Comparing the Transfer Effects of Simultaneous and Sequential Combined Modality Training in Older Adults

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A Thesis

in

The Department

of

Psychology

Presented in Partial Fulfillment of the Requirements

For the Degree of Master of Arts in Clinical Psychology

Concordia University

Montreal, Quebec, Canada

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared

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Entitled: Comparing the Transfer Effects of Simultaneous and Sequential Combined Modality Training in Older Adults

and submitted in partial fulfillment of the requirements for the degree of

Master of Arts (Psychology)

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

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Intervention research has shown that both cognitive training (Hertzog et al., 2009; Lustig et al., 2009) and aerobic exercise training (Colcombe et al., 2003; Bherer, Erickson, & Liu-Ambrose, 2013) are each capable of independently inducing significant improvement on cognitive performances in older adults. Additionally, intervention studies utilizing combined multimodality (cognitive and aerobic) training, while few in number, have shown promise in producing significantly more training gains in older adults than either single modality of training (Eggenberger et al., 2015; Lustig et al., 2009; Oswald et al., 2006; Rahe et al., 2015; Theill et al., 2013). To date, there is no study specifically comparing and contrasting the efficacy of Simultaneous and Sequential multimodal training protocols. To this end, forty-two older adult participants (M = 68.05, SD = 4.65) were recruited to participate in 12 sessions of multimodal training, and were randomly assigned to either the Simultaneous or Sequential training group. Both groups showed significant improvement on measures of processing speed and verbal memory following training. Additionally, the Sequential group showed a significant training group advantage on a measure of working memory. The moderating factors, motivation to engage in cognitive effort (NFC) and baseline aerobic fitness, were included in the analyses to explore their potential influence on the magnitude of training gains. NFC was found to be a significant moderator as those with lower NFC improved more on measures of processing speed and verbal memory. Those with higher aerobic fitness improved marginally more on an interference monitoring task. The findings from the current study have implications for the aging intervention literature as they provide partial evidence for enhanced efficacy for Sequential multimodal training. Additionally, possible training gain-related moderators were identified, which might have implications for participant selection in future intervention studies.

Table of Contents

List of Tables

List of Figures

Introduction

The population in Canada is aging as a result of increasing longevity and decreasing fertility rate (Anderson & Hussey, 2000). The number of seniors in Canada is expected to increase to 25% of the population in 2036 (9.8 million), compared to 14% in 2009 (Statistics Canada, 2011). With these demographic trends, there is increasing interest in research on successful aging and functional independence. Successful aging is commonly defined as 1) having low risk for diseases and disease-related disability; 2) retaining high cognitive and physical functional capacity; and 3) being involved in active engagement with life (Rowe & Kahn, 1997). The focus of the present project is on addressing the second factor, retaining cognitive and physical functional capacity, which may have subsequent positive effects on the first and third factors. To date, the available research evidence supports the efficacy of cognitive training and aerobic exercise training as two pathways to maintain and/or improve cognitive functioning in old age. However, fewer studies have sought to examine the efficacy of combined training formats, or individual difference factors such as motivation as moderators of training efficacy. This thesis therefore aims to address these open questions.

Cognitive Aging

Behavioural Changes. Aging is associated with various cognitive changes, with some cognitive abilities declining more than others (Baltes, Staudinger, & Lindenberger, 1999; Braver & West, 2008; Craik & Bialystok, 2006; Craik & Salthouse, 2011). For example, cognitive functions associated with memory capacity, processing speed, novelty (abilities associated with "fluid intelligence" or "cognitive mechanics") show greater decline than vocabulary and general knowledge (abilities associated with "crystallized intelligence" or "cognitive pragmatics") as a function of age (Baltes et al., 1999; Craik & Bialystok, 2006). Processes related to "crystalized intelligence", such as vocabulary, remain relatively stable or can even improve in healthy old age (Salthouse & Craik, 2011).

In contrast, episodic memory and executive functions (EFs) are two types of cognitive processes most negatively affected by aging, along with their respective neural correlates (Craik & Salthouse, 2011; Raz et al., 1998). Episodic memory refers to a set of processes responsible for encoding and retrieving new information and past personal experience (Nyberg et al., 2012). EFs, on the other hand, are a group of supervisory cognitive processes that are implicated in the organization and execution of complex thoughts and behaviours, and are highly associated with the prefrontal cortex (Alvarez & Emory, 2006; Gunning-Dixon & Raz, 2003). More recent research has implicated the role of cognition in the quality of life in older adults. EFs have been shown to be a significant, more reliable predictor of an older adult's instrumental activities of daily living, such as managing one's finances (iADL: Cahn-Weiner, Boyle & Malloy, 2002; Tomaszewski Farias et al., 2009), functional decline, and mortality (Johnson, Lui, & Yaffe, 2007) than overall cognitive ability.

The decline of the two aforementioned cognitive processes manifests in healthy older adults' generally significantly poorer performance on neuropsychological measures of free and cued recall such as the California Verbal Learning Test (a test of episodic and verbal memory) and measures of EF such as the Wisconsin Card Sorting Task (a test of switching and mental flexibility) when compared to their younger counterparts (Craik & Salthouse, 2011; Spencer & Raz, 1995).

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Neural Changes. The neural underpinnings associated with the observed age-related changes in memory and EFs have been extensively studied. As noted previously, the most significant age-related declines are chiefly episodic memory and EFs. These are processes that implicate medial temporal lobe and prefrontal cortex (Burke & Barnes, 2006; Salthouse & Craik, 2011). Despite the strong association between episodic memory and structures in the temporal lobe (such as the hippocampus), there are also numerous memory-relevant connections with the prefrontal cortex (Spencer & Raz, 1995). These two regions, the temporal and prefrontal cortices, are most affected both anatomically and functionally as a result of aging, as they show more rapid age-related decline in grey matter volume (Raz et al., 1997) and activation (Damoiseaux et al., 2008; Uddin, Superkar, & Menon, 2010) as compared to other brain regions.

More specifically, structural neuroimaging studies comparing young and older adults using MRI have revealed significant gray matter loss in the frontal and temporal lobes in the latter group, with the prefrontal cortex suffering the most rapid volumetric loss, particularly in the orbitfrontal and dorsolateral regions (Raz et al., 1997). Aside from the prefrontal cortex, the superior parietal cortex and the hippocampus appear to be significantly smaller in volume due to aging. Using linear trend analysis, it was estimated that the prefrontal cortex shows an average volumetric reduction of 4.9% per decade. The superior parietal lobe and hippocampus show 4.3% and 2% volumetric reduction per decade, respectively, with comparable rates of change for men and women (Raz et al., 1997). These declines are congruent with the decreased EF and episodic memory seen in normal aging (Salthouse & Craik, 2011). Other brain regions that show age-related volumetric decreases include, but are not limited to: the caudate, cerebellum, and sensory association cortices (Raz et al., 2005).

In addition to grey matter volumetric change, the mean percent of white matter volume has also been estimated to decrease as a function of age (Guttman et al., 1998). Functional neuroimaging studies have also revealed changes in cerebral blood flow level in the aging brain. The resting state cerebral blood flow to the cingulate, parahippocampal, superior temporal, medial frontal, posterior parietal, left insular, and left posterior prefrontal cortices have all been observed to decrease significantly as a result in the aging brain (Damoiseaux et al., 2008; Uddin, Superkar, & Menon, 2010). Protein markers such as brain-derived neurotrophic factor (BDNF) and vascular endothelial growth factor (VEGF), have also been found to decrease as a function of age (Shetty et al., 2005). These decreases appear to indicate specific loss of cerebral functions as a result of aging, consistent with the rather selective changes in behavioural data seen in older adults (Reuter-Lorenz & Park, 2014).

Despite the seemingly inevitable negative changes to the aging brain, there is also evidence that even an aging brain is capable of neuroplasticity and more positive changes (Reuter-Lorenz & Lustig, 2005). For example, compensatory neural recruitment refers to additional activation of other neural regions that counteracts age-related declines in brain function and supports successful performance (see Figure 1: Reuter-Lorenz & Park, 2014; Reuter-Lorenz & Lustig, 2005). This process is elaborated in the Scaffolding Theory of Aging and Cognition (STAC), which posits that the brain attempts to compensate for the various age-related brain changes by engaging in continuous reorganization to maintain cognitive functioning (Park & Reuter-Lorenz, 2009). This scaffolding describes several

Figure 1. Revised Scaffolding Theory of Aging and Cognition (STAC) Model (Reuter-Lorenz & Park, 2014)

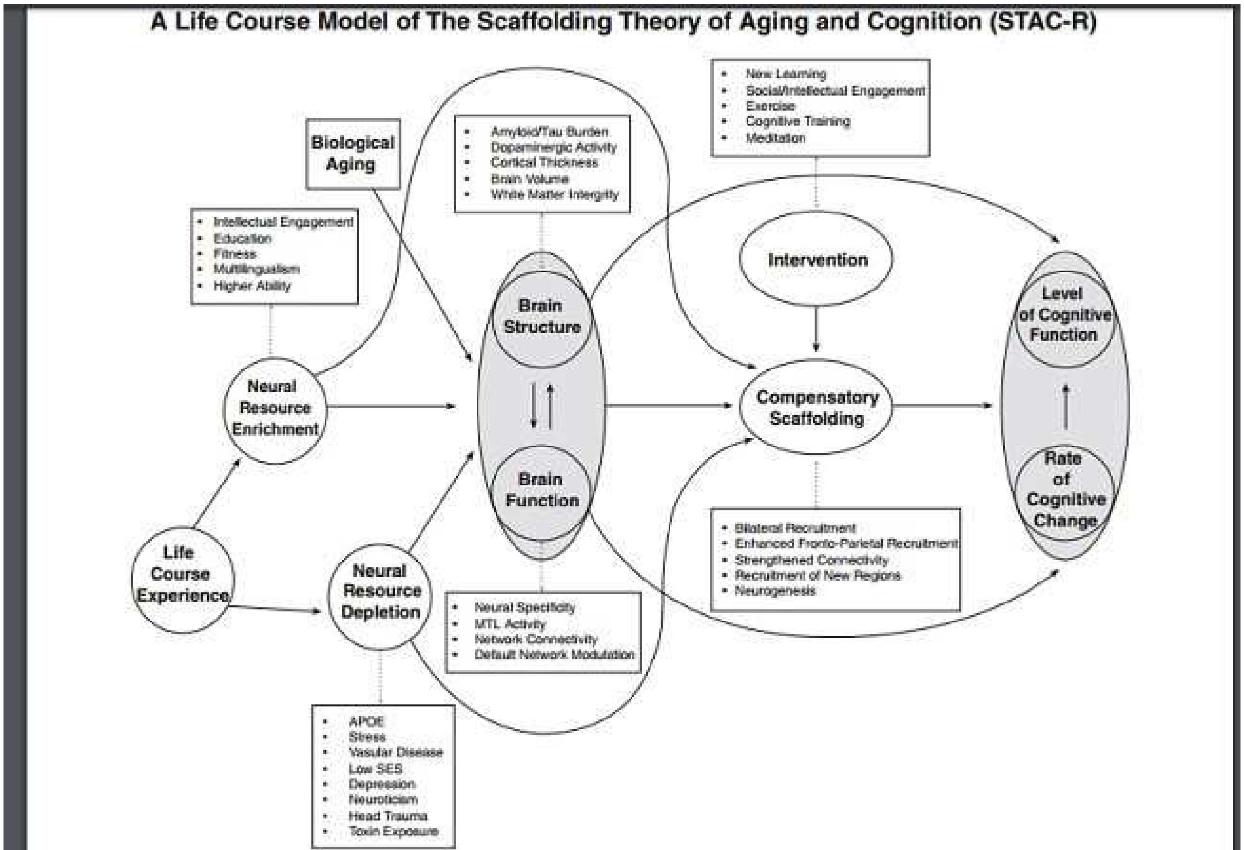


Fig. 2 A conceptual model of the scaffolding theory of aging and cognition-revised (STAC-r)

neural patterns exhibited in older adults, including the recruitment of homologous brain regions, additional prefrontal activation, up-regulation of standard brain regions, strengthening pre-existing connections, formation of new connections, and discarding of weak and faulty connections (Park & Reuter-Lorenz, 2009). A complementary model to STAC is Cabeza's (1996) Hemispheric Encoding/Retrieval Symmetry (HERA) model for memory, which describes compensatory recruitment of homologous contralateral brain regions to maintain cognitive performance in older adults.

Cognitive enrichment. A particularly relevant and promising aspect of the STAC model is termed "neural resource enrichment", which refers to influences that serve to enhance brain structure or function, and can lead to an enhancement of scaffolding. Enrichment may take the form of engagement in intellectual and social activities, aerobic exercise and physical activity, or undertaking new learning. In sum, the STAC model suggests the possibility that late life intervention can produce positive neural changes that are associated with better cognitive outcomes in older adults.

Complementary with the STAC model are the Engagement Hypothesis and the Disuse Hypothesis. The Engagement Hypothesis (Hertzog et al., 2009; Hultsch et al., 1999) states that intellectual abilities in later life could be preserved by a combination of a favorable environment, higher occupational status, and sufficient intellectual stimulation. This may lead to the comparable performance of some older adults whose cognitive performance can rival those of their young counterparts (Hertzog et al., 2009). The disuse hypothesis, on the other hand, follows the popular saying: "use it or lose it", stating that lack of stimulation results in disuse and atrophy of cognitive processes and skills (Fratiglioni, Paillard-Borg, & Winblad, 2004). Related to the notion of disuse is the aim of increasing levels of intellectual stimulation through activity or training to prevent or reverse cognitive declines. Accordingly, numerous studies suggest that cognitive training, aerobic exercise, and engagement, can enhance neuroplasticity (scaffolding) in aging and improve cognitive performance on a behavioural level. The next sections focus on two specific factors, cognitive training and exercise training, given the considerable evidence of their impact on EFs and memory (Hertzog et al., 2009).

Cognitive Training

A research topic undergoing considerable growth concerns the cognitive training of older adults. Studies utilizing cognitive training have demonstrated positive effects in older adults that range from the reduction of global cognitive decline to the preservation of specific cognitive processes such as EFs (Fratiglioni, Paillard-Borg, & Winblad, 2004; Hertzog et al., 2009; Lustig et al., 2009). Across a variety of training formats, three categories have been identified: strategy training, multimodal training, and process training (Lustig et al., 2009). Strategy training focuses on enhancing a particular cognitive task using strategy. For example, method of loci is a commonly used strategy to enhance memory performance (Lustig et al., 2009). While strategy training has proven effective for the target task and closely related transfer tasks, evidence of far transfer and benefits to everyday activities is more mixed (Lustig et al., 2009). For example, In the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study (Ball et al., 2001), participants were randomly assigned to one of the four training groups: one of the two types of strategy training groups (memory or reasoning [EF] training), a speed of processing training group, or a control group. The two strategy training groups exhibited training gains and near transfer effects that were retained five years later (Ball et al.,

2002) The EF reasoning group also suffered significantly less decline on iADLs five years after training (Willis et al., 2006). In a study of memory encoding using the method of loci mental imagery technique, Singer, Lindenberger, and Baltes (2003) found that such strategy training led to modest training gains that were retained after six years in a group of very older adults (mean age of 79.3). However, the modest evidence of transfer effects has limited the use of strategy training in general (Noack et al., 2009).

The second major form of cognitive intervention is process training. This form of intervention involves training specific cognitive processes such as working memory and EFs (Lustig et al., 2009). Overall, process training studies have shown more evidence of broad transfer effects in older adults than strategy training studies (Hertzog et al., 2009; Lustig et al., 2009). Other studies involving working memory training found that older participants showed significant improvement on tasks of EFs and fluid intelligence (Brehmer,Westerberg, & Bäckman, 2012; Karbach & Kray, 2009). Furthermore, working memory training of older adults has led to increased blood flow to prefrontal cortex (Mozolic, Hayasaka and Laurienti, 2010). Additionally, working memory training has also been associated with increased white matter connectivity (Takeuchi et al., 2010) and activation of the frontal regions implicated in working memory (Olesen et al., 2004) in young adults. Taken together, these studies provide evidence for the presence of cognitive and neural plasticity after process training.

