligence. Hypothesis: Performance on the Raven's Standard Progressive Matrices, a measure of fluid intelligence (a cognitive realm not directly trained by the DriveSharp™ program), would improve after the two-week training period.

1.2 Aging and Cognition

Cognitive decline is a universal aspect of aging, sometimes beginning as early as age 30 and progressively worsening throughout the lifetime. Cognitive deterioration, at least to some extent, is expected in many realms of mental functioning as part of the normal developmental process. Most older adults experience age-associated declines in many areas of cognitive functioning (Hedden & Gabrieli, 2004). Numerous cross sectional and longitudinal studies have documented significant decline in processing speed (Verhaeghen & Cerella, 2008), visual attention (Madden & Whiting, 2004), working memory capacity (Braver & West, 2008), learning and recalling new information (Old & Naveh-Benjamin, 2008), and fluid intelligence (for examples, see Horn & Cattell, 1967; Schretlen et al, 2000). A major worry in elderly adults is that this cognitive decline may lead to disorientation, psychosocial problems, decreased mobility, and difficulties performing tasks of every-day life. Along with these functional declines often comes a loss of independence and a need for assistance, placing an emotional and financial strain on individuals, their families, and society.

1.3 Neural Mechanisms of Aging

Throughout the lifespan, the brain is capable of changing—both physically and functionally—as the result of one's experience. Neuroplastic changes can have positive or negative impacts on cognitive ability depending upon the nature of the experience. These effects are thought to reflect the strengthening or weakening of the synaptic connections responsible for various mental abilities (Mahnke, Bronstone & Merzenich, 2006). For example, Hebbian learning processes are known to induce long-term potentiation (LTP), a mechanism that strengthens the association between neurons that frequently fire together. This causes synaptic pathways to become more efficient, increasing the speed with which their respective cognitive processes are executed (Barnes, 2003; Burke & Barnes, 2006; Bliss & Collingridge, 1993). Though the neurochemical complexities are not fully understood, brain plasticity is thought to be the result of a change in the transmembrane potential of one neuron after the post-synaptic neurotransmitter receptors are activated. Second messenger molecules in the cell notice the repeated activation of these neurotransmitters and initiate protein synthesis. Consequently, hormones and growth factors are produced that alter the structure and activity of the neuron. Changes include the growth of the synaptic connection and an increase in the number of receptor cells, making the post-synaptic cell more sensitive to the signal of the neuron before it (Bliss & Collingridge, 1993).

During normal aging, changes in activity patterns and progressive biological susceptibilities contribute to the weakening of these synaptic connections. While LTP can increase the efficiency of highly active neural networks, a reverse effect can also occur if these pathways stop being used. This long-term "depression" weakens the synaptic connections that are less-frequently stimulated. When this happens, the glutamate binding to NMDA receptors on the postsynaptic dendrites brings few calcium ions into the neuron. This small amount of calcium activates enzymes that dephosphorylate the receptors, making them less responsive to glutamate. Long-term depression may also reduce the number of post-synaptic AMPA receptors, further contributing to decreased reactivity of the post-synaptic cell. Age-related cognitive decline is thought to be related to the weakened sensitivity of these synaptic connections (Barnes, 2003).

Long-term depression contributes to the weakening of synaptic connections due to the gradual disuse of certain cognitive abilities over time, creating a self-reinforcing cycle of decreases in behavioral activity, synaptic loss and negative structural change (Churchill, Glavez, Colcombe, Swain, Kramer & Greenough, 2002; Rosenzweig & Bennett, 1996). According to Mahnke, Bronstone, and Merzenich (2006), these negative plastic changes are driven by four age-related behavioral factors. First, as people age, they tend to lessen their involvement in cognitively demanding activities. This may be due to retirement or by making the decision to only pursue the activities they already know they enjoy. When exposure to new activities is reduced, the activation of learning-related systems involving attention, reward, and novelty-detection is lessened. This causes the production of neurotransmitters, receptors, and biochemical constituents of neurons to slow. Also, there is a reduction of stimulation on cognitive, sensory, and motor systems, causing a degradation of dendrites and a weakening of neural communication. Second, sensory input from all systems (auditory, visual, tactile, and proprioceptive) is degraded as a result of the inevitable deterioration of the peripheral sensory organs. As the body ages, there is typically a loss of hair cells in the cochlea in the ear, a loss of photoreceptors in the retina, and changes in the skin's sensitivity. Sensory abilities become less precise; mental representations that are based on these sensory signals take more time to form and do not always accurately represent the external experience. Third, there is a decrease in production and processing of the neuromodulators that control brain plasticity, including acetylcholine, dopamine, serotonin, and norepinephrine. This decreases the communicatory activity in the neural networks and makes learning more difficult. Finally, aging individuals often naturally attempt to adapt their behaviors to either make challenging activities easier or avoid them altogether. For example, as it gets harder to hear the television due to loss of cells in the cochlea, a person might turn up the volume. This compensatory technique increases the damage to the ears and perpetuates the negative reorganization of the brain.

1.4 Theories of Cognitive Decline

While Merzenich and colleagues have provided a neurobiological explanation for age-related cognitive and functional decline, there are other prominent theories that offer perspective on the cognitive mechanisms driving these declines. For example, Salthouse (1991a; 1991b; 1996) has conducted extensive research supporting his processing speed theory of age-related differences in cognition. This theory asserts that declines in aging are the result of the slowing of processing speed functions. In concordance with Merzenich's theory, he proposed that the age changes in cognitive performance are the result of changes in the nature of activities performed as one approaches the latter end of the lifespan (Salthouse, 1991b). These changes come with disuse of mental skills that were once depended upon, and consequently, there is a progressive reduction in the time it takes to perform basic cognitive operations. This prevents more complex, higher-level functions from occurring in an efficient and accurate manner. The ability for critical operations to be activated and processed simultaneously is also compromised, making it difficult to execute the synchronized pattern of synapses required for a specific task. It can be speculated that this cognitive slowing is the result of the deteriorative synaptic and neuronal plasticity mechanisms described above.

Another leading theory, often called the attentional capacity theory, suggests that with age comes a reduction in the available mental energy and resources that are required to perform cognitive operations. This depletion of mental energy particularly affects the ability to sustain the attention necessary for controlled cognitive functioning (Craik & Byrd, 1982; Kahneman, 1973), but also hinders the ability to efficiently utilize and appropriately distribute attentional resources (Levitt, Fugelsang, & Crossley, 2006; Plude & Hoyer, 1985). According to this theory, demanding or cognitively effortful tasks are especially affected with increasing age because attentional capacity is readily exceeded (Craik & McDowd, 1987). Both the processing speed theory and the attentional capacity theory offer slightly different conceptualizations describing how a decline in a fundamental aspect of cognition (processing speed or attention) is the underlying mechanism of age-related decline.

1.5 Cognitive Training Interventions

The malleability of our cognitive functioning provides the opportunity for training interventions to practice and improve specific aspects of mental ability. There has been a substantial amount of research that has supported the idea that interventions can be used to prevent, minimize, or even reverse the negative effects of the aging brain, particularly in the areas most susceptible to declines (Hertzog, Kramer, Wilson, & Lindenberger, 2009). These interventions typically take the form of either direct instruction of useful cognitive strategies or repeated engagement in cognitively demanding or stimulating activities (Smith et al., 2009).

Based on studies that connect negative plasticity mechanisms (via long-term potentiation malfunction) to age-related cognitive and functional decline, we can assume that "use" and stimulation of synaptic regions can prevent or delay their structural deterioration. One theory is that modifying the levels and types of stimulating experiences in one's environment may enhance LTP and induce positive plastic changes in the brain (Hertzog, Kramer, Wilson & Lindenberger, 2009). Technology has allowed for the consolidation of various types of cognitive exercises so that this up-regulation of LTP processes can potentially take effect in humans with daily, computerized training sessions.

1.5.1 Computerized Cognitive Training Programs. The "brain fitness" industry has rapidly developed, and brain training software is now available commercially. Many facilities for older adults in the United States now offer computerized brain training software in addition to the traditional health-promoting activities. According to Dr. Michael Merzenich, the lead scientist at the brain-training software development corporation POSIT Science, the brain-plasticity based programs are designed to intervene on the negative plasticity that occurs in aging by targeting each of the underlying causes of cognitive decline. The programs are intended to strongly engage mental activity by using challenging, computer-adaptive exercises and a daily training schedule to prevent disuse of the brain. Merzenich and colleagues propose that these programs also enhance the accuracy and fidelity of mental representations by improving the auditory and visual systems' ability to engage the cognitive networks. Neuromodulatory systems are strengthened when learning-related neural networks are activated (Mahnke et el, 2006). Additionally, attention-demanding modules of these programs are thought to promote the release of acetylcholinerase and other neuro-modulators that presumably enable plasticity and contribute to overall cognitive efficiency. For example, as Merzenich and colleagues noted, the dopaminergic reward system is activated when an individual performs well in the program; therefore, dopamine systems in the ventral tegmental area and substantia nigra are activated. Also, serotonergic systems are activated when the brain is detecting a new stimulus. Finally, the program guides the users into new behaviors that positively reinforce their enhanced brain function and strengthen their critical life skills (Mahnke et al., 2006).