Within the category of EF process training, Bherer et al. (2005) demonstrated that a computerized dual-task (DT) training protocol led to both training task gains and within-modality and cross-modality transfer (visual identification tasks) in both older and young adults. The same DT training task also led to transfer gains in measures of attentional control and interference monitoring (Bherer et al., 2008). The efficacy of process training has also been shown at a neural level. Using the same DT training protocol from Bherer et al.'s (2005) study, fMRI methods revealed changes in neural activity, specifically the dorsal and ventral prefrontal cortex, that were associated with improved DT performance in younger adults (Erickson et al., 2007a). Similar results were found in older adults in a subsequent study (Erickson et al., 2007b). In particular, older adults displayed increased activation in the left ventral prefrontal cortex and decreased activation in the right ventral prefrontal cortex as a result of the dual-task training. Additionally, there was evidence for increased asymmetry of the ventral prefrontal cortex activation in both older and younger adults. However, older adults' dorsolateral prefrontal cortex showed a decrease in activity whereas the activity of this region increased in younger adults following training. The authors interpreted this difference in activation as advantageous to both age groups; whereas the increased activation in young adults represented higher usage of the involved regions, the decreased activation in older adults represented higher efficiency. Furthermore, at a behavioural level, the age differences in dual-task performance on the training ask were minimized as a result of training.

In general, cognitive training research has revealed a difference in magnitude of training gains as a function of age, such that younger adults exhibit larger training gains than older adults (Lustig et al., 2009). Furthermore, both age groups demonstrate significant near transfer effects (e.g. memory training task to an untrained memory task), but older adults exhibit smaller far transfer effects compared to younger adults. A notable exception to this general trend is EF training, specifically dual-task training, which has been shown to be capable of producing both near and far transfer in older adults (e.g., Li, Roudaia, Lussier, Bherer, & McKinley, 2010). Additionally, there is evidence suggesting that the training gains arising from EF training (task-specific and transfer) are maintained on a long-term basis (Hertzog et al., 2009).

Exercise Training

A second major approach to improving cognitive performance in older adults involves physical exercise or aerobic training. Correlational evidence suggests that cardiovascular health is positively associated with cognitive functioning (Bherer et al., 2013; Colcombe & Kramer, 2003; Reuter-Lorenz & Lustig, 2005). Exercise training has led to improved cognition in older adults, and aerobic activities of moderate intensity are particularly effective (Colcombe & Kramer, 2003) A recent meta-analysis utilizing 18 randomized clinical trials found that aerobic exercise enhanced cognitive functions across all multiple domains, including processing speed (e.g., WAIS-IV Digit Symbol Coding) and memory (e.g., California Verbal Learning Test: Smith et al., 2010; see also Colcombe & Kramer, 2003).

The observed cognitive gains due to aerobic exercise training have also been associated with related neuroanatomical changes (Colcombe & Kramer, 2003; Erickson & Kramer, 2009). For example, older adults who received aerobic training showed increased gray and white matter volume in the prefrontal and temporal cortices, concurrent with improvements in behavioural improvements in EF and memory performance (Colcombe et al., 2006). Additionally, this finding is complemented by neuroimaging evidence showing that physical activity can induce increased white matter integrity, particularly in the frontal and subcortical areas (Burzynska et al., 2014). Increased connectivity between hippocampal, prefrontal, and cingulate regions was also observed with training-related improvements in EF performance (Voss et al., 2010). In addition to a focus on EF changes due to exercise, hippocampal and/or serum biomarkers of plasticity have also been observed (Duzel, Van Praag, & Sendtner, 2016). Notably, the hippocampus is capable of neurogenesis until very advanced age in humans (Bergmann et al., 2015), and is associated with better memory performance (Erickson et al., 2011) suggesting that physical exercise can result in better memory performance and associated brain changes in older adults.

The mechanisms that underlie exercise-related neural and cognitive plasticity include increases in circulating proteins that can successfully cross the blood-brain barrier (Erikson, Hillman & Kramer, 2015). For example, protein biomarkers that decline with normative aging, such as serum BDNF, IGF1, and VEGF, have been observed to increase in concentration following a course of aerobic training (Voss et al., 2013). These neurotropic factors stimulate neurogenesis and related functions, and their increased presence has been associated with increased functional connectivity (Voss et al., 2013).

The duration of aerobic exercise interventions is a potentially important consideration. Studies that have found significant cognitive improvement as a result of aerobic training are typically 6 months in duration (Colcombe et al., 2004). However, a study by Chapman et al. (2013) found that participants who received a 12-week aerobic intervention exhibited improved immediate and delayed memory with associated positive neural changes. Accordingly, other studies have shown that training duration does not lead to differential improvements in neurocognition, for example, interventions utilizing a 12-week schedule did not yield significantly different results from those lasting > 36 weeks (Smith et al., 2015; Hertzog et al., 2009).

Another factor to consider is the intensity of the aerobic exercise. Colcombe and Kramer's review (2003) indicated that aerobic activities of moderate to high intensity are the most effective at producing cognitive improvement. Interestingly, it appears that aerobic training is not as quick at producing significant training gains as cognitive training, given that older participants exhibited significant cognitive and neural plasticity after only five weeks of dual-task training (Bherer et al., 2005; Erickson et al., 2007b). This comparison suggest that cognitive training allows for a more economical and time-efficient means of improving cognition.

Despite efforts to shorten the duration of aerobic training, a common complaint is its monotonous nature. Recently, video games that contain an exercise component (i.e., exergames) have become increasingly common and popular among older adults due to their entertainment value. Older adults have shown marked improvements on the trained task or game, as well as a variety of neuropsychological measures including Trail Making, Stroop, and Digit Span Backwards (Anderson-Hanley et al., 2012; Chao, Scherer, & Montgomery, 2014; Maillot et al., 2012).

Combining Cognitive and Aerobic Training: Multimodal approaches

In contrast to the sizable amount of research to evaluate the efficacy of single-modality training protocols, there is far less work devoted to investigating the combination of two modalities of training (cognitive and physical). Possibly, such multi-modal training could produce even greater cognitive gains than either solely cognitive or physical training. Multimodal approaches were developed in response to the limited far transfer effects of strategy training approaches (Hertzog et al., 2009; Lustig et al., 2009), as there could be possible synergistic benefits resulting from combining different modes of training (Hertzog et al., 2009; Lustig et al., 2009).

Studies investigating the efficacy of multimodal training are relatively few in number. Shatil et al. (2013) compared the transfer effects of cognitive training, aerobic training, and combined cognitive and mild aerobic training performed sequentially. After the training sessions, it was found that only the cognitive and the combined groups showed significant improvement on various measures of EF. A similar study by Eggenberger et al. (2015) found that while all three groups (attention + aerobic, verbal memory + aerobic, aerobic) showed evidence of far transfer, the combined groups performed better on working memory and EF measures than the single-modality aerobic group. Similarly, Oswald et al. (2006) compared the performance of a group of older adults trained with either a purely cognitive task (fluid ability, attention, and memory), a physical training task (balance and motor coordination), a combined cognitive-physical protocol (consisting of both training tasks), and those who were in a control group. The older adults were followed over a five year period. After one year it was found that combined training produced larger far transfer effects on measures of speed of processing, attention, memory, and reasoning, compared to the other training groups. Beyond the first year, only the combined training group showed sustained cognitive improvements, along with significantly improved emotional and physical status (see also Rahe et al., 2015; Theill et al., 2013). Table 1 provides a summary of the combined modality training studies.

Multimodal training has also taken the form of video games with both cognitive and physical components. A meta-analysis conducted by Anderson-Hanley et al. (2012) noted that older adults trained with the Nintendo Wii, a video game console with both cognitive and physical components, improved on a wide range of cognitive functions (see also Boot, Blakely, & Simons, 2008; Kueider et al., 2012).

Taken together, there is sufficient evidence to suggest that combined, multimodal training offers more significant benefits than single modality training alone. Specifically, it appears that combined modality training can produce significantly more near and far transfer effects in older adults than single-modality training. However, there are a few notable issues surrounding the use of multimodal training. For example, it is challenging to identify the "active ingredient" that is responsible for the observed training gains (Lustig et al., 2009), and this is especially true for exergame intervention protocols that are composed of a variety of games that contain both cognitive and physical components, such as those of Nintendo Wii (Anderson-Hanley et al., 2012). It is also still unknown if the cognitive and physical components have any type of interaction effect with each other. Additionally, very little research has been conducted on the administration of multimodal training; specifically, it is unknown if there are significant differences between receiving the cognitive and physical training simultaneously or sequentially.

Determinants of Cognitive Improvements due to Training: Moderating factors

A final dimension of cognitive training research that remains understudied is the potential for individual difference factors to influence the magnitude of training gains. The majority of training studies focus on the detection of group-wise effects and assume that random assignment to training conditions is sufficient to control for variation in background factors. However, there is evidence to suggest otherwise. Of the few available studies that examine moderating factors, there is evidence suggesting that several personal characteristics can attenuate the magnitude of training gains, such as the age and education of the participants. Zinke et al. (2013) found that

Table 1.

Summary Findings from Available Multimodal Training Studies

Authors	Training Groups	Main Outcomes
Shatil et al. (2013)	1. Cognitive + Aerobic (Sequential) 2. Cognitive 3. Aerobic 4. Control	Only the cognitive and combined modality group significantly improved on memory and EF scores
Eggenberger et al. (2015)	1. DANCE (Simultaneous Attention + Aerobic) 2. MEMORY (Simultaneous Verbal Memory + Aerobic) 3. Treadmill Walking	All groups improved significantly on cognitive measures; DANCE and significantly better on working memory and shifting attention; only the combined modality groups maintained training gains after one year
Oswald et al., (2006)	1. Cognitive Training (EF+ memory) 2. Physical Training (Balance + gymnastics) 3. Psychoeducational Training 4. Combined (Cognitive + Physical; Sequential)	Combined training group outperformed other groups in terms of cognitive functions and independent living measures. Only combined training group retained the training gains 1 year after the termination of training
Rahe et al., (2015)	1. Combined Cognitive + Physical (Sequential) 2. Cognitive training	Comparable significant improvements on attention after training; at one year follow-up combined group outperformed purely cognitive training group

the magnitude of improvement from a working memory training protocol could be predicted by age. This is not surprising as there is a strong negative correlation between EFs and age (Raz, 2000).

Perhaps more interestingly, non-cognitive factors have been associated with the magnitude of training gains. For example, Stine-Morrow et al. (2014) found that openness to experience and having a larger social network are associated with greater training gains. Motivation for cognitive challenge is another potential moderator of training gains. One of the major ideas of Hertzog et al. (2009)'s review was that an intellectually stimulating lifestyle is associated with better maintenance of cognitive skills and reduced risk of cognitive decline. As a result, it is perhaps not surprising that people with higher motivation who enjoy doing mentally stimulating activities might have a differential response to training protocols.

While there is no consensus as to how to operationalize intellectual motivation, Need for Cognition (NFC) has been included in a few cognitive aging intervention studies (Hess et al., 2012; Stine-Morrow et al., 2009). The NFC questionnaire was designed to measure a person's preference for mentally challenging activities and tendency to seek out effortful cognitive activities (Fleischhauer et al., 2015). NFC has been found to predict positive 12-month change in cognitive status, and to correlate positively with the number of cognitively stimulating leisure activities that older retirees pursue (Baer et al., 2012). NFC has also been found to predict training gains from cognitive training protocols (Stine-Morrow et al., 2014), but in an interesting way: participants who scored higher on NFC showed smaller training gains than those who scored low on NFC. This could be due to the possibility that high NFC participants had already been engaging in mentally challenging activities to begin with, thus they could not benefit from the cognitive training task as much as participants who had no natural inclination to engage in mentally stimulating activities. One could, however, take a different view and predict that those who enjoy intellectual challenge might work harder when given a cognitive training activity and improve more quickly. Given the dearth of studies that consider moderating factors in intervention studies, it remains an open question as to whether factors such as motivation to engage in mentally challenging activity moderate the effects of cognitive training in a positive or negative way.

Summary and Open Questions

To summarize, there is sufficient evidence that both cognitive and physical single-modality training can lead to both significant near and far transfer in older adults. There is also evidence supporting the efficacy of combined modality training. Additionally, studies have shown that individual differences can lead to differential responses to training. The field of cognitive training in older adults has matured to a point at which questions concerning training efficacy can focus on the refinement of training techniques. For example, preliminary examinations have attempted to investigate whether or not one schedule of training is better than another (Hertzog et al., 2009). Additionally, whether or not there are important individual difference factors that suggest that a “one-size-fits-all” training approach might not be appropriate for all types of participants.

Multimodality training, as mentioned previously, appears to confer more cognitive benefits than single modality training (Eggenberger et al. 2015; Rahe et al., 2015; Theill et al., 2013). However, an important consideration is the possibility that simultaneous training (administering both cognitive and aerobic to the participants at the same time) and sequential training differ in their efficacy. There are pros and cons associated with both methods of training: Simultaneous training helps to avoid monotony and cut down training time, but risks taking attention away from the cognitive task particularly for older adults, as they are more vulnerable to cognitive-motor interference (Al-Yahya et al., 2010; Brünken et al., 2002). For instance, Li et al. (2001) showed that when given a cognitive-motor dual task (memorization and walking), older adults prioritized walking at a cost to concurrent cognitive performance, suggesting that the participants being trained simultaneously with a cognitive and aerobic task might perform less well on the cognitive training component of a combined training protocol. These experiments support the view that Sequential training might be more beneficial for older adults. Along similar lines, Labelle et al. (2013) found that participants committed significantly more errors on a Stroop test while cycling when their peak power output (PPO) was increased from 60% to 80%. Thus, simultaneous combined modality training may therefore be more effective only at mild to moderate levels of physical intensity.

However, it is still currently unknown if simultaneous multimodality training may result in differential training gains compared to sequential multimodal training. The available literature only features combined training protocols that are either simultaneous or sequential in format, but do not compare each format directly, hence creating a research gap to be addressed.

The Current Study

The purpose of the current project is to address the issue of how multi-modal training is best delivered (i.e., in a sequential or simultaneous format) and whether individual differences factors such as motivation to engage in cognitively challenging activity and baseline fitness status moderate the magnitude of training-related changes in measures of EF and memory. It was hypothesized that both simultaneous and sequential groups should exhibit significant gains in the form of improved cognitive performance, as supported by studies utilizing either modality of training (Bherer et al, 2005; Colcombe & Kramer, 2003).

Based upon the literature on age-related increases in cognitive-motor dual-task costs (Al-Yahya et al., 2010; Brünken et al., 2002; Li et al., 2001) it was further hypothesized that the sequential training group would improve more on measures of cognition when compared to the simultaneous group, due to the cognitive advantage of not having to divide their attention during training.

Finally, as a more exploratory question, specific moderators were examined as potential predictors of the magnitude of training-related improvement. For example, baseline level of fitness (such as Sub-maximal VO_2) and motivation for cognitive challenges (NFC) were included in the study as a way of identifying potential moderators of training-related gains in measures of EF and memory.

Method

Participants

Healthy older adult participants (65+ years) were recruited from the community via notices and newspaper advertisements. All participants were free of chronic medical conditions such as heart or muscular diseases (e.g. hypertension, physical injury, etc.), and were not on medications that could affect their test results on cognitive and physical measures.

Screening of readiness to exercise and cognitive fitness were also performed to determine eligibility for the training intervention. For physical screening, the Jones protocol (Jones et al., 1985) was administered by having participants cycle in a standard incremental schedule of increasing intensity up to 85% of their estimated maximum heart rate. The Jones test was terminated if the following occurred: failure of heart rate to increase with increased exercise intensity, drop in systolic BP of >10mm HG from baseline despite increase in workload, subject requested to stop, failure of testing equipment, signs of poor perfusion (lightheadedness, ataxia, etc.), heart rhythm change, excessive rise in BP, physical or verbal manifestation of severe fatigue, signs and symptoms of angina or shortness of breath, or if the participant reached within 10npm of 85% HR max. For cognitive screening, participants were excluded if they scored less than 26/30 on the Montreal Cognitive Assessment (Nasreddine et al., 2005) task. All participants received a small honorarium for their participation. Participants were randomly assigned to either Simultaneous or Sequential training groups.

A total of 85 participants were initially recruited. Ten participants did not make an appearance on the testing dates. Twelve participants were disqualified after the pre-training assessment due to low MoCA scores. Five participants were unable to complete the physical assessment due to physical issues. Two participants had to drop out of the study due to sickness / health issues. Twelve participants were unable to meet the time demands of the training schedule. Two participants had to drop out part way through the training phase due to elevated heart rate. In the end, forty-two participants completed the full experiment. Figure 2 summarizes the participant recruitment and retention information.