Although computer-based training has gained a certain amount of popularity, there is a limited amount of research that has demonstrated the positive effects of these programs. There have been two large, multi-site studies on the effects of computerized cognitive training on older adults. The first—the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study—randomly assigned 2832 independently living, older adults (age 65 or older) to one of three training groups or a control group. All subjects were recruited from senior housing, community centers, and hospitals in six cities across the U.S. Each of the three training groups engaged in 10 sessions of training for memory, reasoning, or speed of processing. Some subjects also received a four-session booster training at 11 and 35 months after the completion of the first 10 sessions. The training sessions were 60-75 minutes long and focused on applying cognitive strategies to solving every-day problems. The control group had no contact during the training parts of the study. Cognitive outcome measures were given immediately after the 10 training sessions, and yearly for five years. The cognitive measure given was designed to assess the directly trained cognitive ability (i.e. memory, reasoning, or speed of processing). Functional outcomes were assessed with self-report measures of daily living and two performance-based measures—an Every Day Problems test and an Observed Tasks of Daily Living behavioral simulation test. Results showed that all three interventions produced improvement in their specific cognitive abilities that was retained across the five years. The improvement remained significant at all five time points. The reasoning training resulted in significantly less functional decline in self-reported instrumental activities of daily living than the control group, indicating that training on higher-level cognitive abilities may generalize to day-to-day, functional improvement. There were also significant increases in the performance-based measure for processing speed, and these subjects had significant increases on a measure of self-rated health (though no significant increases on self-reported instrumental activities of daily living were seen; Wolinsky et al., 2010). This result, however, only occurred in those subjects that received the four session booster trainings, indicating a need for larger doses of training in this cognitive realm (Willis et al., 2006; Wolinsky et al., 2010).

More recently, the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) study looked at the effects of a broadly available cognitive training program designed to improve the speed and accuracy of auditory information processing. Community-dwelling, older adults (age 65 and older) were randomly assigned to the treatment group or to an active control group. The active control group watched computer-based educational videos at the time of training. The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) and a Cognitive Self-Report Questionnaire were used to assess cognition in every-day life. Results showed significant improvements in the Auditory Memory and Attention subtest of the RBANS, which was anticipated because this measure was directly related to the trained task. Performance improvements also generalized to some untrained measures of memory and attention, including word list recall, digits backwards, and letter-number sequencing. These results indicated that the computerized cognitive training did, in fact, improve generalized measures of memory and attention and that the effect was robustly distributed across a range of neuropsychological tasks (Smith et al., 2009).

Despite these two findings that support the positive effects of brain-plasticity based training programs, a recent meta-analysis on the immediate and delayed effects of cognitive interventions concluded that training programs have not shown a definitive delay or slow of progression in brain disease (Papp, Walsh, & Snyder, 2009). This, however, doesn't necessarily mean these computerized interventions are not effective, it merely highlights a need for further research on how the programs can be appropriately designed and used in the aging population.

1.5.2 Principles of Posit Science's Brain Plasticity-Based Visual Training Programs. Pioneering work by Dr. Merzenich and others has shown that the brain can undergo anatomical changes when stimulated by the Posit Science training programs. These programs adapt on a moment-to-moment and session-by-session basis to the unique abilities of each user. They are designed to train speed and accuracy by driving the brain to make accurate discriminations while operating on stimuli with rapid time courses over brief periods of time. The activities are constructed to closely resemble the demands of real-world performance so that the effects will be more likely to generalize (Delahunt et al., 2008).

The specific program used in this study (DriveSharp™) encompasses two training activities. The first, Jewel Diver, targets divided visual attention, sustained visual attention, divided visual attention, and visual precision. Performance on this task is based on the number of objects the user is able to track at once. The second task in DriveSharp™, Road Tour, targets the ability to extract useful information from peripheral vision while inhibiting irrelevant information. In other words, the activity is designed to enhance the operational visual attentional area, or the Useful Field of View (UFOV). Pilot research by Merzenich demonstrated that younger participants (mean age 27) performed significantly better than older participants (mean age 63) on both of these training activities. Merzenich also established that after 10 training sessions, the mean performance of the older participants approached that of the younger participants (Delahunt et al., 2008).

For the purpose of this study, DriveSharp™ training can be conceptualized as intending to directly improve the following cognitive abilities related to attention: sustained visual attentions, selective visual attention, divided visual attention, and the speed with which visual attentional functions are carried out. These subcomponents of visual attention have been historically conceptualized as separate but overlapping cognitive abilities, and studies have shown that different combinations of anatomical areas carry out specific operations underlying each attentional dimension. For example, the more basic aspects of attention involve orienting to a stimulus, or actively focusing on a target location. This specific type of attention has been shown to activate areas of the posterior parietal cortex in positron emission tomography studies, and is generally referred to as the posterior attentional system (Peterson et al., 1988).

Higher in the taxonomy of visual attention is selective attention, which involves searching a visual display, selecting appropriate focal targets, and reducing attention to the irrelevant stimuli present (Koch & Ullman, 1985). While neurons are selective in the range of activation depending upon the nature of the target, the role of the attentional system is to allocate activation according to which stimuli are important to direct one's focus (Sohlberg & Mateer, 2001). Attention of this nature involves the posterior attentional system interacting with the thalamus, which assists in recognition of the pertinent patterns in the environment so that one can focus on relevant stimuli while disengaging from irrelevant stimuli (Petersen et al., 1987). Previous research has shown that selective attention declines with age because of the reduced ability to inhibit the attention to irrelevant stimuli (McDowd & Filion, 1992).

At the top of the attention taxonomy are the more complex abilities that rely on attentional processes, such as divided attention and working memory (Sohlberg & Mateer, 2001), which are widely known to be susceptible to age-related declines (Hartley, 1993; Salthouse, 1991). These higher-level attentional functions involve and overlap with executive functions, such as planning and organization. In addition to the basic neurocircuitry described above, mental processing at this more executive level engages the prefrontal cortex, which assists in the aspects of attention that require organization, integration, and flexible thinking (Sohlberg & Mateer, 2001).

According to Merzenich and colleagues, DriveSharp™ is designed to enhance positive neuroplasticity mechanisms underlying the cognitive realms that are engaged by the program (Mahnke, Bronstone, & Merzenich, 2006). Since both Jewel Diver and the Useful Field of View exercises demand various aspects of visual attention, it is hypothesized that increases in neuropsychological outcome measures would be the result of upregulation of LTP and increased neural efficiency in one or more of these anatomical systems described above.

1.5.3 Evidence for Transfer Effects. Specifically, training has been shown to improve functioning in cognitive realms that are directly trained (Ball et al., 2002; Smith et al., 2009; Willis et al., 2006), but support for the idea that transfer of cognitive training can occur to dissimilar tasks has been limited (Kramer & Willis, 2002; Edwards et al., 2007). There has, however, been evidence that training in more fundamental cognitive realms can produce a transfer effect to improvement in more complex abilities. Speed of processing training, for example, has been shown to transfer to improvement on everyday abilities (based on the Timed Instrumental Activities of Daily Living test; Edwards et al., 2002) and to improvement on on-road driving performance (Roenker, Cissel, Ball, Wadley, & Edwards, 2003). Both of these tasks have little resemblance to the simple speed of processing exercises that participants were trained with and require much more complex cognitive activity. The most encouraging study on transfer effects to date (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) provided evidence that training on a task of working memory produced improvements not only on the directly trained measure of working memory processes, but also on an untrained measure of fluid intelligence. Furthermore, it was found that there was a dose dependent increase in the levels of fluid intelligence. Since previous theories have stated that working memory and fluid intelligence both require that more basic cognitive mechanisms (such as attentional control; Conway et al., 2002) be working properly for efficient and successful use, it could be argued that the training-related gain in fluid intelligence could be explained by the fact that working memory accounts for much of the variance of the individual differences in fluid intelligence. However, the increase in fluid ability levels remained intact even after controlling for pre-existing individual differences in working memory as well as gains in working memory capacity at each time point (as measured by simple or complex span tasks). This suggests that the training-related gain in fluid intelligence is not directly the result of the relationship between working memory and fluid ability, and that a true transfer effect occurred.

According to Cattell's theory (1963), fluid intelligence is used in situations that present new problems, requiring the brain to adapt to the situation and figure out a solution using higher-level mental processes. Fluid intelligence is closely related to professional and academic success (Rohde & Thompson, 2007) and is the strongest indicator of general intelligence (Neisser et al., 1996). There is a rapid decline in fluid ability into old age (Bugg, Zook, DeLosh, Devalos & Davis, 2006; Maitland et al., 2000), and research has shown that this decline is a significant predictor of age-related functional impairment (Burdick et al., 2003). Improvement in this area of cognition would undoubtedly enhance the functioning of older adults, but since the underlying nature of fluid intelligence is to solve novel problems, it is a difficult aspect of cognition to increase with practice. So far, the research by Jaeggi and colleagues provides the only evidence for the increase of fluid intelligence by training a less-complex, more fundamental cognitive ability. It suggests, however, that because fluid intelligence is conceptualized as a cluster of many intellectual abilities (such as processing speed and attention; Cattell, 1971; Horn, 1982), improvement on the fluid intelligence construct as a whole may be achieved by training these other elementary mental operations as well.

CHAPTER 2

METHODS

2.1 Participants

The target population (n=32) was a community sample of older individuals between the ages of 60-75, who were active drivers, without past or current neurological or serious psychiatric history. All participants were required to have Mini-Mental Status Exam (MMSE; Folstein, Folstein, & McHugh, 1975) scores of 26 or greater. No participants were enrolled in the study who had medical conditions that would likely predispose them to imminent functional decline (e.g. recent stroke); or severe sensory losses that would interfere in training or driving. No participants had recent cognitive training.

2.2 Design

A randomized, waitlist controlled design was used. The intervention group began the intervention while the wait-list control group began the intervention after 2 weeks time (the time to complete the intervention; see Figure 1).

2.3 Intervention

Posit Science Cortex™ with Insight Drive Sharp™

Sixteen individuals were randomly assigned to the cognitive training program called Posit Science Cortex™ with Insight™ DriveSharp ™, heretofore called

DriveSharp™. This is a computer program encompassing two engaging tasks. These include:

1. Jewel Diver™ – the participant acts as a deep-sea diver tracking sunken jewels and in order to do so, he/she has to follow them on the screen when a bubble or fish hides them.

2. Road Tour™ - the participant takes a trip along Route 66, locating road signs and identifying other cars along the way to expand useful field of view and increase processing speed.

The purpose of this program is to help an individual improve his or her visual attention and useful field of view. Each exercise continually adapts to the individual's performance so that the training is always at an appropriate level for that specific person (Zelinski, Yaffe, Ruff, Kennison & Smith, 2007). Each exercise requires between 8 and 10 hours of training. Participants were required to engage in training at its recommended dosing (60 min/day, 5 days/week, 2 weeks).

2.4 Procedures

2.41 Recruitment. Research participants were selected from the MIT AgeLab research participant database (COUHES #602001612) and through MIT COUHES approved community advertising. A telephone screening script, confirmation letter and directions were used when contacting research participants about participation in the study.

2.42 Screening. All participants completed a number of screening steps to determine eligibility (e.g., no neurological or psychiatric disabilities). This included a phone screen that asked for demographic data, driving history, and health information. After the individual was deemed eligible and he or she agreed to move forward, the individual was scheduled for a baseline screening assessment.

Participants were consented to participate. During this process the time commitment, procedures, and compensation for the study were explained. Once consented, participants were assessed with the Mini Mental Status Exam (MMSE; Folstein, et al., 1975). Only participants with scores of 26 or higher, cut-off for normal cognitive functioning, were allowed to continue to the Repeatable Battery for Assessment of Neuropsychological Status (RBANS; Randolph, 1998). The RBANS is an individually administered test measuring attention, language, visuospatial constructional abilities, and immediate and delayed memory. It consists of 12 subtests, which yield five Index scores and a Total Scale score. Normative information from the manual for the Index and Total scores is based on 540 healthy adults who ranged in age from 20–89 years old. To continue with the training, individuals needed to have RBANS overall scores representative of normal aging (taken to be 2 standard deviations within the normative population range, 70-130).

2.43 Randomization. After all registered participants had been interviewed and assessed, they were randomly assigned to either the immediate intervention group (DriveSharp™) or a waitlist control group (control condition) using a fixed randomization scheme with assignment alternating between intervention and control (see Figure 1).

2.45 Neuropsychological_Assessment. All participants were given identical neuropsychological assessments. These assessments occurred at two and three time-points: the first at baseline and the second and third after the intervention depending on whether the individual was in the initial treatment arm or the waitlist control. At these times, participants were administered the Trail Making Tests, counterbalanced by participants for either the A/B or C/D version, the three Useful Field of View (UFOV) subtests (Ball, et al., 1988), and the Raven's Progressive Matrices test (Raven, et al., 2003). The assessments in the neuropsychological battery were different from the training exercises, ensuring that any changes seen in the performance on the assessment would represent true generalization of improvement rather than a familiarization with visually similar tasks.

Trail Making (Reitan & Wolfson, 1986): This is a neuropsychological test of visual attention and task switching. The task requires that participants connect-the-dots of 25 consecutive targets on a sheet of paper. There are two versions of the trail-making test: A/B and C/D. Trails A and C are measures of visual scanning and processing speed. Trails B and D are measures of visual attention, divided attention, and executive control. The goal is for the participant to finish the test as quickly as possible without making mistakes. The primary measure is time for completion.

Useful Field of View (UFOV) test (Ball et al., 1988): The UFOV test measures the speed at which one can rapidly process multiple stimuli across the visual field. UFOV does not correlate with visual acuity but rather is a measure of attentional resources and their spatial distribution (Ball et al., 1988). The test, administered on a personal computer, requires identifying targets presented at varying durations (16.67–500 ms). Three subtests are administered (processing speed, divided attention, and selective attention). Scores for each subtest can range from 16.67 to 500 ms and are combined into a single composite score (Ball & Owsley, 1993).

Raven's Standard Progressive Matrices (Raven, 1962). This is a neuropsychological test measuring fluid intelligence abilities, including problem solving, pattern completion, and abstract reasoning. The test is comprised of 60 visual analogy multiple-choice problems. Each problem presents an image with a missing component, and the test taker must choose one of six item options that will best fill the missing segment to complete the larger pattern. For the purposes of this study, the RSPM was divided into three test variations with 20 problems in each variation.

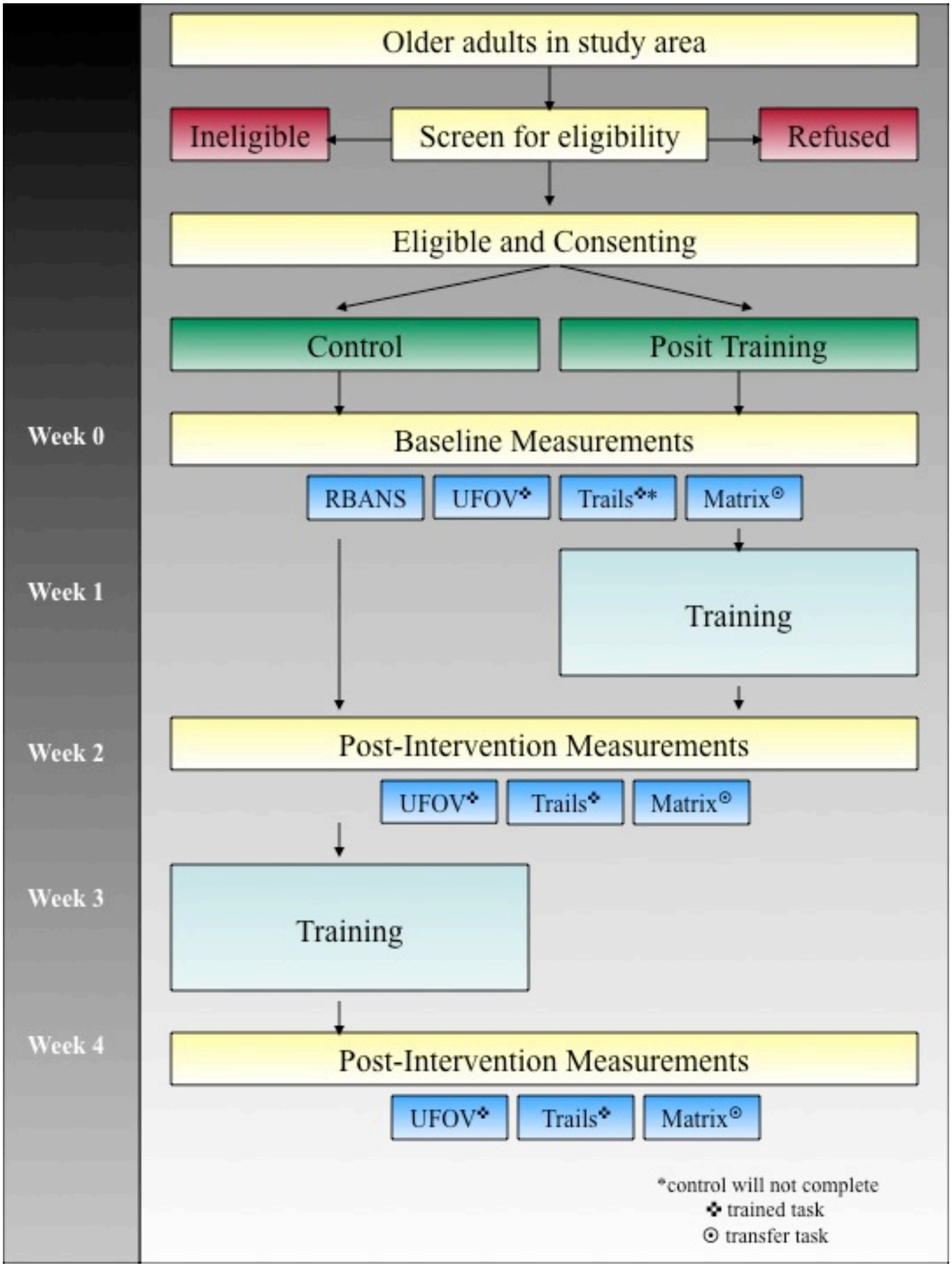
2.46 Intervention Compliance Assessment. The intervention compliance was assessed through self-report and verified through Posit records. Individuals were asked to keep record of time spent on the intervention in an attempt to measure compliance. This was measured continuously throughout the study period.