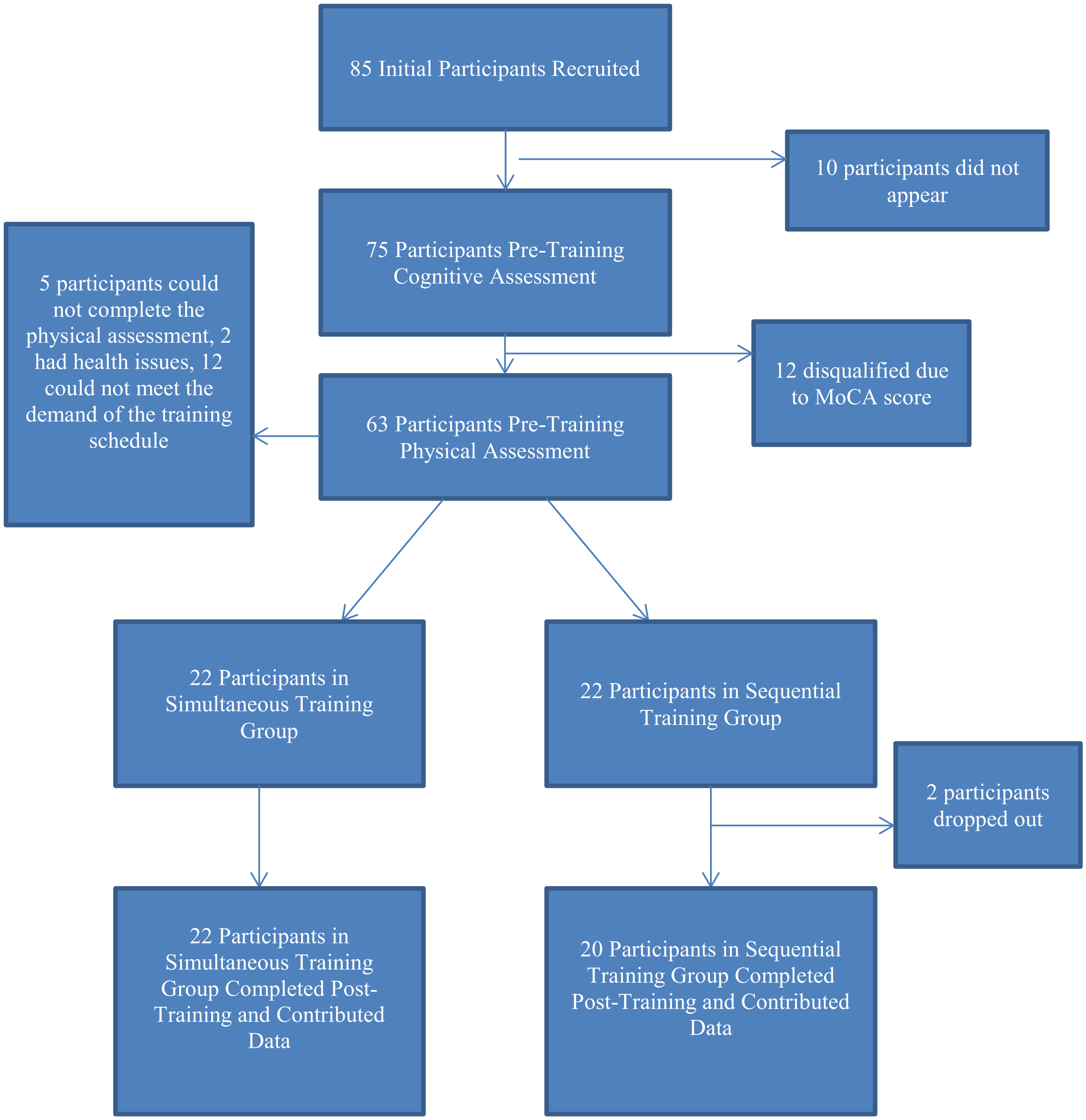
Materials

The materials are divided into three groups: background / screening measures, training tasks, and outcome measures. Additional outcome measures (balance, mobility, social engagement, hearing acuity) were administered for other purposes and will not be reported here.

Background/Screening Measures

Montreal Cognitive Assessment (MoCA: Nasreddine et al., 2005) is a brief cognitive screener primarily used in a clinical setting to diagnose mild cognitive impairment (MCI) in older adults. The MoCA has been clinically validated for its use as a brief clinical screener for MCI (Nasreddine et al., 2005). It is a paper-and-pencil test that takes approximately 10 minutes to administer. An individual obtaining a score of less than 26/30 is suspected of having MCI, whereas a score equal or greater than 26 suggests a normal level of cognitive functioning. MoCA contains questions encompassing several cognitive domains including: a memory task that requires the recalling of words; visuospatial tasks that require drawing of a clock and a cube (in three dimensions); EFs tasks such as trailing making, phonemic fluency, and verbal similarity; working memory tasks that require mental arithmetic and digit span forward and backward; an

Figure 2. Flow chart of number of participants at each stage



attention task that requires tapping to a target letter; language capability tasks that require the naming of several animals and the repetition of two sentences; and finally a task that requires the evaluation of the participant's orientation to time and place. A score of one was added to the scores of four participants who had received less than 12 years of education as a corrective factor (Nasreddine et al., 2005).

Jones Test (Jones et al., 1985**)** is the physical pre-training assessment employed in this study. Once the participant was warmed up and in a comfortable position on the bike, the participant was instructed to pedal without any added load to obtain the necessary pedaling frequency. After one minute, the initial load of 17 Watts was added. The Borg scale (0-20) (Borg, 1982) was administered to the participant. The heart rate was monitored in the last 20 seconds of every minute. The participant was asked if he/she can carry on. Then the power was increased by an equal amount of 17 Watts (100kpm/min). Blood pressure was measured every second minute. Throughout the test the participant was encouraged to pedal steadily and regularly and was kept informed of the progress of the test. When the participant stopped pedaling or if the participant was within 10 beats of 85% max heart rate, or if a score of 17 was reached on the Borg (0-20) scale, the test would be terminated. The participant would then be encouraged to cool down by pedaling a reduced load for at least 5 minutes. Heart rate was recorded every minute and blood pressure was recorded every second minute until blood pressure decreased below 145/95 mmHG and heart rate was below 100 bpm.

Training Tasks

iPad Divided Attention Training Task is a digital cognitive training task similar to the one employed by Bherer et al. (2005). For the current study, the training task was adapted for iPad Air (MD785CL/B) on an IOS 8.2. The training program was delivered on a wireless network, and the training data were automatically saved on a remote server after each training session was completed.

The participant held the iPad in a landscape orientation and responded to visual stimuli with their thumbs. The participants had to match each stimulus by manually pressing the corresponding target stimulus from a list of possible responses. Participants worked with one or two different categories (animals and planetary bodies) depending on the condition. There were two types of blocks, pure (A) and mixed (B). In the pure blocks, participants were presented with single-pure trials, in which one stimulus was presented from the same category throughout the block, and the participant selected the matching item from three possible responses arranged in a vertical column, counterbalanced to appear on the left or right of the screen (Figure 3).

In the mixed-blocks (B), the participants were presented with a mixture of single-mixed and dual-mixed trials. In the single-mixed trials, the participants were presented with one stimulus, and were also presented with two sets of three possible responses shown on the left or right (Figure 4). In the dual-mixed trials, participants were presented with two stimuli simultaneously (one from each category), and would then respond by selecting the two matching options with their two thumbs (Figure 5).

All participants performed the iPad training task in the same ABBBBA order. During the first pure block (A), participants were given a brief practice session in order to familiarize themselves with the single-pure trials. They then completed a full pure block (A), followed by a practice session that introduces the single-mixed and dual-mixed trials, then five mixed blocks (B), and finally a pure block (A). Mean response time and the

Figure 3. Single-Pure Trial (Right)

Figure 4. Single-Mixed Trial

Figure 5. Dual-Mixed Trial

number of incorrect responses were the two primary outcome measures derived from this training task. For both of these outcomes, a smaller value would indicate better performance (faster response latencies and fewer errors being made). It should be noted that analyses using median RT of correct times yielded similar results.

Physical Training. The aerobic training component involved recumbent cycling, and was chosen to be free of balance demands and allow participants in the Simultaneous training group to hold the iPad comfortably at the same time as cycling. The 12-week training program progressed in physical workload over time. In the first four weeks of training, participants cycled at 40% of their estimated maximum heart rate (as determined by the Jones Test). In the next four weeks of training, workload was increased to 44% of each person's estimated maximum heart rate, and the final four weeks were at 48% of each person's estimated maximum heart. Each training session began with a 5 minute low-intensity warm-up on the bike, followed by 25 minutes cycling at the target heart rate (40%, 44%, 48%), and a 5 minute cool-down. The participants then performed 5 minutes of stretching exercises to minimize any potential physical discomfort or muscle soreness.

Outcome Measures

iPad Divided Attention Near-Transfer Task. The iPad task also provided pre- and post-training session data that were employed as measures of near transfer. The sessions also contained pure blocks (A) and mixed blocks (B), and participants were given the same instructions as in the training sessions. However, the stimuli in these sessions were from two different categories distinct from those used during the training phase (fruits and transportation methods; see appendices A-C), and the near-transfer assessment was shorter than the training sessions. The near-transfer divided attention task followed an ABBA format in which the participants completed a pure block, followed by two mixed blocks, and finally a pure block. Furthermore, all the participants performed this near-transfer task while seated without performing the concurrent cycling. The same dependent variables (response time, errors) were derived for analyses.

Letter Number Sequencing, another subtest of the WAIS-IV (Wechsler, 2008), was included to assess working memory. The test requires the examiner to present several lists of random letters and numbers to the participants verbally, and they must verbally give a response by rearranging the list so that the all the numbers are given first in an ascending order (1-9), followed by the letters in alphabetical order (A-Z). For example, if the participant was presented with Q-1-T-6-Z, the correct response would be 1-6-T-Q-Z. The test starts with a list span length of two characters and progresses all the way to nine characters, and each span length contains three trials. The participant is required to provide the correct response to at least one trial of a span length before they can progress to the next span length, and the test is terminated if he/she fails to provide at least one correct response for any given span length. The dependent variable derived from this measure is the total number of correct sequences recalled by the participants (out of a possible 30).

Digit Symbol (Wechsler, 2008), one of the subtests of the Wechsler Adult Intelligence Scale (WAIS-IV), was included to measure processing speed. The measure has been found to have excellent internal consistency reliability at $r = 0.93$, as well as split-half reliability of $R = 0.95+$ (Wechsler, 2008). The test pairs nine random symbols with the numbers 1-9, and there are rows of empty squares with the numbers on top that need to be filled with the correct corresponding symbols. The participant is given 120 seconds (s) to fill in the squares with as many correct corresponding symbols as possible in the presented order without skipping any squares or making a mistake. The score of this test is reflected by the number of correct symbols that the participant fills in by the end of the given 120 s test time, minus the number of incorrect symbols filled in, if any. The maximum possible score is 135.

Colour-Word Interference Task of Stroop (MacLeod, 1991) is a very common neuropsychological measure used for estimating an individual's ability to resolve conflicts and catch errors (Banich et al., 2000; Lezak 2004). Two conditions were employed in the current study: the congruent and incongruent conditions. In the congruent (colour) condition, participants attempt to read out loud as many colour of the inks (the colours were *green, blue, tan,* or *red)* as possible in 120 s. In the incongruent (colour-word) condition, participants were presented with words that were printed in non-matching colour ink, and they were asked to read out the colour of the ink instead of the word (for example, if presented with the word *red* and it was printed in blue ink, the participant would be required to say "blue" in order to get a correct response. The participants were also given 120 s to read out as many correct responses as possible. From each condition, the speed was derived by dividing the correct responses by 120 s to get the number of correct responses per second. A ratio obtained from dividing the colour-word condition speed by the colour condition was obtained, with a higher ratio indicating better interference monitoring.

Immediate and Delayed Memory Tests are two subtests of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS: Randolph et al., 1998). RBANS was included to assess training-related transfer to memory performance.

For the purpose of this study, only the subtests measuring immediate and delayed memory were included. In the Immediate Word List Recall, participants were given a list of 10 words and were then asked to immediately recall the words back in any order (RBANS Immediate Word List Recall). The same process was then repeated three more times with the same list of words. After approximately 15 minutes, participants were then asked to free-recall the list of words again in any order without any prompt or reminder (RBANS Delayed Word List Recall), and then were asked to complete a recognition task in which he/she had to identify the 10 correct words from a list of 20 words (Delayed Word List Recognition).

In another measure, RBANS Story Recall, participants were verbally presented with a short story, and were then asked to recall the details of the story in the exact same wording. This process was then repeated one more time. After a 15 minute delay, the participant was asked to free-recall the details of the story, again in the same wording, if possible (Delayed Story Recall). The test-retest reliability of the RBANS has been noted to be comparable to the WAIS-3 (R = 0.84) (Randolph, 1998).

Procedure

During the initial evaluation session, all participants underwent neuropsychological testing (including the iPad Divided Attention Near Transfer Task described above) to establish their baseline level of cognitive functioning. The cognitive assessment was then followed by a physical assessment the next day in which the participants' blood pressure, height, weight, heart rate, etc. were measured. In addition, the participants were asked to perform the sit-to-stand task and various physical tasks on an instrumented platform (reported elsewhere). Following the physical assessment, participants were given the Jones test.

The participants who were qualified to participate then proceeded to the training phase in the following week, during which they performed the recumbent cycling again under the supervision of a certified physical trainer and the iPad divided attention training program. Those in the Simultaneous group received the cognitive and physical training at the same time in order to practice dividing their attention between the two tasks, whereas those in the Sequential group performed the DT training in a separate room, followed by the cycling. Both groups completed 12 sessions of training over a 6-week period. An 80% attendance rate was maintained throughout the study.

After the final training sessions, both groups underwent the post-training assessment, which contained the same tests and measures as the cognitive assessment performed at the beginning of the study. The participants then received their final honorarium and a brief explanation of the study's purpose. They were also given an opportunity to ask any question or express any concern before they were officially given the termination form to sign. The participants were also asked to complete a three month follow-up package consisting of various questionnaires (not reported here) by mail.

The outcome measures of interest were the pre-post differences in the neurocognitive tasks (EF and memory tests), and any improvement seen on the tests would be indicative of transfer effects from the training protocol (iPad Divided Attention Training Task and the cardiovascular training).

Data Analysis

Data Screening. Data from 22 participants in the Simultaneous group and 20 participants in the Sequential group were analyzed. One participant in the Simultaneous group had a pre-training Stroop score that was above the cut-off (i.e., > 3.5 *SD*), and the score was replaced with the most extreme score within 3.5 *SD*. Similarly, a participant in the Sequential group had a pre-training RBANS Story Delayed Recall that was above the cut-off and it was replaced. Additionally, due to colour identification issues, two participants in the Simultaneous group could not complete the Stroop task, and thus the data cells were designated as missing data.

The reaction time and error rate of the iPad training tasks received two stages of outlier checks. First, within-subject outliers (*SD* > 3.5) were identified and windsorized. After aggregation, the between-subject outliers were then identified (*SD* > 3.5) and windsorized.

In general, outliers and missing data on the various tests were identified and windsorized (replaced with the most extreme values that fell within 3.5 standard deviations). Data distributions for outcome variables that were not normal (with a skewness/kurtosis of > +/- 3) were given a square root transformation.

Results

Baseline Group Differences

Means and standard deviations for all the measures employed in the current study are presented in Table 2. As seen in the table, the two groups did not differ significantly in their baseline measures, suggesting that there were no systematic confounding factors between training groups.

Divided Attention Training Task

In addition to establishing that the two training groups did not differ in their baseline scores or demographic variables, another preliminary analysis was carried out on the iPad training task to establish that the participants in fact showed the expected improvements in dual-task performance as a function of time. It was also of interest to assess whether the training approach (Simultaneous vs. Sequential) affected the overall level of dual-task performance or the rate of improvement for one group over another. To review, it was predicted that the Simultaneous group would perform significantly worse than the Sequential group due to the requirement of dividing their attention between the cognitive training task and physical training based on research suggesting that EFs become compromised during cardiovascular activity (Labelle et al., 2013).

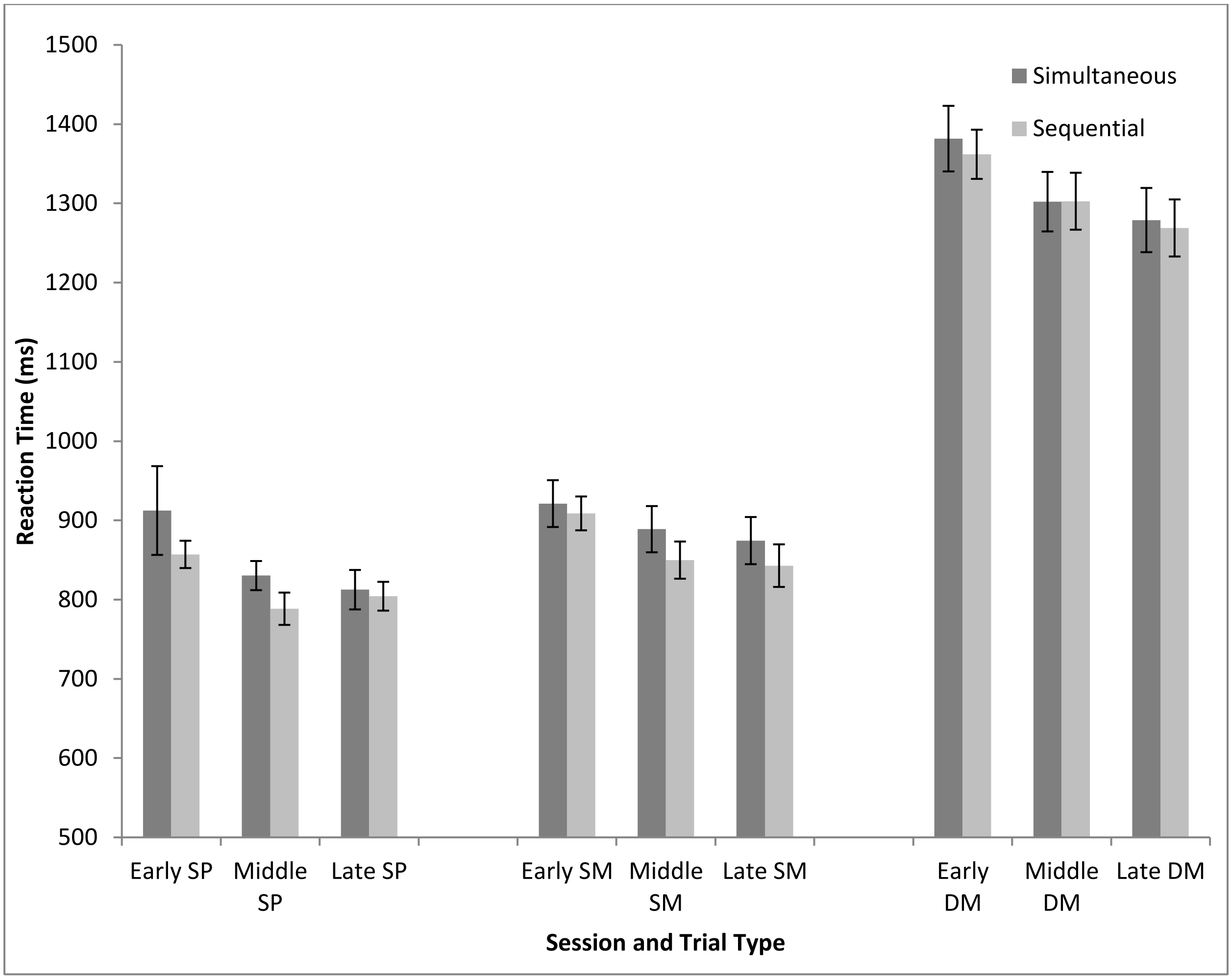
Reaction Time. Figure 6 depicts the mean RTs across all 12 sessions for each training group and trial type. To determine the magnitude of improvement on reaction time on the cognitive training task, data from the 12 training sessions were divided into 3 time bins, with the mean RT of Sessions 1-4 comprising Early RT, the mean of Sessions 5-8 comprising Middle RT, and the mean of Sessions 9-12 as Late RT. Accordingly, Figure 6 shows mean RTs across the

Table 2.
Means and standard deviations for all baseline measures by training condition

Source	Simultaneous	Sequential	*p*
Age (years)	67.60 (3.90)	68.53 (5.39)	0.541
Education (years)	16.76 (2.84)	16.12 (2.87)	0.494
Percent Female	36.4 %	35.0%	0.937
Weight (kg)	68.84 (13.03)	72.09 (14.19)	0.449
MoCA (max. 30)	27.18 (1.71)	27.80 (1.64)	0.240
Resting Heart Rate (bpm)	66.45 (18.65)	68.81 (1.33)	0.781
ETDRS Left Eye (logMAR)	0.16 (0.19)	0.16 (0.21)	0.954
ETDRS Right Eye (logMAR)	0.25 (0.23)	0.16 (0.22)	0.221
Sub-maximal VO_2 (ml/kj/min)	37.86 (5.74)	36.51 (9.44)	0.580
Letter Number Sequencing (/30)	18.91 (1.85)	18.70 (2.36)	0.750
Digit Symbol (/135)	64.64 (12.22)	62.25 (11.93)	0.918
Stroop Ratio (# of word per second; CW/C)	0.87 (0.15)	0.87 (0.21)	0.969
RBANS Immediate Word Recall (/40)	26.64 (5.31)	27.15 (3.65)	0.725
RBANS Immediate Story Recall (/24)	17.5 (3.60)	19.40 (0.93)	0.124
RBANS Delayed Word Recall (/10)	4.91 (2.52)	5.85 (1.81)	0.181
RBANS Delayed Story Recall (/12)	8.45 (2.81)	9.45 (1.57)	0.172

Note. MoCA = Montreal Cognitive Assessment. ETDRS = Early Treatment Diabetic Retinopathy Study. RBANS = Repeatable Battery for the Assessment of Neuropsychological Status.

Figure 6. Mean RT of all three types of trial types across training stages by group



Note. SP = Single Pure Trials. SM = Single Mixed Trials. DM = Dual Mixed Trials.

three time bins for each training group and trial type. A 3 (Time: Early vs. Middle vs. Late) x 3 (Trial Type: Single Pure vs. Single Mixed vs. Dual Mixed) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. The analysis revealed a significant effect of time, $F(2, 46) = 121.55$, $p < 0.001$, $\eta p^2 = 0.841$, such that participants' reaction time on the iPad task was markedly shorter after the training phase. Post-hoc pairwise comparisons using Bonferroni correction revealed that the mean RT of Late training sessions ($M = 995.17$ ms, $SE = 24.62$) was significantly faster than mean RT of the Middle training sessions ($M = 1031.72$ ms, $SE = 22.31$; $p < 0.001$), which in turn was significantly faster than that of the Early training sessions ($M = 1151.70$ ms, $SE = 23.10$; $p < .001$). Furthermore, there was a significant effect of trial type, $F(2, 46) = 569.32$, $p < .001$, $\eta p^2 = 0.96$, such that the mean RTs differed significantly from one another. Post-hoc pairwise comparisons using Bonferroni correction revealed that mean RT on the Single Pure trials ($M = 870.91$, $SE = 19.43$) was significantly faster than RTs on Single Mixed trials ($M = 929.99$ ms, $SE = 23.77$, $p < 0.001$). Mean RT on Single Mixed was significantly faster than that of Dual Mixed ($M = 1377.69$ ms, $SE = 29.21$; $p < 0.001$). The analysis also revealed a significant interaction effect of time and trial type, $F(4, 92) = 4.71$, $p = .002$, $\eta p^2 = 0.17$, suggesting that there was a moderate difference in the magnitude of improvement of participants' RT depending on the trial condition across time. Finally, the main effect of training group, $F(4, 92) = 4.71$, $p = .002$, $\eta p^2 = 0.17$, and the interaction effect of training group and time, $F(4, 92) = 4.71$, $p = .002$, $\eta p^2 = 0.17$, were non-significant.

RT costs. To further examine the dual-task training data, two types of cost measures were derived from the three trial types, in accordance with previous work (Bherer et al., 2005; 2008; Lussier et al., 2012). First, Task-Set Cost was derived by subtracting the RT of Single Pure trials from that of Single Mixed trials; second, Dual-Task Cost was derived by subtracting the

RT of Single Mixed trials from the RT of Dual-Mixed trials. Task-Set Cost was found to be an indicator of the requirement to prepare for and maintain multiple task sets in the Single Mixed trials when compared with the Single Pure trials, whereas dual-task cost was indicative of the process required to perceive multiple stimuli and execute the two responses in a coordinated manner (Bherer et al., 2005; Lussier, Gagnon, & Bherer, 2012). Thus, the two task costs were used as the dependent variables in a series of follow-up mixed ANOVAs.

For Dual-Task Cost, a 3 (Time: Early vs. Middle vs. Late) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. The results revealed a significant main effect of time, $F(2, 50) = 5.00$, $p = .011$, $\eta p^2 = 0.17$, such that participants' dual-task costs were markedly reduced over time. Further post-hoc pairwise comparisons using Bonferroni correction revealed that Dual-Task Cost during the early training phase ($M = 472.34$ ms, $SE = 19.14$) was marginally larger than that of the late training phase ($M = 429.57$ ms, $SE = 16.09$; $p = .059$). All other main effects and interaction effects were non-significant. There was also no significant main effect of group, $F(1, 25) = 0.241$, $p = .628$, $\eta p^2 = 0.01$, nor was there a significant interaction effect between group and time $F(2, 50) = 0.305$, $p = .739$, $\eta p^2 = 0.012$.

For Task-Set cost, a 3 (Time: Early vs. Middle vs. Late) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was also employed. The results did not reveal any significant main effects or interactions, and there was also no significant main effect of group, $F(1, 23) = 0.09$, $p = 0.763$, $\eta p^2 = 0.01$, nor was there a significant interaction effect between group and time $F(2, 46) = 0.244$, $p = .785$, $\eta p^2 = 0.01$. All other main effects and interactions associated with the two derived cost scores were non-significant (*ps* > 0.61).

Error Rate. To assess the reduction of error rate of the trained task over time, a 3 (Time: Early vs. Middle vs. Late training phases) x 3 (Trial Type: Single Pure vs. Single Mixed vs. Dual

Mixed) x 2 (Training Groups: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. The analysis revealed a significant effect of time, $F(2, 78) = 15.835$, $p < .001$, $\eta p^2 = 0.289$, such that participants' error rates on the iPad task were substantially reduced after training overall. Furthermore, there was a significant effect of trial types, $F(2, 78) = 56.72$, $p < .001$, $\eta p^2 = 0.593$, such that the trial types (Single Pure, Single Mixed, or Dual Mixed) had an large effect on the error rates of the participants. Post-hoc pairwise comparisons using Bonferroni correction revealed significant error rate differences among all conditions, such that error rate of the Single Pure trials (M =0.22 errors, SE = 0.05), was significantly lower than that of the Single Mixed Trials (M = 0.854 errors, SE = 0.22; $p = .012$), which in turn was significantly lower than that of the Dual Mixed trials (M =11.18 errors, SE = 1.50; $p < .001$). Additionally, the analysis also revealed a significant time x trial type interaction $F(4, 156) = 15.975$, $p < .001$, $\eta p^2 = 0.291$, suggesting that there are significant differences in the rates of change of errors among different trial types. Thus, dual-task cost and task-set cost of the errors were used as dependent variables in a series of follow-up mixed ANOVAs. Lastly, the main effect of group was $F(1, 21) = 1.093$, $p = .308$, $\eta p^2 = 0.049$, and the interaction effect between group and time was $F(2, 42) = 0.025$, $p = .975$, $\eta p^2 = 0.001$.

Error costs. Cost scores (Dual-Task Costs, Task Set Costs) were derived for the error rate data in keeping with the RT analyses. For Dual-Task Cost, a 3 (Time: Early vs. Middle vs. Late) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. This analysis revealed a significant main effect of time, $F(2, 78) = 16.235$, $p = <.001$ $\eta p^2 = 0.294$, such that participants' error dual-task costs were markedly smaller after the training phase. Further post-hoc pairwise comparisons using Bonferroni correction revealed that dual-task costs during the early training phase (M = 16.84, SE = 2.63) were significantly larger than during the middle training phase (*M* = 6.93 errors, *SE* = 1.15 *p* = .001) and late training phase (*M* = 7.20 errors, *SE* = 1.00; *p* <.001). All other main effects and interaction effects were non-significant. There was also no significant main effect of group, $F(1, 39) = 0.001$, $p = .979$, $\eta p^2 = 0.000$, nor was there a significant interaction effect between group and time $F(2, 78) = 0.161$, $p = .852$, $\eta p^2 = 0.004$.

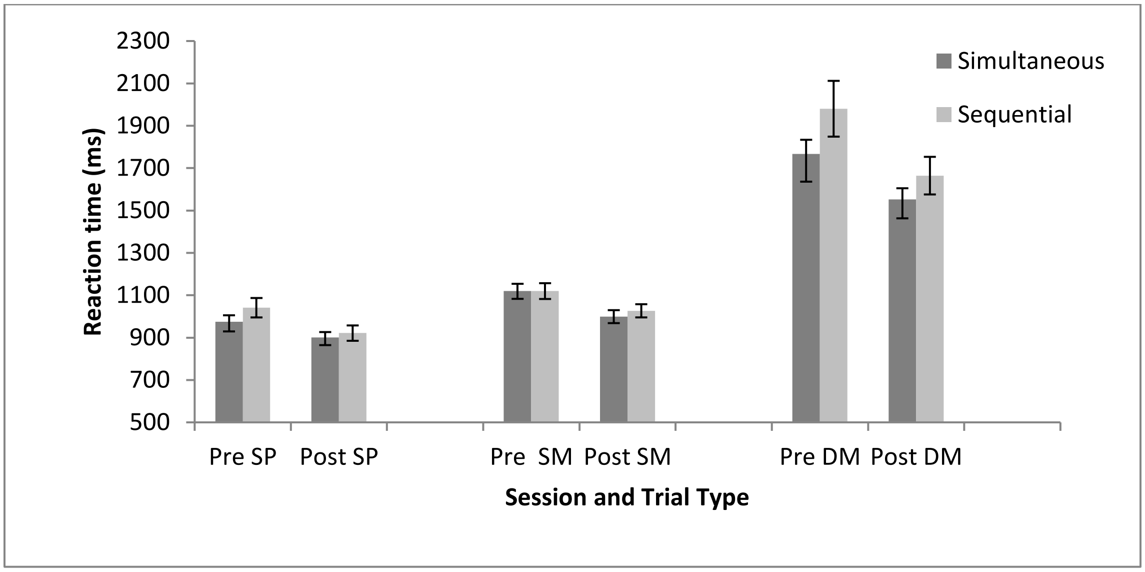
For task-set cost, a 3 (Time: Early vs. Middle vs. Late) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was also carried out. The analysis revealed a significant main effect of time, $F(2, 80) = 4.47$, $p = 0.014$, $\eta p^2 = 0.101$, such that participants' numbers of errors committed on the dual-task cost was markedly smaller after the training phase by a small but significant degree. Further post-hoc pairwise comparisons using Bonferroni correction revealed that the task-set-costs during early training (*M* = 1.27 errors, *SE* = 0.45) were marginally larger than that of the middle training phase (*M* =0.29 errors, *SE* = 0.21; *p* = .0052). All other main effects and interaction effects were non-significant. There was also no significant main effect of group, $F(1, 40) = 1.893$, $p = .177$, $\eta p^2 = 0.045$, nor was there a significant interaction effect between group and time $F(2, 80) = 1.615$, $p = .205$, $\eta p^2 = 0.039$.

Divided Attention Near-Transfer Task

Reaction Time. The near transfer task was given in the same manner to both training groups during the pre- and post-training assessments (i.e., under full attention), albeit with different visual stimuli (fruits and transportation methods as opposed to the planetary bodies and animals used in the DT training task). Additionally, the near-transfer task is also two blocks shorter, following an ABBA format as opposed to the DT training task's ABBBBA format. Figure 7 depicts mean RTs across the three trial types and training groups. To assess the magnitude of improvement on reaction time on the near-transfer task, a 2 (Time: pre-vs. post-training) x 3 (Trial Type: Single Pure vs. Single Mixed vs. Dual Mixed) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. The analysis revealed a significant effect of time, $F(1, 33) = 79.96$, $p < 0.001$, $\eta p^2 = 0.708$, such that participants' reaction time on the near transfer divided attention task was markedly shorter after the training phase. Accordingly, Figure 7 shows mean RTs across the different trial types and assessment phases between the two training groups. Furthermore, there was a significant effect of trial type, $F(2, 66) = 88$, $p < .001$, $\eta p^2 = 0.882$, such that the three trial conditions differed significantly from one another, as shown in post-hoc pairwise comparisons using Bonferroni adjustment: overall mean RT on Single Pure trials ($M = 959.58$ ms, $SE = 21.83$) was significantly shorter than on Single Mixed ($M = 1066.50$ ms, $SE = 22.315$) trials ($p < 0.001$). Mean RT on Single Mixed trials was significantly shorter than on Dual Mixed trials ($M = 1741.14$ ms, $SE = 58.27$, $p < 0.001$). The analysis also revealed a significant interaction effect of time and trial type $F(2, 66) = 17.68$, $p < 0.001$, $\eta p^2 = 0.349$, suggesting that there was a moderate difference in the magnitude of improvement of participants' RT depending on the trial condition across time. Finally, the analysis revealed no significant group main effect $F(1, 33) = 1.371$, $p = .250$, $\eta p^2 = 0.04$, nor an interaction effect between group and time $F(1,3) = 1.259$ $p=.270$, $\eta p^2 = 0.037$.