2.5 Data Analysis

The sample was analyzed for differences between-subjects on demographic variables such as age, gender, and compliance. The dependent measures were the performance on each neuropsychological test. A mixed model ANOVA was used with one between-subject factor of group (intervention and control) and one within-subject factor of time (pre- and post-intervention). It was predicted that the ANOVA would reveal a significant effect for the interaction of group by time. Furthermore, it was predicted that follow-up comparisons will show that the source of the significant effect is due to higher performance of the intervention group at time 2 in comparison to the performance of the control group at time 2.

A paired samples t-test was used to compare the change in test performance pre- and post-intervention for the whole group; visits 1 and 2 were compared for the intervention participants and visits 1 and 3 were compared for the waitlist control participants.

Figure 1. Study Design



CHAPTER 3

RESULTS

3.1 Baseline Comparisons

Table 1 presents demographic characteristics and cognitive profiles (determined by the RBANS) of the total sample of 32 participants. Additionally, the baseline comparisons of the waitlist control group and the treatment group are displayed. The entire sample had a mean age of 66.56 years (standard deviation = 5.15) and was composed of 17 women and 15 men, 28 of whom were right handed, three left-handed, and one ambidextrous. The total sample had 17.09 mean years of completed education (standard deviation = 2.64). The waitlist control group was composed of 16 participants (7 female and 9 male) with a mean age of 66.31 (standard deviation = 5.83). The treatment group also included 16 participants (8 female and 8 male) with a mean age of 66.81 (standard deviation = 4.55). As shown, the waitlist control and training groups did not differ significantly in gender, age, or race. Baseline cognitive performance was also similar between groups. There were no significant differences found in the RBANS total scores or across the five subtests.

Table 1. Demographic information and baseline cognitive profiles (mean standard score on RBANS) for participants assigned to Waitlist Control versus DriveSharp™ conditions

	Total Sample (n=32)	Waitlist Control (n=16)	DriveSharp™ (n=16)	*p*-value
Age	66.56 (5.15)	66.31 (5.83)	66.81 (4.55)	0.79
% female	46.9%	43.8%	50.0%	0.73
% White	90.6%	93.8%	87.5%	1.00
% right handed	87.5%	87.5%	87.5%	0.70
Years of education	17.09 (2.64)	16.38 (2.78)	17.81 (2.72)	0.13
RBANS Total Score	104.22 (13.58)	103.94 (11.35)	104.50 (15.89)	0.91
RBANS Immediate Memory	99.78 (11.78)	97.81 (12.91)	101.75 (10.59)	0.35
RBANS Visuospatial	106.44 (16.70)	105.75 (17.86)	107.13 (16.00)	0.82
RBANS Language	100.59 (11.80)	97.94 (10.34)	103.25 (12.88)	0.21
RBANS Attention	109.69 (15.93)	111.63 (15.87)	107.75 (16.26)	0.50
RBANS Delayed Memory	103.28 (11.49)	102.56 (10.83)	104.00 (12.42)	0.73

3.2 Cognitive Performance

Participants were evaluated with three main tests of attention and a test of fluid intelligence. Presented on Tables 2-4 are comparisons of performance pre- and post-training with DriveSharp™ on the Trailmaking Test A/C and Trailmaking Test B/D (Table 2), the Useful Field of View task (UFOV; Table 3), and Ravens Progressive Matrices (Table 4).

3.21 Comparisons of performance on the Trail Making test at baseline and after training with DriveSharp™.

Trail Making A/C. For the total sample that received the training, a paired-samples t-test was used to evaluate the impact of the intervention on participants' scores on the Trail Making A/C. There was a statistically significant decrease in the time to completion on Trail Making A/C from baseline (*M* = 36.64 seconds, *SD* = 13.99) to post-intervention (32.19 seconds, *SD* = 10.20), *t*(31) = 2.22, *p* = 0.03, *d* = 0.39 (see Table 2 and Figure 2).

Trail Making B/D. For the total sample that received the training, a paired-samples t-test was used to evaluate the impact of the intervention on participants' scores on the Trail Making B/D. There was no statistically significant difference in the time to completion from baseline (*M* = 87.83, *SD* = 37.18) to post-intervention (*M* = 87.01, *SD* = 43.33), *t*(31) = 0.12, *p* = 0.91, *d* = 0.02 (see Table 2 and Figure 2).

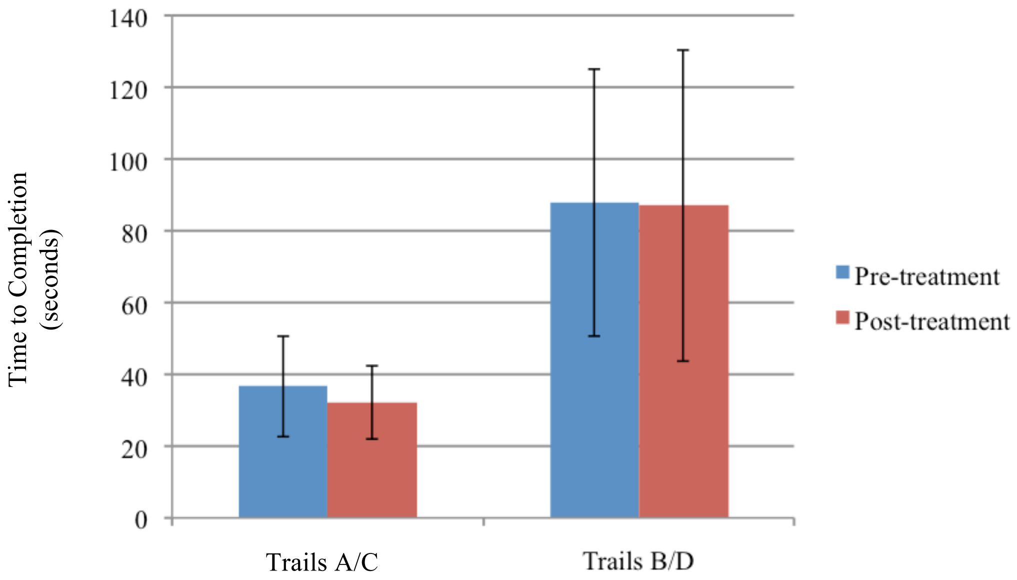
Table 2. Comparison of performance on time to completion (seconds) for the Trail Making test between pre- and post-intervention with DriveSharp™

Total Sample	Time to Completion (n=32)			
	Pre	Post	*p*-value	*d*
Trail Making A/C	36.64 (13.99)	32.19 (10.20)	0.03*	0.36
Trail Making B/D	87.83 (37.18)	87.01 (43.33)	0.91	0.01

* denotes significance ($p \leq 0.05$)

Figure 2. Performance of entire sample on the Trail Making Test at baseline and post-training with DriveSharp™

Trail Making Test Performance



3.22 Comparisons of performance on the UFOV test at baseline and after training with DriveSharp™.

<u>UFOV Processing Speed.</u> For the total sample that received the training, a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Processing Speed. There was a statistically significant change in reaction time from baseline (*M* = 27.41 milliseconds, *SD* = 29.10) to post-intervention (*M* = 17.01 milliseconds, *SD* = 1.77), *t*(31) = 2.06, *p* = 0.05, *d* = 0.50. However, when two outliers (more than 2.5 standard deviations from the mean) were removed, the results did not retain their significance: baseline (*M* = 21.14 milliseconds, *SD* = 13.05) to post-intervention (*M* = 16.70 milliseconds, *SD* = 0.00), *t*(29) = 1.86, *p* = 0.07, *d* = 0.48 (see Table 3 and Figure 3). Despite the non-significant results, there was still a moderate effect size for this change in processing speed.