RT costs. Similar to the training data, task-set and dual-task costs were derived. For dual-task cost, a 3 (Time: Early vs. Middle vs. Late) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. This analysis revealed a significant main effect of time, $F(1, 33) = 24.981$, $p = <.001$, $\eta p^2 = 0.431$, such that participants' reaction time on the dual-task cost was markedly smaller after the training phase. Further post-hoc pairwise comparisons using Bonferroni correction revealed that the overall dual-task cost during early training ($M = 754.08$, $SE = 55.12$) was significantly larger than that of the late training phase (M

Figure 7. Near Transfer Task: Mean RT of all three types of trial types across assessment stages by group



Note. SP = Single Pure Trials. SM = Single Mixed Trials. DM = Dual Mixed Trials.

= 595.21, *SE* = 37.51). All other main effects and interaction effects were non-significant. There was also no main effect of group, $F(1, 33) = 2.834$, $p = 0.102$, $\eta p^2 = 0.079$, nor was there a significant interaction effect between group and time $F(1, 33) = 4.014$, $p = .053$, $\eta p^2 = 0.108$.

For task-set costs, a 3 (Time: Early vs. Middle vs. Late) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was also employed. The results did not reveal any significant main effects or interaction. As well, there was also no main effect of group, $F(1, 33) = 0.848$, $p = 0.364$, $\eta p^2 = 0.025$, nor was there a significant interaction effect between group and time $F(1, 33) = 2.705$, $p = .110$, $\eta p^2 = 0.076$.

Error Rate. To assess the reduction of error rate on the near transfer divided attention task due to training, a 2 (Time: pre-vs. post-training) x 3 (Trial Type: Single Pure vs. Single Mixed vs. Dual Mixed) x 2 (Training Groups: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. The analysis revealed a significant effect of time, $F(1, 40) = 6.887$, $p = .012$, $\eta p^2 = 0.147$, such that participants' error rates on the near transfer task were substantially reduced after training overall. Furthermore, there was a significant main effect of trial type, $F(2, 80) = 59.51$, $p < .001$, $\eta p^2 = 0.598$, such that the trial types (Single Pure, Single Mixed, or Dual Mixed) had an large effect on the error rates of the participants. Post-hoc pairwise comparisons using Bonferroni correction revealed significant error rate differences among all conditions, such that error rate of the Single Pure trials ($M = 0.265$ $SE = 0.09$), was significantly lower than that of the Dual Mixed trials ($M = 2.59$ $SE = 0.30$) ($p < 0.001$). The error rate on Single Mixed trials ($M = 0.547$, $SE = 0.94$) was significantly lower than that of the Dual Mixed trials ($p < 0.001$). All other main effects and interactions were not statistically significant ($ps \geq .218$); specifically, the main effect of group was $F(1, 21) = 1.093$, $p = .308$, $\eta p^2 = 0.049$, and the interaction effect between group and time was $F(2, 42) = 0.025$, $p = .975$, $\eta p^2 = 0.001$. See Table 3 for a summary of the mean RTs and number of errors of the near transfer task during the pre- and post-training assessment sessions.

Error costs. Cost scores (Dual-Task Costs, Task Set Costs) were derived for the error rate data in keeping with the RT analyses. For Dual-Task Cost, a 2 (Time: Pre vs. Post) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was employed. This analysis did not reveal a significant main effect of time, $F(1, 40) = 0.084$, $p = .774$, $\eta p^2 = 0.002$, such that participants' error dual-task costs were not significantly smaller after the training phase. The Time x Group interaction was also not significant, $F(1, 40) = 0.033$, $p = .857$, $\eta p^2 = 0.001$. There was also no significant main effect of group, $F(1, 40) = 0.773$, $p = .384$, $\eta p^2 = 0.019$.

For task-set cost, a 2 (Time: Pre vs. Post) x 2 (Training Group: Simultaneous vs. Sequential) mixed factorial ANOVA was also carried out. The analysis did not reveal a significant main effect of time $F(1, 40) = 0.00$, $p = .983$, $\eta p^2 = 0.000$. The Time x Group interaction was also not significant $F(1, 40) = 0.512$, $p = .479$, $\eta p^2 = 0.013$, nor was there a significant main effect of group $F(1, 40) = 0.153$, $p = .698$, $\eta p^2 = 0.004$ (p =.698).

Unlike the DT training task, the participants did not exhibit improved Dual-Task Cost as a result of training on the near transfer task.

Far Transfer Effects

To test whether combined exercise and cognitive training produced a positive transfer effect on each of the neurocognitive measures, and whether or not there were differences between training groups, a 2 (Time: Pre vs. Post) x 2 (Group: Simultaneous vs. Sequential) mixed factorial ANOVA was carried out for each of these measures. Means and standard deviations for the relevant far transfer tests are presented in Table 4.

Table 3.

Mean RTs and number of errors across different trial types before and after training

Trial Types	Pre-Training RT (ms)	Post-Training RT (ms)	Pre-Training Error (# of errors)	Post-Training Error (# of errors)
Single Pure	995.16	910.17	0.48	0.05
Single Mixed	1104.82	1011.86	0.76	0.33
Dual Mixed	1829.20	1603.40	2.88	2.33

Table 4.

Means and Standard Deviations of Far Transfer Outcome Measures by Training Group and Assessment Session.

Outcome Measures	Simultaneous		Sequential	
	Pre	Post	Pre	Post
LNS (/30)	19.23 (1.97)	18.77 (2.22)	18.70 (2.36)	19.55 (2.37)
Digit Symbol Coding (/135)	66.09 (14.44)	70.22 (15.43)	64.25 (11.93)	65.25 (12.65)
Stroop ((# of word per second; CW/C)	0.68 (0.10)	0.70 (0.16)	0.68 (0.25)	0.67 (0.12)
RBANS Word List Immediate Recall	26.64 (5.31)	27.64 (5.87)	27.15 (3.65)	28.85 (4.36)
RBANS Short Story Delayed Recall	8.45 (2.81)	9.91 (2.18)	9.45 (1.57)	10.00 (1.81)
RBANS Short Story Immediate Recall	17.5 (3.60)	18.77 (3.84)	19.40 (4.16)	19.40 (3.30)
RBANS Word List Delayed Recall	4.91 (2.52)	6.05 (3.19)	5.85 (1.81)	6.58 (1.83)

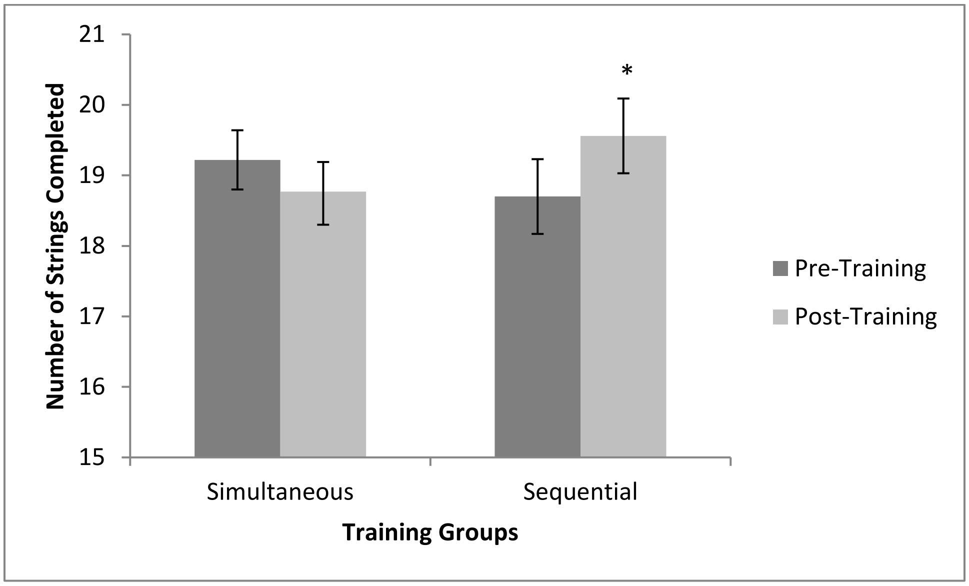
Note: LNS = Letter Number Sequencing. RBANS = Repeatable Battery for Assessment of Neuropsychological Status.

Letter Number Sequencing was assessed as a measure of working memory. The analysis revealed no significant time effect, $F(1, 40) = 0.728$, $p = .339$, $\eta p^2 = 0.018$, such that participants were not significantly better after training at rearranging letters and numbers into alphabetical and numerical order, respectively. There was also no significant group main effect found, $F(1, 40) = 7.924$, $p = .008$, $\eta p^2 = 0.165$, such that the two training groups did not differ overall. Interestingly, there was a significant interaction of time and group, $F(1, 40) = 7.924$, $p = .008$, $\eta p^2 = 0.165$, such that the two groups differed in their rates of change over time. Paired-samples contrasts with Bonferroni correction showed that the Simultaneous group's performance did not significantly differ from Time 1 ($M = 18.70$, $SE = 0.49$) to Time 2 ($M = 19.56$, $SE = 0.51$). In contrast, the Sequential group performed better over time by completing more strings of numbers and letters during Time 2 when compared to their performance at Time 1.

Interestingly, the Simultaneous group actually performed slightly worse on LNS following training, although the difference was not significant ($p = 0.16$). See Figure 8 for a graphical depiction of the LNS performance across the two assessment sessions by group.

Digit Symbol Coding is a measure of processing speed. There was a marginally significant time main effect found on the Digit Symbol Coding, $F(1, 40) = 3.687$, $p = .06$, $\eta p^2 = 0.084$, indicating a slight improvement on their speed of matching the symbols to their corresponding numbers within two minutes. There was no significant group effect found $F(1, 40) = .715$, $p = .403$, $\eta p^2 = 0.018$, nor was there a significant interaction effect of time and training group $F(1, 40) = 1.375$, $p = .248$, $\eta p^2 = 0.033$.

Figure 8. LNS performance across pre- and post-training sessions by group



The Stroop task is an EF measure of interference monitoring. There was no significant time effect found on the ratio of colour word/colour task Stroop task, $F(1, 40) = 0.165$, $p = .69$, $\eta p^2 = 0.005$. Thus, the participants did not improve significantly on their speed at which they read the incongruent stimuli relative to the congruent stimuli within two minutes after the training sessions. There was also no significant group effect found, such that the two training groups changed the same way when collapsed over time. There was no interaction effect between time and training group. The group main effect was also non-significant, $F(1,35) = 0.016$, $p = .90$, $\eta p^2 = 0.000$, nor was there a significant group by time interaction effect: $F(1, 38) = 0.013$ $p = .909$, $\eta p^2 = 0.000$.

A similar analysis of the memory-related outcome measures revealed a significant time effect on RBANS Immediate Word List Recall, $F(1, 40) = 7.447$, $p = .009$, $\eta p^2 = 0.157$ and on RBANS Delayed Story Recall Subtest, $F(1, 40) = 7.683$, $p = .008$, $\eta p^2 = 0.162$. These results suggest that participants were able to recall more words and story components, respectively, during the post-training assessment when compared to the their baseline assessment. No other main effects or interactions proved to be significant, and the main effect of group was not significant $F(1, 40) = 0.363$ $p = .550$, $\eta p^2 = 0.009$ and $F(1, 40) = 0.933$, $p = .340$, $\eta p^2 = 0.023$, respectively. The non-significant group by time interaction were $F(1, 40) = 0.501$ $p = .483$, $\eta p^2 = 0.012$ and $F(1, 40) = 1.234$, $p = .273$, $\eta p^2 = 0.031$.

Analyses on the RBANS Delayed Word List Recall and Immediate Story Recall did not reveal any significant main effects or interactions. The respective non-significant group main effects were: $F(1, 38) = 0.923$, $p = .343$, $\eta p^2 = 0.024$ and $F(1, 40) = 1.466$, $p = .233$, $\eta p^2 = 0.035$. Additionally, the non-significant group by time interaction effects were: $F(1, 40) = 0.363$ $p = .550$, $\eta p^{2} = 0.009$ and $F(1, 40) = 2.279$, $p = .139$, $\eta p^{2} = 0.054$, respectively.

Moderators of Training Gains

As an exploratory and secondary analysis, potential moderators for trainings were included in the study. As noted previously, the participants' baseline aerobic fitness measure (sub-maximal VO_2) and preference for intellectually stimulating activities (NFC) were included in the analyses. Regression analyses were conducted using the two potential moderators as predictors.

Training Task Moderators. To see if the potential mediators influenced the rate of improvement of the training task during the training phase, a slope of each participant's iPad training task data was estimated separately for each trial type (SP, SM, DM). These were used as outcome variables in a series of multiple regressions.

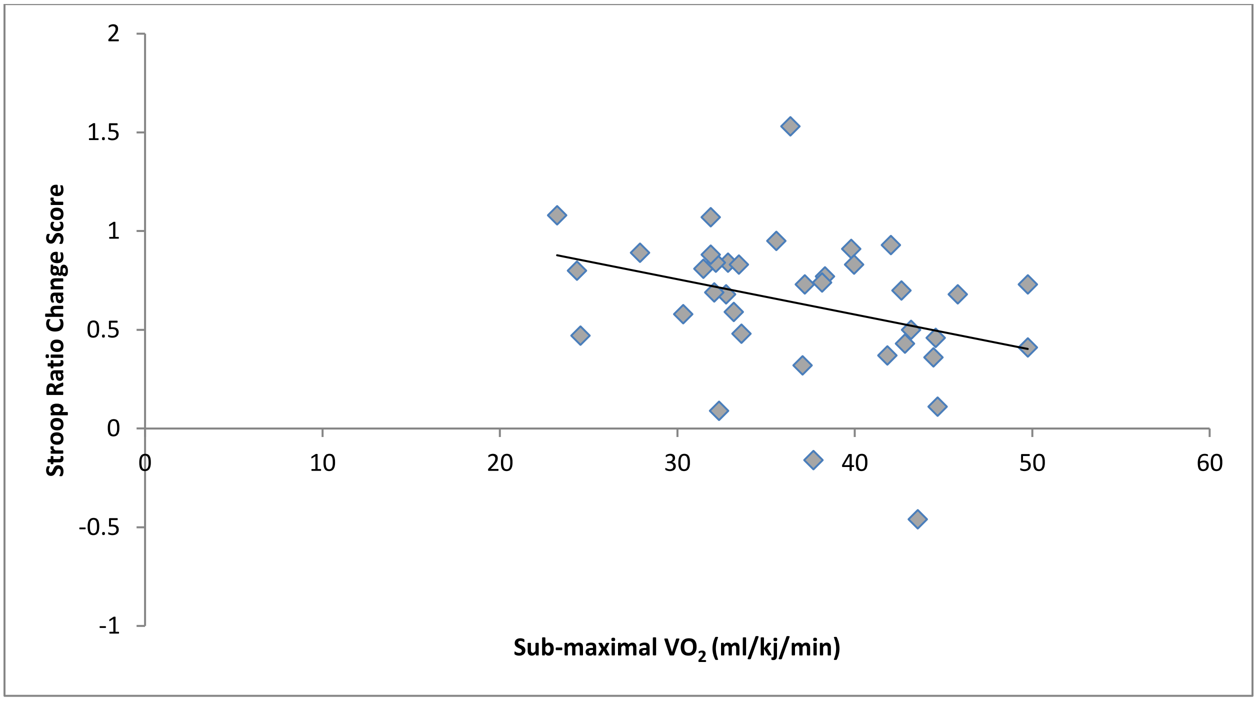
For the first exploratory moderator analysis, sub-maximal VO_2 from the Jones Protocol was used as an independent variable to predict the slopes of RT on all trial types. However, it did not significantly predict the slopes of RT on all trial types (*ps* > 0.62), suggesting that baseline aerobic fitness was not associated with the improvement of the training task over time. Similarly, NFC was used as a predictor in a linear regression to predict slopes of the participants' RT overtime. However, it did not significantly predict the slopes of RT on any of the three trial types (*ps* > 0.61), suggesting that motivation to engage in intellectual activities was not associated with the degree of improvement on the training task.

Near Transfer Task Moderators. Similarly, sub-maximal VO_2 was used as a predictor for the near transfer task's training slopes. However it did not significantly predict the slopes of RT on any of the near transfer task trial types (*ps* > 0.71) suggesting that baseline aerobic fitness was not associated with the magnitude of improvement on the near transfer task. Similarly, NFC was used as a predictor in a linear regression to predict slopes of the participants' RT overtime. However, it did not significantly predict the slopes of RT on any of the trial types (*ps* > 0.63), suggesting that motivation for intellectual activities was not associated with the improvement of the near transfer task over time.

Far Transfer. In order to predict pre-post change scores in the far transfer neuropsychological measures pre-post change scores in the far transfer neuropsychological measures The baseline estimated Sub-maximal VO_2 variable derived from the Jones Fitness Test was used to predict change scores of the various outcome measures in a series of multiple regressions in an attempt to see if physical fitness could predict changes in outcome measure scores. A significant regression predicting the change score of the Stroop Task, β = - .336, $t(35)$ = -2.107, p = .0.042, with an R^2 of 0.11, indicating that the lower an individual's baseline aerobic fitness level, the more likely that he/she would be able to marginally improve on tasks of interference monitoring. See Figure 9 for a scatter plot between Sub-maximal VO_2 and Stroop Change Score. The remaining regressions did not show that estimated sub-maximal VO^2 was a significant predictor of far transfer training gains.

A second individual differences variable under consideration was motivation to engage in cognitively challenging activity, which was measured using NFC. The participants were categorized as either high or low in NFC based on a median split, several paired-samples *t*-tests were conducted to compare pre- and post-training gains of each group. It was found that those who scored low on NFC improved significantly on the Digit Symbol Coding from pre- to post-training, $t(18) = 2.55$, $p = .02$. Low NFC participants also improved on RBANS immediate word recall task, $t(18) = 2.55$, $p = .02$, as well as on the RBANS delayed list recall task, $t(18) = 2.63$, *p*

Figure 9. Scatterplot between Sub-maximal VO_2 and Stroop Change Score



= .02. The high motivation group did not improve significantly on any of the cognitive measures from pre- to post-training sessions. See Table 5. for the means and standard deviations of the outcome variables for which there were moderating effects by NFC.

Finally, the DM slopes from the trained task were considered as a predictor of the change scores in the far transfer tasks in an attempt to address whether the magnitude of the transfer effects was commensurate with the magnitude of improvement in the trained task. They did not significantly predict changes in any of the transfer tasks (*ps* >.312).

Table 5.

Means and Standard Deviations of Far Transfer Outcome Measures by NFC Group and Assessment Sessions.

	Low NFC		High NFC	
	Pre-Training	Post-Training	Pre-Training	Post-Training
Digit Symbol Coding	63.71 (13.20)	66.41 (13.15)	62.28 (10.63)	63.39 (11.99)
RBANS Immediate Word List Recall	27.11 (3.61)	29.06 (3.47)	26.12 (5.13)	26.35 (6.52)
RBANS Delayed Story Recall	9.33 (1.78)	10. 00 (1.57)	8.58 (2.23)	9.71 (1.65)

Note. NFC = Need for Cognition. RBANS = Repeatable Battery for Assessment of Neuropsychological Status. Low and high NFC were derived from median split.

Discussion

The primary aim of this study was to compare the magnitude of training-related improvements in cognitive performance after receiving exercise and cognitive training, either sequentially or simultaneously. A neurocognitive battery including measures of EF and memory comprised the transfer tasks in this study. It was hypothesized that scores on the cognitive measures would improve for both training groups after the intervention phase, given the demonstrated efficacy of combined training protocols (Eggenberger et al., 2015; Hertzog et al., 2008; Lustig et al., 2009; Oswald et al. 2006; Rahe et al., 2015). Additionally, due to previous research finding suggesting that moderate intensity physical exercise can impair EF performance when performing a cognitive and an aerobic task Simultaneously (Labelle et al., 2013), it was hypothesized that the Simultaneous group would exhibit smaller training gains when compared to the Sequential group.

The current intervention literature has advanced to a point at which it is mature enough for researchers to address second order issues, such as how to fine-tune training protocols and modes of training. To date, there is ample evidence suggesting that cognitive and aerobic training can independently improve cognitive functioning in healthy, older adults relative to either no-treatment controls or active / placebo controls (Colcombe & Kramer, 2003; Hertzog et al., 2008; Lustig et al. 2009). While there is less evidence for the superiority of combined-modality training compared to single modality training, it is quite evident that combined modality-training does produce significant training gains (Hertzog et al., 2008; Lustig et al., 2009). Thus, the current research question was not whether or not combined-modality training is effective, but whether there are factors such as format and baseline individual differences that could enhance/reduce training efficacy.

The present results suggest that both groups of participants significantly improved on the DT training task and the near-transfer DT task, consistent with previous studies (Bherer et al., 2005; 2006; 2008; Lussier et al., 2012). Additionally, significant improvement following training was observed on three out of the seven far transfer outcome measures, suggesting that the training protocol was effective at improving untrained cognitive processes. Additionally, exploratory analyses using aerobic fitness and need for cognition measures as moderators showed that those who report lower inclination to engage in mentally stimulating activities significantly improved on three of the far transfer tasks after training, whereas those with higher inclination did not.

DT Training Task

It was important to ensure that the DT training was effective at producing training gains to replicate other studies (Bherer et al., 2005; Lussier et al., 2012). After checking for between-group confounds, we next confirmed that the DT training protocol resulted in improved DT performance on the trained task, which was a result consistent with previous studies utilizing the protocol (Bherer et al., 2005; 2006; 2008), as participants from both training groups showed significant reduction in their reaction time and error rates across all three trial types, suggesting that the DT training protocol was effectively at producing training-related changes in older adults. There were also significant Time x Trial Type interaction, such that improvements on RT and error rates were the greatest for the dual mixed trials, followed by single mixed, and then single pure conditions. This pattern is also consistent with results from previous studies using the DT training task, in showing that participants became more adept at managing dual task activities, as seen by the significant improvement on the dual-task cost (Lussier et al., 2012). Interestingly, there was no significant between-group difference observed, thus both groups improved by the same amount, suggesting that dividing attention and cycling did not negatively affect dual task performance during training. While there was some indication on visual inspection of the training data that the Simultaneous group did not improve as much as the Sequential group, the difference was non-significant (Figure 6). This however does suggest that there is a trend towards the predicted direction, which is in line with other findings that indicate a dual-task cost to cognitive performance when a physical task is performed concurrently (Labelle et al., 2013; Li et al., 2001). A potential explanation for the lack of a significant group difference could be that stationary cycling was used as the physical training protocol as opposed to walking. Specifically, the latter has an additional balance requirement which is absent in recumbent biking. Additionally, as the present study employed a moderate level of aerobic intensity (40% to 48% of heart rate reserve), it is possible that such intensity was sufficient to induce the impairment in EF that was observed in Labelle et al. (2013)'s study.

Furthermore, as a follow-up to check for potential mediators on the DT training task, the iPad task training slope for Dual-Mixed trials RT was also used to predict the magnitude of improvement in the far transfer tasks, although it was not found to be a significant predictor. The dual-task cost and task-set cost slopes were also not found to be significant predictors on the improvement of transfer tasks, suggesting that there were no significant moderators of interest on the training task.

Similar to the trained cognitive task, there were no significant group differences observed on the near transfer divided attention task: It was found that both groups significantly improved on both RT and error rate of the untrained near transfer task, in line with Lussier et al. (2012). Additionally, the same Time x Trial Type interaction seen in the trained task was observed, although only on RT and not the error rate. Further analysis revealed a significant reduction in dual-task cost from pre- to post-training assessments, suggesting that participants also became more adept at managing the dual-task process. This finding suggests a significant degree of transfer in the divided attention process from the training protocol.

In assessing whether the schedules of training led to differential gains in EF and memory (far transfer) it was found that successive training was more beneficial than Simultaneous training for working memory, as measured by the LNS. This is in line with the expectation that training under full attention might be more beneficial than under divided attention. Additionally, there was also a marginally significant overall improvement on processing speed, as measured by Digit Symbol Coding. By contrast, response inhibition, as measured by the Stroop task, did not significantly improve under either training schedule. While dual-task processing and task-switching both contain elements of attentional control and share a significant amount of variance (Miyake et al., 2000), it is possible that the significant differences in the underlying neural substrates between the two tasks made it difficult for significant training-related transfer to occur, as postulated by the neural overlap principle (Dahlin et al, 2008). This principle suggests that two tasks require shared underlying neural structures in order for significant transfer to occur. For the iPad training task, Erickson et al., (2007) found that the older adult participants showed activity in inferior prefrontal, temporal, extrastriate, and parietal brain regions, along with the basal ganglia. The interference condition of the Stroop, on the other hand, has been associated with anterior cingulate cortex, the dorsolateral prefrontal cortex and the left interior frontal gyrus in older adults (Langenecker, Nielson, & Rao, 2004), which are areas associated with resolving conflicts and catching errors (Banich et al., 2000). Given the lack of shared underlying neural structures, the lack of transfer to the Stroop task was not unexpected. On the other hand, working memory (measured by LNS) and processing speed are generally associated with activities in dorsolateral prefrontal cortex (Reuter-Lorenz et al., 2002) and the prefrontal cortex in general, respectively. Some of the shared underlying neural structures associated with working memory and processing speed and those associated with the DT training task might help explain why performance on the LNS and Digit Symbol saw improvement (the former only in the Sequential group).

In assessing whether the schedules of training led to differential gains in verbal memory (far transfer) it was found that participants were significantly better overall at both short and long term recall, as measured by RBANS Word List Immediate Recall and Short Story Delayed Recall. In contrast, the participants' scores on RBANS Word List Delayed Recall and Short Story Immediate Recall were not observed to have improved following training. One possible explanation for the significant improvement on the memory measures might be the presence of aerobic exercise training. As noted earlier, aerobic exercise is associated with neurogenesis in the hippocampus, which is correlated with better memory performance (Duzel et al., 2016; Erickson et al., 2011; Kramer, Erickon, & Colcombe, 2006).

While neuroimaging was not performed for this study, it is known from previous studies that DT training and moderate-intensity aerobic exercises can lead to changes in cortical structure and function. The improvement observed in some of the EF tasks could be a result of cognitive plasticity in the prefrontal cortex as a response to the DT training task as seen in Erickson et al. (2007). This would be consistent with the STAC model (Park & Reuter-Lorenz, 2009) in that older adults may develop compensatory recruitment of other brain regions to better perform cognitive tasks. The improvement on the far transfer verbal memory tasks could be the result of increased hippocampal size (Erickson et al., 2011) and neurogenesis in the hippocampus (Duzel et al., 2016) as a result of aerobic training. Additionally, there is ample evidence suggesting that aerobic exercises can lead to global cognitive improvement aside from verbal memory (Bherer, Erickson, Liu-Ambrose, 2013).

Moderators of Training Gains

The secondary objective of the study was to explore potential moderators of training gains and transfer gains, as most intervention studies do not consider individual differences and are more focused on between-group differences. To address this aim, baseline aerobic fitness level (Sub-maximal VO_2) and inclination to engage in mentally stimulating activities (Need for Cognition) were chosen. In order to operationalize the rate of learning on the divided attention training task, individual slopes were computed across all 12 training sessions for each participant's RT data for each trial type (single pure, single mixed, dual mixed). Neither Sub-maximal VO_2 nor NFC significantly predicted the training slopes of the three trial types in the training task, suggesting that aerobic fitness and tendency to seek out mentally-stimulating activities do not moderate the rate at which participants improved on the training task, despite the wide range of baseline RTs (1243 -1881 ms) among the participants. Thus, it appears that the degree of improvement on the trained cognitive task is not affected by, or limited to, a subset of individuals. Although NFC is not a direct index of effort, one might also conclude from these results that highly motivated individuals did not necessarily work harder than less motivated individuals during the training sessions.

A related but distinct question to address was whether or not the potential moderators could predict changes in scores of the far transfer tasks. This was more difficult to detect given that the effect size of training was much greater in the trained task ($\eta^2 = 0.841$) than on the far transfer tasks (the highest being a η^2 of 0.162). The two potential moderators were used as predictors in a series of linear regressions to predict change scores in the far transfer measures.

Sub-maximal VO_2 significantly predicted changes in scores on the Stroop Task, with a negative association between the measures, suggesting that the lower the baseline aerobic fitness an individual possesses, the more likely that he/she would benefit from the training protocol and improve more on the Stroop task. This is a result that parallels the NFC findings, and it is possible that those with higher baseline aerobic fitness might have reached a cognitive plateau and were not able to benefit as much from the training as those with lower baseline fitness. Sub-maximal VO_2 did not significantly predict training gains in the other far-transfer measures. While the current literature contains a sizable amount of research on the cross-sectional relation between aerobic fitness level and cognitive ability (Bherer, Erickson & Liu-Ambrose, 2013), the role of fitness level as a moderator of the *rate* of training gains has rarely been examined. Thus, there is a need to further examine physical characteristics that may potentially mediate the rate of training gains in older adults, which might implicate the role of aerobic fitness in the quality of life in older adults.

The second moderator under consideration, Need for Cognition (NFC), on the other hand, was found to be a significant mediator of far transfer training gains. Specifically, it was found that older adults with low baseline NFC performed significantly better on their post-training scores on Digit Symbol Coding, RBANS Word List Immediate Recall, and RBANS Delayed Short Story Recall when compared to their baseline scores, suggesting that those individuals who are not motivated to pursue cognitively challenging leisure activities improved more on measures of processing speed and verbal memory than those who challenge themselves more regularly. The result's pattern parallels the result from Stine-Morrow et al. (2014)'s study in that NFC was negatively related to training gains. As noted by Stine-Morrow et al. (2014), while NFC has conceptual overlap and moderate correlations with personality constructs such as Openness, it appears that embracing novelty and imagination (Openness) is associated with significant positive training gains, whereas preference for mental work (NFC) is not, suggesting a nuanced difference in the constructs that they represent. Another possible explanation of the presently observed moderation result is that those high in NFC might already be engaging in mentally-stimulating tasks in their everyday lives, thus they might have reached a cognitive "plateau", and thus were unable to improve in response to the training protocol. More research is needed to confirm this possibility. The significant findings associated with NFC and training gains have implications for future intervention designs, such that the recruitment of participants with low baseline NFC might be most effective. This also implies that those with high NFC might need a significantly different form of intervention in order to show training gains.

There were several limitations in the study that need to be addressed. The first is regarding the fact that the same version of RBANS was used for both the pre-training and post-training sessions, thus potential practice effects are a potential concern for the results of this study (Benedict & Zgaljardic, 1998). As noted earlier, the neurocognitive measures that had the highest improvement were two of the four RBANS memory subtests. While learning effects are less of a concern for the EF measures, previous research has also demonstrated that practice effects can produce significant change on various EF measures over one year (Basso, Bornstein, & Lang, 1999). However, there is also evidence to the contrary regarding the significance of practice effects on neuropsychological tests, particularly in older adult (aged 65 - 74 years) samples (Mitrushina & Satz, 1991). Nevertheless, the significant training effects on the RBANS measures should still be interpreted with caution although the moderation findings should be less vulnerable to practice effects.

Another limitation of the current study is the relatively strict inclusion criteria used in the present study to ensure safety for the participants' health from the aerobic training. As a result, the recruited participants were free of any significant health conditions (e.g. hypertension, heart condition, etc.) and were relatively fit, which might limit the generalizability of our findings to a broader range of older adults. The selectivity of the current sample may have also limited the degree to which aerobic fitness could predict the magnitude of training-related gains in near and far transfer tasks. Future studies could apply the same training design to other older adult populations, such as those with mild cognitive impairment. There is evidence suggesting that cognitive interventions can help enhance global cognitive abilities in those with MCI (Reijinders, van Heugten, & van Boxtel, 2012), and perhaps a combined modality approach might offer even more benefits to them.