For the DriveSharp™ group, a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Processing Speed. There was no statistically significant difference in the reaction time from baseline (*M* = 30.01 milliseconds, *SD* = 36.87) to post-intervention (*M* = 16.70 milliseconds, *SD* = 0), *t*(15)=1.44, *p* = 0.17, *d* = 0.36. When one outlier was removed, the results remained insignificant, *t*(15)=1.22, *p* = 0.24, *d* = 0.88.

For the waitlist control group who subsequently underwent the DriveSharp™ training (comparison between visits 1 and 3), a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Processing Speed. There was no statistically significant difference in the reaction time from baseline (*M* = 24.81 milliseconds, *SD* = 19.41) to post-intervention (*M* = 17.33 milliseconds, *SD* = 2.50), *t*(15)=1.73, *p* = 0.11, *d* = 0.43. When one outlier was removed, the results remained insignificant, *t*(14)=1.46, *p* =

0.17, *d* = 0.38.

Figure 4 presents the performance on UFOV Processing Speed reaction times between groups during their first two visits. A mixed-model ANOVA with one between-subjects factor of group (DriveSharp™, Control) and one within-subjects factor of testing (visit 1, visit 2) was conducted. There was no significant interaction between groups and time, *F*(1,30) = 0.33, *p* = 0.57, partial eta squared = 0.01. There was a main effect for time, *F*(1,30) = 4.17, *p* = 0.50, partial eta squared = 0.12, with both groups showing a reduction in UFOV Processing Speed over time and no between-subject group differences, *F*(1,30) = 0.18, *p* = 0.67, partial eta squared = 0.01. The absence of a statistically significant interaction group and time indicated training did not improve UFOV processing speed. The significant effect for time indicated that both groups showed similar improvement in UFOV, regardless of training.

Due to the multi-visit design with a waitlist control, analyses were run to determine the change between visits among the waitlist control group (see Table 5). Paired sample t-tests showed that there was no significant change between visits 1 and 2 (both pre-treatment visits), *t* = 1.46, *p* = 0.17, *d* = 0.53, indicating that this specific subtest was not significantly susceptible to practice effects.

In summary, after outliers were removed, there were no significant reductions in reaction times on the UFOV Processing Speed for the total, DriveSharp™, or waitlist control groups who had received training; however, all three groups showed reductions with moderate effect sizes. For the waitlist control group who completed UFOV testing during three visits, there were no significant differences between visits 1 and 2. When comparing DriveSharp™ and waitlist control groups between visits 1 and 2, a main effect of time was found with no between-subject difference.

UFOV Divided Attention. For the total sample that received the training, a paired-samples t-test was used to evaluate the impact of the intervention on UFOV divided attention. There was a statistically significant change in reaction time from baseline (M = 83.04 milliseconds, SD = 90.06) to post-intervention (M = 24.82 milliseconds, SD = 22.73), $t(31) = 4.18$, $p < 0.01$, $d = 0.89$. When two outliers were removed from analyses (more than 2.5 standard deviations from the mean), the results remained statistically significant: baseline (M = 64.46 milliseconds, SD = 74.60) to post-treatment: (M = 19.37 milliseconds, SD = 7.61), $t(29) = 3.71$, $p < 0.01$, $d = 0.85$ (see Table 3 and Figure 3).

For the DriveSharp™ group (n=14, after removal of outliers), a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Divided Attention. There was a statistically significant difference in the reaction time from baseline (M = 88.82 milliseconds, SD = 88.14) to post-intervention (M = 20.51 milliseconds, SD = 10.03), $t(13)=2.91$, $p = 0.01$, $d = 1.09$.

For the waitlist control group who subsequently underwent the DriveSharp™ training (comparison between visits 1 and 3; n=16), a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Divided Attention. There was a statistically significant difference in the reaction time from baseline (M = 52.52 milliseconds, SD = 58.06) to post-intervention (M = 18.37 milliseconds, SD = 4.72), $t(15)=2.38$, $p = 0.03$, $d = 0.83$.

Figure 4 presents the performance on UFOV Divided Attention reaction times between groups during their first two visits. A mixed-model ANOVA with one between subjects factor of group (DriveSharp™, Control) and one within-subjects factor of testing (visit 1, visit 2) was conducted. As mentioned above, two outliers (more than 2.5 standard deviations from the mean) were removed from the dataset. There was no significant interaction between groups and time, *F*(1,28) = 3.32, p = 0.08, partial eta squared = 0.11. There was, however, a main effect for time, F(1,28) = 16.7, p < 0.01, partial eta squared = 0.38, with both groups showing a reduction in UFOV Divided Attention over time and no between-subject group differences, F(1,28) = 3.16, p = 0.09, partial eta squared = 0.10

Analyses between visits 1 and 2 among the waitlist control group (see Table 5) showed that there was no significant change between visits 1 and 2, *t*=0.27, *p*=-.79, *d*= 0.09. This suggests that this particular subtest is not significantly susceptible to practice effects.

In summary, UFOV Divided Attention improved for the total sample following training. However, since no significant differences were found between the change in performance of the waitlist control group and the DriveSharp™ group from visit 1 to visit 2, a true training effect may not be present.

UFOV Selective Attention. For the total sample that received the training, a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Selective Attention. There was a statistically significant change in reaction time from baseline (*M* = 114.12 milliseconds, *SD* = 60.16) to post-intervention (*M* = 72.42 milliseconds, *SD* = 38.83), *t*(31) = 5.92, *p* < 0.01, *d* = 0.83 (see Table 3 and Figure 3).

For the DriveSharp™ group, a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Selective Attention. There was a statistically significant difference in the reaction time from baseline (*M* = 132.13 milliseconds, *SD* =

67.64) to post-intervention (*M* = 82.93 milliseconds, *SD* = 46.69), *t*(15) = 4.38, *p* < 0.01, *d* = 1.09.

For the waitlist control group who subsequently underwent the DriveSharp™ training (comparison between visits 1 and 3; n=16), a paired-samples t-test was used to evaluate the impact of the intervention on UFOV Selective Attention. There was a statistically significant difference in the reaction time from baseline (*M* = 96.11 milliseconds, *SD* = 47.03) to post-intervention (*M* = 61.50 milliseconds, *SD* = 26.68), *t*(15) = 4.06, *p* = 0.001, *d* = 1.02.

Figure 4 presents the UFOV Selective Attention reaction times between groups during their first two visits. One outlier was removed from analysis (more than 2.5 standard deviations from the mean). A mixed-model ANOVA with one between-subjects factor of group (DriveSharp™, Control) and one within-subjects factor of testing (visit 1, visit 2) was conducted. There was a significant interaction between groups and time, F(1,29) = 6.79, p = 0.01, partial eta squared = 0.11. There was also a significant main effect for time, F(1,29) = 16.46, p = 0.00, partial eta squared = 0.36, with both groups showing a reduction in UFOV Divided Attention over time and no between-subject group differences, F(1,28) = 3.16, p = 0.25, partial eta squared = 0.05.

Due to the multi-visit design with a waitlist control, analyses were run to determine the change between visits among the waitlist control group (see Table 5). Paired sample t-tests showed that there was no significant change between visits 1 and 2, *t* = -0.49, *p* = 0.63, *d* = -0.14, indicating that this subtest was not significantly susceptible to practice effects.

In summary, significant reductions in reaction times were observed for the total group that received training, the DriveSharp™ group, and the waitlist control group after they received training. Effect sizes were large for this reduction in reaction time (*d* = 0.83). When comparing DriveSharp™ and waitlist control groups between visits 1 and 2, an interaction effect was found. Additionally, a main effect of time was found with no between-subject difference. The significant between-group interaction (between the waitlist control and DriveSharp™ group) along with the significant main effect of time might indicate that although a true training effect is present, there may also be some practice effects.

Table 3. Comparison of performance on reaction time (milliseconds) for the Useful Field of View subtests between pre- and post-intervention with DriveSharp™

	Reaction Time (n=32)			
	Pre	Post	*p*-value	*d*
UFOV: Processing Speed	21.14 (13.05) °	16.70 ° (0.00)?	0.07 °	0.48
UFOV: Divided Attention	64.46 (74.60) °	19.37 ° (7.61)	< 0.01* °	0.85
UFOV: Selective Attention	114.12 (60.16)	72.21 (38.96)	< 0.01*	0.83

* denotes significance ($p \leq 0.05$); ° outliers removed from analysis

Figure 3. Performance of entire sample on the UFOV subtests at baseline and post-training with DriveSharp™

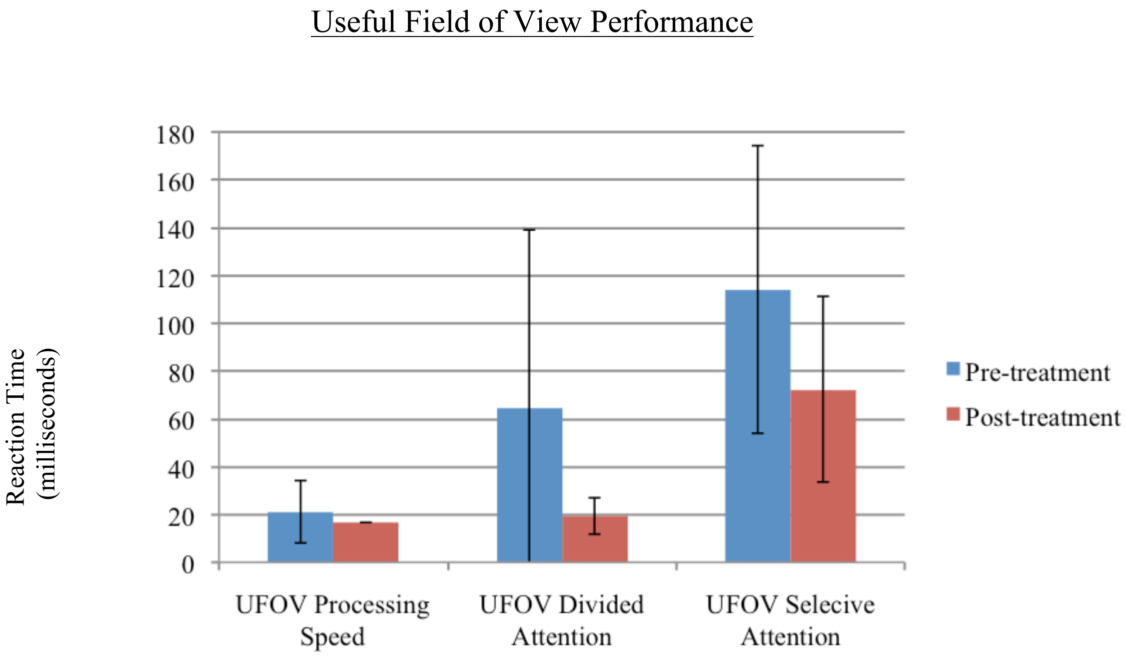
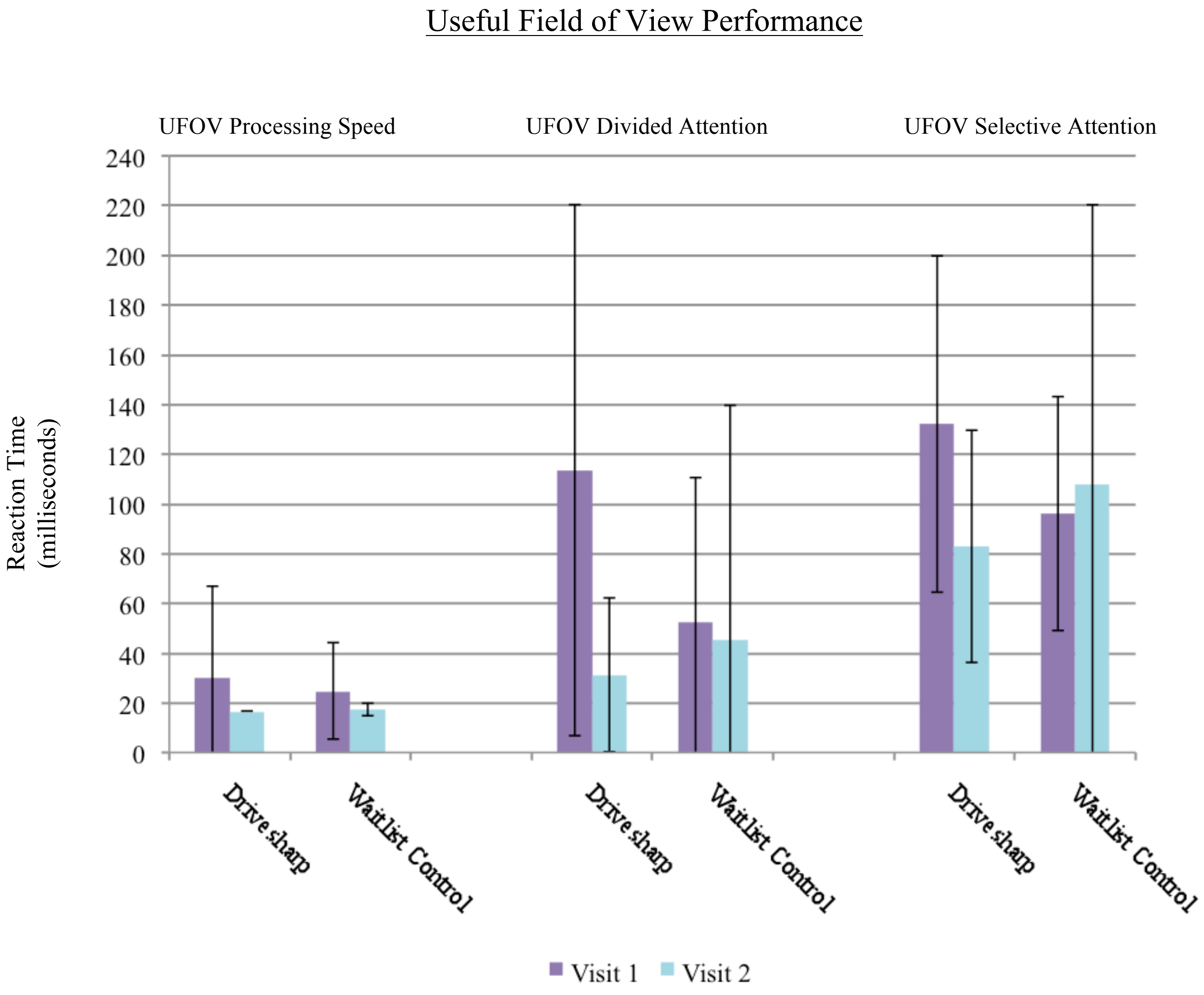


Figure 4. Performance on UFOV subtests between groups within visits



3.23 Comparisons of performance on the Raven's Progressive Matrices test at baseline and after training with DriveSharp™.

Raven's Progressive Matrices. For the total sample that received the training, a paired-samples t-test was used to evaluate the impact of the intervention on performance on the Raven's Progressive Matrices task. There was no statistically significant change in total number of matrix problems correct from baseline (*M* = 13.90 correct, *SD* = 3.31) to post-intervention (*M* = 13.93 correct, *SD* = 3.23), *t*(29) = -0.07, *p* = .942 (see Table 4 and Figure 5).

Figure 6 presents the performance on the Raven's Progressive Matrices test between groups during their first two visits. A mixed-model ANOVA with one between-subjects factor of group (DriveSharp™, Control) and one within-subjects factor of testing (visit 1, visit 2) was conducted. There was no significant main effect for time (from pre- to post-treatment), *F*(1,29) = 0.00, *p* = 0.96, partial eta squared = 0.00. The interaction between group and time was also not significant, *F*(1,29) = 3.20, *p* = 0.09, partial eta squared = 0.10.

Table 4. Comparison of performance on number correct for the Raven's Advanced Progressive Matrices test between pre- and post-intervention with DriveSharp™

Total Sample	Number Correct (n=32)			
	Pre	Post	*p*-value	*d*
Raven's Matrices	13.9 (3.32)	13.93 (3.23)	0.94	0.03

Figure 5. Performance of entire sample on the Raven's Progressive Matrices test at baseline and post-training with DriveSharp™