A third limitation worth considering was the omission of the "switching" condition of the Stroop task. As found by Lussier et al., (2012), it was the switching condition that improved significantly following training. Thus, future intervention studies should include the switching condition to provide multiple indices of EF (i.e., response inhibition in the interference condition; shifting in the switch condition). Nevertheless, the present results are in agreement with previous work (Lussier et al., 2012) in showing that the interference condition is not responsive to dual-task training or exercise training.

Although not necessarily a limitation per se, the current study employed the standard 12-sessions of aerobic training that are commonly used in other exercise intervention studies and would be considered "short-term" (Colcombe & Kramer, 2003). As noted by Colcombe and Kramer (2003), short-term aerobic training has been found to be at least as beneficial in terms of cognitive training gains as compared to moderate-term training (4-6 months), though not as much as long-term training (6 months +). However, it should be noted that there is also evidence suggesting that the length of the aerobic training is not associated with differential improvements in neurocognition (Smith et al., 2015). Additionally, 12 sessions of moderate intensity aerobic training was shown to be capable of producing training-related neural changes (Smith et al., 2015). Given the available evidence, employing the short-term training schedule (12 weeks) was the most economical option, and coupled with cognitive training, was expected to be adequate to effect neurocognitive improvements. The intensity of the aerobic training employed was considered moderate (at 40%, 44%, 48% of estimated heart rate reserve, MET >3.0 - < 6.0) (ACSM, 2013), which is the level of intensity shown to be effective at producing cognitive gains (Colcombe & Kramer, 2003). Future studies contrasting simultaneous and sequential combined training schedules should include a longer training phase to directly assess these assertions.

A related issue is the duration of the cognitive training. Relative to the aerobic training (requiring 12 sessions to produce training gain and related neural changes), it appears that the divided attention dual-task training is capable of producing training gains and related neural changes in as little as five, one-hour training sessions (Erickson et al., 2007). Based on available evidence, it is difficult to ascertain what the minimal number of training sessions is to produce significant training gains and related neural changes in either aerobic or cognitive training as it would be challenging and resource-intensive to carry out such investigation to determine the "Goldilocks zone" for the correct intensity and duration of the training. To complicate matters, there is even less available research on the "correct" combination of aerobic and cognitive training (in terms of intensity and duration) in combined modality training. While the DT training task was found to be capable of creating training gains faster than the aerobic training (Bherer et al, 2005; 2008), the current study utilized 12 combined training sessions to ensure the emergence of significant training gains. Future intervention studies using combined modality training should be designed to parametrically vary different combinations of training to produce the greatest magnitude of gains in the least amount of resource / time.

An additional limitation of the study was the lack of a motivational questionnaire for the participants' engagement in physical activity, in parallel with the NFC questionnaire. The Borg scale (Rating of Perceived Exertion) is a standard measure of subjective physical effort, but is not a measure of motivation per se. The current study's results did not suggest that cognitive NFC was predictive of the performance on the dual-task training, but perhaps future studies could examine how much effort participants put into the training protocols more directly by varying incentives to attain certain levels of proficiency at training (Strobach, 2011). As noted previously, several studies have found associations between motivation and long-term cognitive change (Hess et al., 2011) and with the magnitude of training gains (Stine-Morrow et al., 2014). Future studies could investigate these associations further to refine the training protocols utilized in combined modality intervention research.

The main manipulation of the study was the mode of delivery of multimodal training (Simultaneous vs. Sequential). This created a practical quandary in that the Sequential group ended up having double the amount of total training / contact time, since they received the aerobic training and cognitive training in succession. While technically both groups still received the same amount of cognitive and aerobic training (approximately 35 minutes each for each module), it is recognized that the Sequential group did receive twice the amount of training time, which potentially could have influenced the interpretation of the results. Given that the baseline cognitive and physical capacities of both training groups were not significantly different, and that there were no group differences observed in all outcome measures (except for LNS), it would be safe to assume that this discrepancy in training duration between groups did not result in any significant differences in the outcome measures. That being said, it is still recognized that overall training duration remains a potential confound nevertheless (e.g., it could be argued that the Sequential group achieved comparable training gains as the Simultaneous group only as a function of the increased training time). Additionally, there is evidence that simple social engagement can lead to protection against cognitive decline (Barnes et al., 2004; Loveden, Ghisletta, & Lindenberger, 2005), thus the increased social interaction in the Sequential group could have confounded our results. However, given that the alternative would be to reduce each individual portion of the Sequential training (i.e. 17.5 minutes of cognitive and 17.5 minutes of aerobic training), choosing to proceed with the current study design was the superior option.

While the presently chosen cognitive training task has demonstrated transfer gains and related neural changes (Erickson et al. 2007), it is also recognized that other forms of cognitive training are also effective. For example, working memory training paradigms have also proven effective producing significant far transfer gains in EF tasks and subjective measures of attention (Richmond et al., 2011). Furthermore, Zinke et al. (2014) found that the gains can be maintained nine months after the conclusion of working memory training, which is consistent with other findings (Borella et al., 2010; Brehmer, Westerberg, & Bäckman, 2012). Although working memory training of older adults is at a very early stage of development and there are still methodological issues that need to be addressed (Shipstead, Redick, & Engle, 2012), it might prove to be an effective method of cognitive training for older adults that could be included in future multi-modality intervention studies.

Finally, other forms of divided attention cognitive training task have found that improvement on the trained task was associated with enhanced measures of everyday functioning in older adults, specifically in their iADL (Edwards et al., 2012). While the current study did not include measures of iADL, they are an important consideration for future studies. Far transfer gains from training would not be very meaningful if they had no ecological implication. Training tasks that lead to far transfer gains, which in turn lead to improvements on everyday functioning, would be the ultimate goal of the intervention literature. While the ACTIVE study suggested that EF training can lead to improved iADL in older adults (Wolinsky et al., 2006), more research would be required to ascertain this link with multi-modal training.

To summarize the current study, the combined training protocol led to significant training gains, along with both significant near transfer to an untrained but similar divided attention task, and far transfer to working memory, processing speed, and verbal memory measures. The mode of training (Sequential or Simultaneous) did not result in many significant group differences in training gains except in the case of LNS, in which the Sequential group improved significantly more so than the Simultaneous group. Thus, this might be considered evidence that Simultaneous combined-modality training is a more effective method of intervention, at least for very demanding working memory test performance. Additionally, Need for Cognition was found to be a significant moderator of training gains, such that participants with low Need for Cognition improved significantly on several far transfer tasks while those with high Need for Cognition did not, suggesting that future intervention studies might consider employing Need for Cognition as one of those screening tools in order to maximize the amount of training gains. Overall, this study has provided evidence for the efficacy of multi-modal training and the presence of inter-individual differences that may result in differential training gains. Future studies in aging research might consider focusing on further refinement of training methodology in the rapidly growing field of cognitive intervention research.

References

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: a meta-analytic review. *Neuropsychology Review*, *16*(1), 17-42.

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: a systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, *35*(3), 715-728.

American College of Sports Medicine. (2013). *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins.

Anderson, G. F., & Hussey, P. S. (2000). Population aging: a comparison among industrialized countries. *Health Affairs*, *19*(3), 191-203.

Anderson-Hanley, C., Arciero, P. J., Brickman, A. M., Nimon, J. P., Okuma, N., Westen, S. C., & Zimmerman, E. A. (2012). Exergaming and older adult cognition: a cluster randomized clinical trial. *American Journal of Preventive Medicine*, *42*(2), 109-119.

Baer, L. H., Tabri, N., Blair, M., Bye, D., Li, K. Z., & Pushkar, D. (2012). Longitudinal associations of need for cognition, cognitive activity, and depressive symptomatology with cognitive function in recent retirees. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, gbs112.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., & ACTIVE Study Group. (2002). Effects of cognitive training interventions with older adults: a randomized controlled trial. *Journal of the American Medical Association*, *288*(18), 2271-2281.

Baltes, P. B., Staudinger, U. M., & Lindenberger, U. (1999). Lifespan psychology: Theory and application to intellectual functioning. In *Annual review of psychology* (pp. 471-507). Annual Reviews.

Banich, M. T., Milham, M. P., Atchley, R., Cohen, N. J., Webb, A., Wszalek, T. & Magin, R. (2000). fMRI studies of Stroop tasks reveal unique roles of anterior and posterior brain systems in attentional selection. *Journal of Cognitive Neuroscience* , *12*(6), 988-1000.

Barnes, L. L., De Leon, C. M., Wilson, R. S., Bienias, J. L., & Evans, D. A. (2004). Social resources and cognitive decline in a population of older African Americans and whites. *Neurology*, *63*(12), 2322-2326

Basso, M. R., Bornstein, R. A., & Lang, J. M. (1999). Practice effects on commonly used measures of executive function across twelve months. *The Clinical Neuropsychologist*, *13*(3), 283-292.

Belleville, S., & Bherer, L. (2012). Biomarkers of cognitive training effects in aging. *Current Translational Geriatrics and Experimental Gerontology Reports*, *1*(2), 104-110.

Benedict, R. H., & Zgaljardic, D. J. (1998). Practice effects during repeated administrations of memory tests with and without alternate forms. *Journal of Clinical and Experimental Neuropsychology*, *20*(3), 339-352.

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A review of the effects of physical activity and exercise on cognitive and brain functions in older adults. *Journal of Aging Research*, *2013*.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychology and Aging*, *20*(4), 695

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2006). Testing the limits of cognitive plasticity in older adults: application to attentional control. *Acta Psychologica*, *123*(3), 261-278.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research*, *34*(3), 188-219.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, *129*(3), 387-398.

Borella, E., Carretti, B., Riboldi, F., & De Beni, R. (2010). Working memory training in older adults: evidence of transfer and maintenance effects. *Psychology and Aging*, *25*(4), 767.

Borg, G. (1982). Ratings of perceived exertion and heart rates during short-term cycle exercise and their use in a new cycling strength test. *International Journal of Sports Sedicine*, *3*(3), 153-158.

Braver, T. S., & West, R. (2008). Working memory, executive control, and aging. *The Handbook of Aging and Cognition*, *3*, 311-372.

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: training gains, transfer, and maintenance. *Frontiers in Human Neuroscience*, *6*. 1-7

Brünken, R., Steinbacher, S., Plass, J. L., & Leutner, D. (2002). Assessment of cognitive load in multimedia learning using dual-task methodology. *Experimental psychology*, *49*(2), 109-119.

Burke, S. N., & Barnes, C. A. (2006). Neural plasticity in the ageing brain. *Nature Reviews Neuroscience*, *7*(1), 30-40.

Burzynska, A. Z., Chaddock-Heyman, L., Voss, M. W., Wong, C. N., Gothe, N. P., Olson, E. A., & Kramer, A. F. (2014). Physical activity and cardiorespiratory fitness are beneficial for white matter in low-fit older adults. *PloS one*, *9*(9), e107413.

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: compensatory brain activity in high-performing older adults. *Neuroimage*, *17*(3), 1394-1402.

Cahn-Weiner, D. A., Boyle, P. A., & Malloy, P. F. (2002). Tests of executive function predict instrumental activities of daily living in community-dwelling older individuals. *Applied Neuropsychology*, *9*(3), 187-191.

Canadian Medical Association (2013). Preparing for Canada's Aging Society Retrieved from: https://www.cma.ca/Assets/assets-library/document/en/advocacy/Aging-society-e.pdf

Chao, Y. Y., Scherer, Y. K., & Montgomery, C. A. (2014). Effects of Using Nintendo Wii™ Exergames in Older Adults A Review of the Literature .*Journal of Aging and Health*, 0898264314551171

Chapman, S. B., Aslan, S., Spence, J. S., DeFina, L. F., Keebler, M. W., Didehbani, N., & Lu, H. (2013). Shorter term aerobic exercise improves brain, cognition, and cardiovascular fitness in aging. *Frontiers in Aging Neuroscience*, *5*. 1-9

Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., ... & Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *61*(11), 1166-1170.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults a meta- analytic study. *Psychological Science*, *14*(2), 125-130.

Colcombe, S. J., Kramer, A. F., Erickson, K. I., Scalf, P., McAuley, E., Cohen, N. J., & Elavsky, S. (2004). Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(9), 3316-3321.

Craik, F. I.,M. & Bialystok, E. (2006). Cognition through the lifespan: mechanisms of change. *Trends in Cognitive Sciences*, *10*(3), 131-138.

Craik, F. I.,M. & Salthouse, T. A., Eds. (2011). *The handbook of aging and cognition*. Psychology Press.

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L. & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science*, *320*(5882), 1510-1512.

Damoiseaux, J. S., Beckmann, C. F., Arigita, E. S., Barkhof, F., Scheltens, P., Stam, C. J., & Rombouts, S. A. R. B. (2008). Reduced resting-state brain activity in the "default network" in normal aging. *Cerebral Cortex*, *18*(8), 1856-1864.

Duzel, E., van Praag, H., & Sendtner, M. (2016). Can physical exercise in old age improve memory and hippocampal function? *Brain*, *139*(3), 662-673.

Edwards, J. D., Ruva, C. L., O'Brien, J. L., Haley, C. B., & Lister, J. J. (2013). An examination of mediators of the transfer of cognitive speed of processing training to everyday functional performance. *Psychology and Aging*, *28*(2), 314.

Eggenberger, P., Schmacher, V., Angst, M., Theil, N. & D de Bruin. E. (2015). Does multicomponent physical exercise with simutnaeous cognitive training boost cognitive performance in older adults? A 6–month randomized controlled trial with a 1-year follow-up. *Clinical Intervention in Aging,* 1335-1349.

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., & Kramer, A. F. (2005). Neural correlates of dual-task performance after minimizing task-preparation. *Neuroimage*, *28*(4), 967-979.

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E. & Kramer, A. F. (2007). Training-induced functional activation changes in dual-task processing: an FMRI study. *Cerebral Cortex*, *17*(1), 192-204.

Erikson, K.I., Hillman, C.H., & Kramer, A.F. (2015). Physical activity, brain, and cognition. *Current Opinion in Behavioral Sciences.* (4), 27-32

Erickson, K. I., Miller, D. L., & Roecklein, K. A. (2012). The aging hippocampus interactions between exercise, depression, and BDNF. *The Neuroscientist*,*18*(1), 82-97.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., ... & Wojcicki, T. R. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences*, *108*(7), 3017-3022.

Floyd, M., & Scogin, F. (1997). Effects of memory training on the subjective memory functioning and mental health of older adults: A meta-analysis. *Psychology and Aging*, *12*(1), 150.

Frackowiak, R. S. (1991). Decreases in regional cerebral blood flow with normal aging. *Journal of Cerebral Blood Flow and Metabolism*, *11*, 684-689.

Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *The Lancet Neurology*, *3*(6), 343-353.

Gunning-Dixon, F. M., & Raz, N. (2003). Neuroanatomical correlates of selected executive functions in middle-aged and older adults: a prospective MRI study. *Neuropsychologia*, *41*(14), 1929-1941.

Guttmann, C. R., Jolesz, F. A., Kikinis, R., Killiany, R. J., Moss, M. B., Sandor, T., & Albert, M. S. (1998). White matter changes with normal aging. *Neurology*, *50*(4), 972-978.

Haut, M. W., Kuwabara, H., Leach, S., & Arias, R. G. (2000). Neural activation during performance of number-letter sequencing. *Applied Neuropsychology*, *7*(4), 237-242.

Hess, T. M., Emery, L., & Neupert, S. D. (2012). Longitudinal relationships between resources, motivation, and functioning. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *67*(3), 299-308.

Heuninckx, S., Wenderoth, N., & Swinnen, S. P. (2008). Systems neuroplasticity in the aging brain: recruiting additional neural resources for successful motor performance in elderly persons. *The Journal of Neuroscience*, *28*(1), 91-99.

Hultsch, D. F., Hertzog, C., Small, B. J., & Dixon, R. A. (1999). Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychology and Aging*, *14*(2), 245.

Johnson, J. K., Lui, L. Y., & Yaffe, K. (2007). Executive function, more than global cognition, predicts functional decline and mortality in elderly women. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *62*(10), 1134-1141.

Jones, N. L., Makrides, L., Hitchcock, C., Chypchar, T., & McCartney, N. (1985). Normal Standards for an Incremental Progressive Cycle Ergometer Test 1–3. *American Review of Respiratory Disease*, *131*(5), 700-708.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science*, *12*(6), 978-990.

Kelly, A. C., & Garavan, H. (2005). Human functional neuroimaging of brain changes associated with practice. *Cerebral Cortex*, *15*(8), 1089-1102.

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R. & Colcombe, A. (1999). Ageing, fitness and neurocognitive function. *Nature*, *400*(6743), 418-419.

Labelle, V., Bosquet, L., Mekary, S., & Bherer, L. (2013). Decline in executive control during acute bouts of exercise as a function of exercise intensity and fitness level. *Brain and Cognition*, *81*(1), 10-17.

Langenecker, S. A., Nielson, K. A., & Rao, S. M. (2004). fMRI of healthy older adults during Stroop interference. *Neuroimage*, *21*(1), 192-200.

Li, K. Z. H., Lindenberger, U., Freund, A. M., & Baltes, P. B. (2001). Walking while memorizing: Age-related differences in compensatory behavior. *Psychological Science*, *12*(3), 230-237.

Li, K. Z. H., Roudaia, E., Lussier, M., Bherer, L., Leroux, A., & McKinley, P. A. (2010). Benefits of cognitive dual-task training on balance performance in healthy older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *65*(12), 1344-1352.

Lövdén, M., Ghisletta, P., & Lindenberger, U. (2005). Social participation attenuates decline in perceptual speed in old and very old age. *Psychology and Aging*, *20*(3), 423.

Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older adults. *Training-induced Cognitive and Neural Plasticity*, 118

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: a review and future directions. *Neuropsychology Review*, *19*(4), 504-522.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychological bulletin*, *109*(2), 163-203.

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. A. & Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences*, *103*(33), 12523-12528.

Maillot, P., Perrot, A., & Hartley, A. (2012). Effects of interactive physical-activity video-game training on physical and cognitive function in older adults. *Psychology and Aging*, *27*(3), 589.

Milham, M. P., Banich, M. T., Claus, E. D., & Cohen, N. J. (2003). Practice-related effects demonstrate complementary roles of anterior cingulate and prefrontal cortices in attentional control. *Neuroimage*, *18*(2), 483-493.

Mitrushina, M., & Satz, P. (1991). Effect of repeated administration of a neuropsychological battery in the elderly. *Journal of Clinical Psychology*,*47*(6), 790-801

Mozolic, J. L., Hayaska, S., & Laurienti, P. J. (2010). A cognitive training intervention increases resting cerebral blood flow in healthy older adults. *Frontiers in Human Neuroscience*, *4*, 16.

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., ... & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53*(4), 695-699.

Nyberg, L., Cabeza, R., & Tulving, E. (1996). PET studies of encoding and retrieval: The HERA model. *Psychonomic Bulletin & Review*, *3*(2), 135-148.

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping*, *25*(1), 46-59.

Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: aging and neurocognitive scaffolding. *Annual Review of Psychology*, *60*, 173.

Randolph, C., Tierney, M. C., Mohr, E., & Chase, T. N. (1998). The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): preliminary clinical validity. *Journal of Clinical and Experimental Neuropsychology*, *20*(3), 310-319.

Ratiu, P., Talos, I. F., Haker, S., Lieberman, D., & Everett, P. (2004). The tale of Phineas Gage, digitally remastered. *Journal of Neurotrauma*, *21*(5), 637-643.

Raz, N., Gunning, F. M., Head, D., Dupuis, J. H., McQuain, J., Briggs, S. D., ... & Acker, J. D. (1997). Selective aging of the human cerebral cortex observed in vivo: differential vulnerability of the prefrontal gray matter. *Cerebral cortex*, *7*(3), 268-282.

Raz, N., Gunning-Dixon, F. M., Head, D., Dupuis, J. H., & Acker, J. D. (1998). Neuroanatomical correlates of cognitive aging: evidence from structural magnetic resonance imaging. *Neuropsychology*, *12*(1), 95.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., ... & Acker, J. D. (2005). Regional brain changes in aging healthy adults: general trends, individual differences and modifiers. *Cerebral Cortex*, *15*(11), 1676-1689.

Randolph, C. (1998). *Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)*. San Antonio, TX: Psychological Corporation.

Reijnders, J., van Heugten, C., & van Boxtel, M. (2013). Cognitive interventions in healthy older adults and people with mild cognitive impairment: a systematic review. *Ageing Research Reviews*, *12*(1), 263-275

Reuter-Lorenz, P. A., Jonides, J., Smith, E. E., Hartley, A., Miller, A., Marshuetz, C., & Koeppe, R. A. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *Journal of Cognitive Neuroscience*, *12*(1), 174-187.

Reuter-Lorenz, P. A., & Lustig, C. (2005). Brain aging: reorganizing discoveries about the aging mind. *Current Opinion in Neurobiology*, *15*(2), 245-251.

Rhodes, M. G. (2004). Age-related differences in performance on the Wisconsin card sorting test: a meta-analytic review. *Psychology and Aging*, *19*(3), 482.

Richmond, L. L., Morrison, A. B., Chein, J. M., & Olson, I. R. (2011). Working memory training and transfer in older adults. *Psychology and Aging*, *26*(4), 813.

Rowe, J. W., & Kahn, R. L. (1987). Human aging: usual and successful. *Science*, *237*(4811), 143-149.

Rowe, J. W., & Kahn, R. L. (1997). Successful aging. *The Gerontologist*, *37*(4), 433-440.

Rypma, B., Berger, J. S., Prabhakaran, V., Bly, B. M., Kimberg, D. Y., Biswal, B. B., & D'Esposito, M. (2006). Neural correlates of cognitive efficiency. *Neuroimage*, *33*(3), 969-979.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General*, *132*(4), 566.

Sen, S., Duman, R., & Sanacora, G. (2008). Serum brain-derived neurotrophic factor, depression, and antidepressant medications: meta-analyses and implications. *Biological Psychiatry*, *64*(6), 527-532.

Shatil, E. (2013). Does combined cognitive training and physical activity training enhance cognitive abilities more than either alone? A four-condition randomized controlled trial among healthy older adults. *Frontiers in Aging Neuroscience*, *5*.

Shetty, A. K., Hattiangady, B., & Shetty, G. A. (2005). Stem/progenitor cell proliferation factors FGF-2, IGF-1, and VEGF exhibit early decline during the course of aging in the hippocampus: Role of astrocytes. *Glia*, *51*(3), 173-186.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological bulletin*, *138*(4), 628.

Smith, P. J., Blumenthal, J. A., Hoffman, B. M., Cooper, H., Strauman, T. A., Welsh-Bohmer, K. & Sherwood, A. (2010). Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. *Psychosomatic Medicine*, *72*(3), 239.

Statistics Canada. (2011). Seniors. Retrieved from http://www.statcan.gc.ca/pub/11-402-x/2011000/chap/seniors-aines/seniors-aines-eng.htm

Spencer, W. D., & Raz, N. (1995). Differential effects of aging on memory for content and context: a meta-analysis. *Psychology and Aging*, *10*(4), 527.

Stine-Morrow, E. A., Payne, B. R., Roberts, B. W., Kramer, A. F., Morrow, D. G., Payne, L., ... & Janke, M. C. (2014). Training versus engagement as paths to cognitive enrichment with aging. *Psychology and Aging*, *29*(4), 891.

Strobach, T., Frensch, P., Müller, H., & Schubert, T. (2012). Age-and practice-related influences on dual-task costs and compensation mechanisms under optimal conditions of dual-task performance. *Aging, Neuropsychology, and Cognition*, *19*(1-2), 222-247.

Takeuchi, H., Sekiguchi, A., Taki, Y., Yokoyama, S., Yomogida, Y., Komuro, N., ... & Kawashima, R. (2010). Training of working memory impacts structural connectivity. *The Journal of Neuroscience*, *30*(9), 3297-3303.

Theill, N., Schumacher, V., Adelsberger, R., Martin, M., & Jäncke, L. (2013). Effects of Simultaneously performed cognitive and physical training in older adults. *BMC Neuroscience*, *14*(1), 103.

Tomaszewski Farias, S., Cahn-Weiner, D. A., Harvey, D. J., Reed, B. R., Mungas, D., Kramer, J. H., & Chui, H. (2009). Longitudinal changes in memory and executive functioning are associated with longitudinal change in instrumental activities of daily living in older adults. *The Clinical Neuropsychologist*, *23*(3), 446-461.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: a meta-analytic study. *Psychology and Aging*, *7*(2), 242.

Voss, M. W., Erickson, K. I., Prakash, R. S., Chaddock, L., Kim, J. S., Alves, H., ... & Kramer, A. F. (2013). Neurobiological markers of exercise-related brain plasticity in older adults. *Brain, Behavior, and Immunity*, *28*, 90-99.

Voss, M. W., Prakash, R. S., Erickson, K. I., Basak, C., Chaddock, L., Kim, J. S., ... & Kramer, A. F. (2010). Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. *Frontiers in Aging Neuroscience*, *2*.

Wechsler, D. (2008). Wechsler Adult Intelligence Scale: WAIS-IV Technical and Interpretive Manual. San Antonio, TX: The Psychological Corporation.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., & ACTIVE Study Group. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association*, *296*(23), 2805-2814.

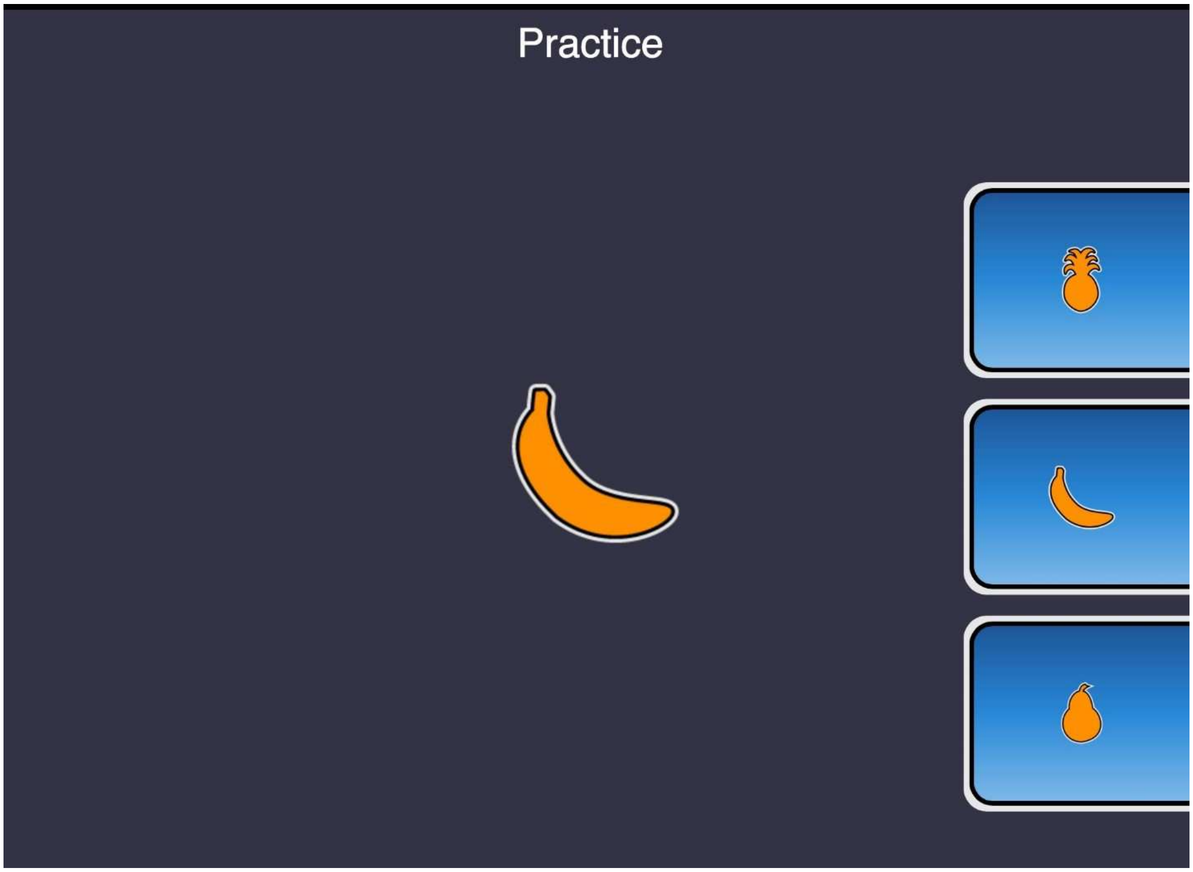
Wilson, R. H., & McArdle, R. (2007). Intra-and inter-session test, retest reliability of the Words-in-Noise (WIN) test. *Journal of the American Academy of Audiology*, *18*(10), 813-825.

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement Disorders*, *23*(3), 329-342.

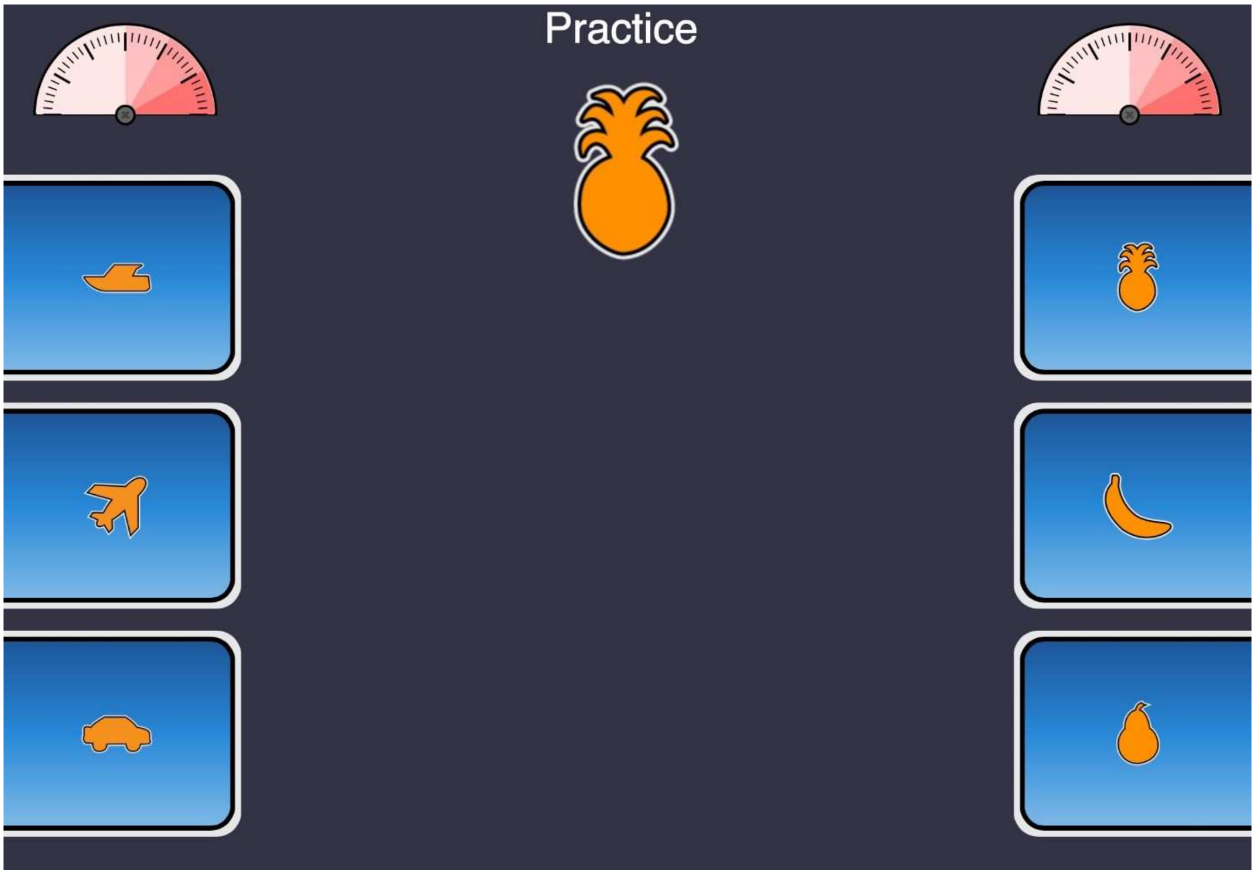
Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. *Blackwell Handbook of Developmental Psychology,* 445-469.

Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2014). Working memory training and transfer in older adults: Effects of age, baseline performance, and training gains. *Developmental Psychology*, *50*(1), 304.

Appendix A: Near Transfer Task Single-Pure Trial



Appendix B: Near Transfer Task Single-Mixed Trial



Appendix C: Near Transfer Task Dual-Mixed Trial