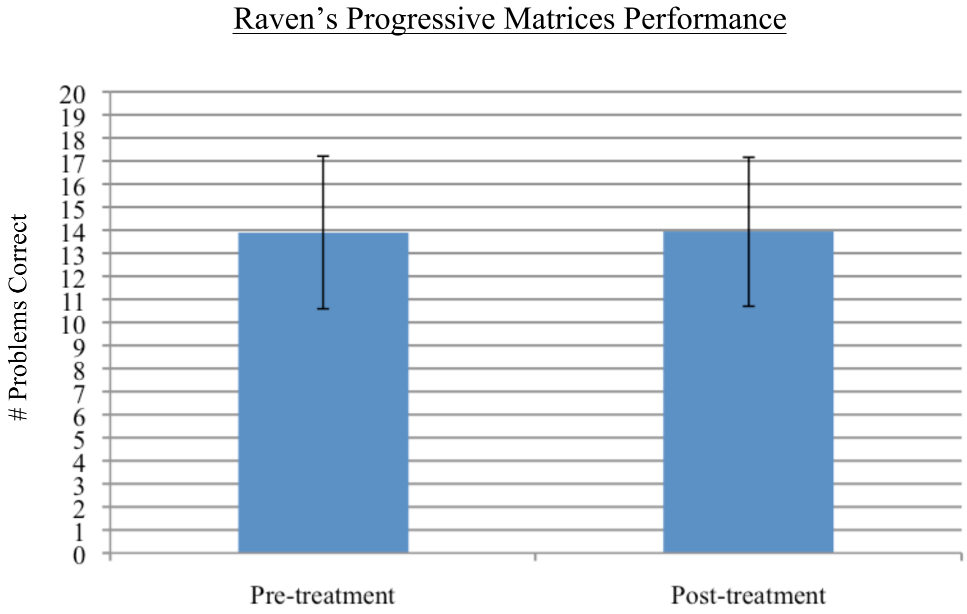
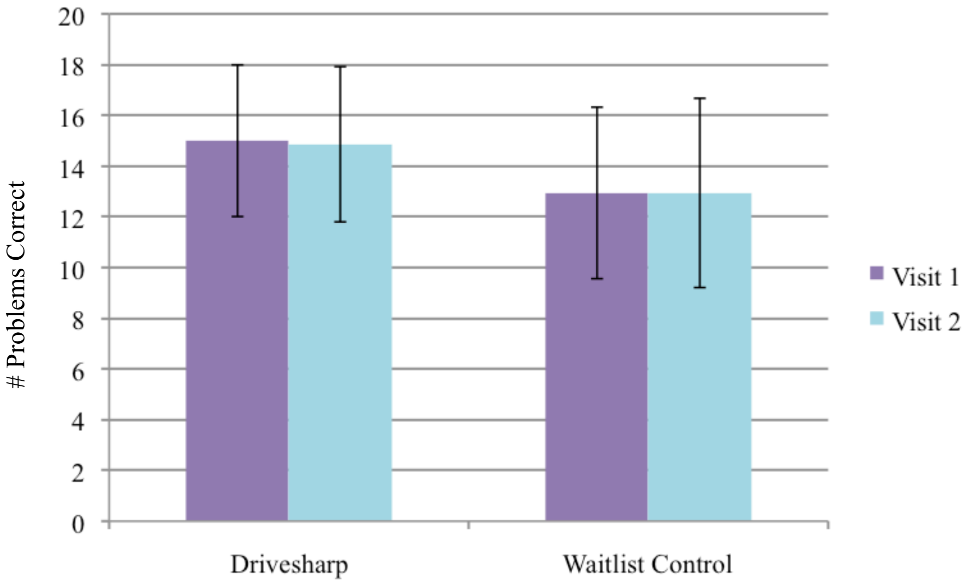

Raven's Progressive Matrices Performance

Figure 6. Performance on Raven's Progressive Matrices between groups within visits

<u>Raven's Progressive Matrices Performance</u>



3.3 Correlations between demographic data, baseline cognitive functioning and performance on neuropsychological outcome measures.

Of note, there was a significant negative correlation between the age of the subjects and the change in the speed with which they completed Trails A (calculated by subtracting the pre-treatment score, or the score at visit 1 for both groups, by the post-treatment score, or visit 2 for the treatment group and visit 3 for the waitlist control group), $r = -0.35$, n = 32, $p = 0.02$; in other words, the older the participants were, the more they improved on this test after treatment with DriveSharp™. Performance on the Immediate Memory portion of the RBANS also correlated with change in the time to completion of Trails A, $r = -0.39$, n = 32, $p = 0.03$; these results suggest that baseline memory functioning correlated with improvement on Trails A after treatment with DriveSharp™.

Performance on the Visuospatial Construction portion of the RBANS was significantly correlated with the change in the speed of reaction on both the UFOV Divided Attention and Selective attention subtests ($r = -0.42$, n = 32, $p = 0.02$ and $r = -0.44$, n = 32, $p = 0.01$, respectively, indicating that better performance on the Visuospatial Construction portion of the RBANS correlates with less of a change in reaction time from pre- to post-treatment on these UFOV subtests.

Finally, reduction in response time pre- to post-treatment on Trails A was significantly correlated with an increase in performance pre- to post-treatment on the Raven's Progressive Matrices, $r = -0.41$, n = 32, $p = 0.03$. These results suggest that those that were improving on Trails A were also improving on the Raven's Progressive Matrices after treatment with DriveSharp™.

CHAPTER 4

DISCUSSION

The present study examined the relationship of a computer-based training program, specifically DriveSharp™, and performance on various measures of cognitive functioning. Participants between the ages of 60 and 75 were randomly assigned to either a treatment or a waitlist control group; both groups completed the DriveSharp™ training program at some point during the study. All participants completed baseline assessments using the RBANS on which there were no differences between groups. Pre- and post-intervention measures included standardized and laboratory neuropsychological tests of the cognitive abilities that DriveSharp™ was designed to enhance (e.g., processing speed and various aspects of visual attention) and standardized measure of a more complex cognitive ability that was not directly activated in the DriveSharp™ activities (fluid intelligence). The specific aims of this study addressed whether DriveSharp™ training could 1) improve performance on Trail Making Test A/C and B/D—measures of different aspects of visual attention, 2) improve performance on three UFOV subtests—measures of information processing related to attention, and 3) whether the directly trained effects of DriveSharp™ could transfer to an improvement on the Raven's Progressive Matrices test—a measure of fluid intelligence. These specific outcome measures were chosen to assess change in a range of cognitive abilities that are known to be susceptible to declines during the normal aging process.

4.1 DriveSharp™ and the Trail Making Test

The Trail Making Test A/C is a measure that requires perceptual speed and attentional function (e.g., visual scanning, vigilance, and concentration). Age-associated performance decrements for Trails A/C have been well documented, and are thought to be the result of the general slowing of psychomotor speed and attentional abilities (Ivnik, Malec, Smith, Tangalos & Petersen, 1996). The Trail Making Test A/C has been correlated to types of attention involving alerting, visual search, and orienting to chosen information (Wahlin, Backman, Wahlin, & Winblad, 1996). In this study, alternate versions of the test (A or C) were given pre- and post-training to avoid group practice effects.

Given Posit Science's claim that DriveSharp™ improves both attentional capacity and processing speed, it was hypothesized that two weeks of training with this program would improve performance (i.e., decrease the time to completion) on this task. The results of this study supported the hypothesis that computerized training with DriveSharp™ improved performance on Trail Making Test A/C for the combined group. This indicates that basic aspects of attention, including visual search, the ability to focus on a simple sequence of relevant stimuli, and psychomotor speed were improved after the DriveSharp™ training.

It also has been shown that older adults show an age-related deficit in the aspect of attention that involves performing dual tasks (Hartley, 2001), or divided attention. The decline in divided attention is thought to relate to both the slowing of the attentional processes involved in the task and the use of a more cautious task coordination strategy during dual tasks (Glass et al., 2000). With that in mind, the Trail Making Test B/D was chosen for this study to measure cognitive flexibility, dual processing, and the ability to inhibit a dominant response while maintaining set. Research has shown that older individuals have more difficulty on Trailmaking B/D (Salthouse, Atkinson, & Berish, 2003; Van Gorp, Satz, & Mitrushina, 1990), but that performance on this task is responsive to training and intervention (Edwards, Wadley, et al., 2005).

Given that the Jewel Diver task and part of the UFOV task in the DriveSharp™ training both were designed to exercise divided attention, it was hypothesized that improved performance would be seen on Trails B/D after training. This hypothesis, however, was not supported. These results suggest that the more complex attentional abilities demanded by the set-switching nature of Trails B/D were not improved by the DriveSharp™ training. The addition of the divided attention component may have required more complex aspects of attention that had not responded as well, if at all, to training.

4.2 DriveSharp™ and the UFOV test

The UFOV test, the most widely used test of visual attention, includes three subtests that measure various aspects of how effectively and efficiently one extracts visual information from the environment. Each of these measures the speed at which one can rapidly process multiple stimuli across the visual field, and each requires specific facets of visual attention in order to perform the task efficiently. The first subtest, UFOV Processing Speed, measures the threshold for discriminating stimuli presented in the field of view. The second, UFOV Divided Attention, also measures reaction time to environmental stimuli, but requires dual processing of a stimulus in the periphery. The third, UFOV Selective Attention, adds irrelevant information to the periphery so the relevant target must be searched for. The three subtests build upon one another, with the third and most challenging subtest (Selective Attention) requiring basic attentional processing, dual processing, and inhibitory processing to filter out irrelevant information.

These subtests are similar to the Road Tour part of the DriveSharp™ training, which is designed to improve reaction time during these three tasks that measure various aspects of attention. Therefore, it was hypothesized that improvement in reaction time would be seen in all three UFOV subtests after the two weeks of training with DriveSharp™. This hypothesis, however, was only partially supported; significant improvement was seen on only the Selective Attention subtest, suggesting that the training effects of DriveSharp™ were limited to specific aspects of attention captured in the performance of this measure. As described above, selective attention involves the ability to focus on relevant information while filtering out irrelevant information in the environment, so it can be assumed that an improvement in this ability underlies the post-training improvement seen on this measure. Significant improvement in reaction time was not seen on the UFOV Processing Speed subtest, which requires only basic attentional function related to speed of information processing (though post-training decrease in reaction time did produce a moderate effect size).

In addition, there was no significant change on the UFOV Divided Attention subtest, which also involves the more complex attentional function of dual processing. Non-significant improvement with a moderate effect size was produced, however, suggesting that there was some effect of training. Since the primary difference between the Divided Attention and Selective Attention subtests is the requirement of inhibiting irrelevant distracters (Zelinski et al., 2007), this may be the locus of function that was most responsive to the DriveSharp™ training.

4.3 Drivesharp™ and the Raven's Progressive Matrices test

The Raven's Progressive Matrices test was chosen to determine whether or not the training produces a transfer effect, that is, an improvement in fluid abilities (e.g., reasoning) that are not directly trained by the DriveSharp™ tasks. The types of cognitive abilities related to fluid intelligence are thought to be very susceptible to age-related declines (Bugg et al., 2006). Research has shown that functional decline may be correlated with deterioration of fluid abilities (Maitland, Intrieri, Schaie, & Willis, 2000), so improvements of this type could lead to important changes in the quality of life of older individuals.

Jaeggi et al. (2009) showed that training on a task of working memory produced improvements not only on the directly trained measure of working memory processes, but also on an untrained measure of fluid intelligence. Based on the idea that basic attentional machinery is an underlying component of the more complex process of fluid intelligence, it was hypothesized that an increase in attentional efficiency would transfer to an improvement on the Raven's Progressive Matrices test. This hypothesis was not supported, indicating that the attentional mechanisms that were improved by training did not transfer to an improvement in fluid intelligence.

4.4 Implications of Study

Visual attention is a multi-faceted cognitive domain that has been shown to be improved by training with tasks related to visual search, divided attention, and speed of processing (Ball et al., 2002). According to this study, when speed of processing training (i.e., putting time pressure on the execution of tasks) was combined with attentional demand of increasing visual complexity (i.e., more distracters present as the training progresses), improvement was seen on a timed visual search task and a task demanding selective attention. The results of this study suggest that it is possible to use DriveSharp™ to rectify these age-related cognitive deficits by stimulating positive neuroplastic processes underlying specific facets of attention related to selectively attending and searching for relevant material in the visual display.

Previously in this paper, two popular theories were proposed to explain the potential mechanisms underlying age-related cognitive change: the processing speed theory and the attentional capacity theory. Though these theories are often seen as competing, the results of this study suggest that both can be used to explain the vulnerabilities susceptible to training-related improvements in age-related decline.

As explained above, Salthouse and colleagues have proposed in their processing speed theory that the gradual disuse of mental skills that occurs as we advance into later life results in a decrease in the time and efficiency of our basic mental operations (Salthouse, 1996). From this specific theoretical perspective, it is postulated that two weeks of DriveSharp™ training in this study may have stimulated the synaptic regions involved in specific facets of attention, likely related to selective attention and visual search. The speed with which these attentional processes could be carried out was increased, thereby improving performance on two tasks that depend heavily on this particular attentional ability.

The results can also be interpreted from the attentional capacity perspective, which has been described as a deficiency in utilizing and appropriately distributing attentional resources (Craik & Byrd, 1982; Levitt, Fugelson, & Crossley, 2006). The improvement on UFOV Selective Attention measure points toward an increase in the ability to inhibit irrelevant information. Trail Making Test A/C also requires this type of ability in order to inhibit the numbers on the page that are not relevant to moment-to-moment focus on the specific sequence of numbers. This inhibitory process is heavily intertwined specifically with processing control rather than general speed per se, involving the ability to slow down processing of less-relevant information (McDowd & Filion, 1992) while directing faster processing to the relevant information. By acting on this mechanism, two weeks of DriveSharp™ training in this study may have improved the attentional control abilities surrounding inhibition of irrelevant material. This is thought to be the most vulnerable aspect of visual attention during the aging process, specifically in conditions where visual search is required (Plude & Hoyer, 1985).

Additional insights can be gleaned from the cognitive abilities that did not respond to training. These included the measure of attentional processing speed (UFOV Processing Speed), two measures of divided attention (UFOV Divided Attention and Trail Making Test B/D), and the measure of fluid intelligence (Raven's Progressive Matrices). It should be noted that while the combined group's change in reaction time on the UFOV Processing Speed measure was not significant, it did decrease and analyses resulted in a moderate effects size. Still, the absence of a significant effect on the cognitive ability that is widely thought to underlie age-related decline is somewhat confusing, particularly since basic attentional functions were responsive to training and it is likely that these rely on speed of execution. The most likely explanation is that the UFOV Processing Speed subtest was not rigorous enough to detect any effects, or that training was only helpful when exercises became more demanding of attentional resources.

The absence of significant training impact on the more complex, directly-trained mental abilities, such as set-shifting and dual processing of relevant information, is more easily justified. These higher-level cognitive abilities involve frontal brain regions for executive functions (e.g., working memory), which may have not responded as easily to the type of training used in this study. We know from previous research that it is possible to train such abilities (e.g., Jaeggi et al., 2008; Willis et al., 2006), however, the training design in these studies often involved direct and constant practice with working memory exercises. Even though parts of DriveSharp™ were designed to exercise divided attention, which often requires working memory, the amount and intensity of this type of training may not have been enough to produce effects. It should also be noted that there was a non-significant improvement with a moderate effect size on the UFOV Divided Attention test from pre- to post-training; this decrease in reaction time after training suggests that there may be some training effect present, just not as strong of an effect as seen on the UFOV Selective Attention test. This could be explained by the theory that the attentional process most sensitive to age-related decline is the ability to inhibit irrelevant information (Gazzaley, Cooney, Rissman, & D'Esposito, 2005), and that the cognitions where decline has already occurred are the most susceptible to improvement. Inhibition of task-irrelevant stimuli is essentially the key operation involved in selective attention; although it is utilized in divided attention as well, divided attention is perhaps more reliant on the mechanisms of task-switching and dual-processing.

Furthermore, there was no improvement on the Raven's Progressive Matrices, indicating that the attentional mechanisms that were improved by training did not transfer to an improvement in fluid intelligence. This again may be the result of not enough training of higher-level abilities that activate frontal, executive regions as well as the basic attentional machinery. The premise under which the initial hypothesis was made had to do with the idea that more fundamental cognitive abilities (e.g., processing speed, attention, and working memory) help to make up the cluster of functions necessary for reasoning and fluid intelligence (Cattell, 1971; Horn, 1982). These results imply that there either was not enough training with DriveSharp™ to make the attentional improvements necessary to increase the broader function of fluid intelligence, or that the training program was not targeting the specific functions necessary for the transfer effect to occur. As previously stated, working memory or other higher-level functions may be the key target function that would allow this to occur.

4.5 Limitations and Future Research

The small sample size was a limitation of this study that may have prevented a transfer effect from occurring. The small sample size impacted the statistical analyses, resulting in limited power and the threat of Type II error. Also, despite the lack of significant differences between groups on demographic and cognitive screening measures, the pre-treatment performance on some of the neuropsychological measures differed significantly. There were large standard deviations due to within group differences in baseline performance, making it more difficult to find statistically significant improvement from pre- to post-treatment. Therefore, the use of a larger sample size may have produced more accurate statistical effects, which may have resulted in significant change on measures for which there was non-significant improvement with a moderate effect size (such as UFOV Divided Attention).

The sample itself was made up with individuals who were relatively young, healthy, and cognitively intact. Moreover, they all owned a computer and had time available to engage in training and complete the study; this is not necessarily a true representation of the broader population of older adults who could benefit from treatment. Taken together, these factors limit the generalizability of the results. Future studies should consider the broader population that would eventually have access to this type of technology.

Further studies on improving complex cognitive abilities (such as fluid intelligence) by training more fundamental processes are needed. The results of this study suggest that training attentional systems alone might not target the appropriate functions to produce a transfer effect. Additionally, previous research (Jaeggi et al., 2008) found that there was a dosage effect of working memory training on fluid intelligence performance. This indicates that if it is possible to see an effect on fluid intelligence by training attentional systems, our dose of training was not enough. Future research should either target more complex cognitive abilities with frontal lobe involvement, such as working memory, or increase the dose of training with visual attention exercises.

Finally, this study does not address the generalizability of the results to real-world functioning. It is unknown whether an increased ability to perform Trail Making Test A/C and UFOV Selective Attention would translate into any functional, day-to-day improvements. So far, research surrounding the effects of cognitive training interventions have been mixed. Some studies suggest significant self-reported quality of life improvements along with the improvements seen on laboratory assessments of cognition (Smith et al., 2009). Some have only reported modest effects on tasks of daily living (Willis et al., 2006), while others report no significant transferable changes (Papp, Walsh, & Snyder, 2009). While this study shows that training-related cognitive change is possible, further studies should utilize outcome measures that represent behaviors seen in every day life. Clarification is needed on how best to use this type of technology so that optimal transfer to real-world functioning will occur.

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