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Near and Far Transfer of Working Memory Training Related Gains in Healthy Adults

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Near and Far Transfer of Working Memory Training Related Gains in Healthy Adults

By

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Abstract

Enhancing intelligence through working memory training is an attractive concept, particularly for middle-aged adults. However, investigations of working memory training benefits are limited to younger or older adults, and results are inconsistent. This study investigates working memory training in middle age-range adults. Fifty healthy adults, aged 30-60, completed measures of working memory, processing speed, and fluid intelligence before and after a 5-week web-based working memory (experimental) or processing speed (active control) training program. Baseline intelligence and personality were measured as potential individual characteristics associated with change. Improved performance on working memory and processing speed tasks were experienced by both groups; however, only the working memory training group improved in fluid intelligence. Agreeableness emerged as a personality factor associated with working memory training related change. Albeit limited by power, findings suggest that dual n-back working memory training not only enhances working memory but also fluid intelligence in middle-aged healthy adults.

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List of Symbols, Abbreviations, and Nomenclature

Abbreviation	Definition
Aospan	Automated Operation Span task
CCFT	Cattel's Culture Fair Test
DS	Digit Span
IPAQ	International Physical Activity Questionnaire
POMS	Profile of Mood States
PSQI	Pittsburgh Sleep Quality Index
PS	Processing Speed
RAPM	Raven's Advanced Progressive Matrices
RM-ANOVA	Repeated measures analysis of variance
SM	Spatial maintenance
SMM	Spatial maintenance plus manipulation
SS	Symbol Search
WAIS-IV	Wechsler Adult Intelligence Scale - Fourth Edition
WASI-II	Wechsler Abbreviated Scale of Intelligence - Second Edition
WM	Working Memory

CHAPTER 1: INTRODUCTION

Working memory and fluid intelligence are two highly related, yet distinct, aspects of human intellect. Working memory is defined as the maintenance and mental manipulation of information and includes storage-specific capacity and processing-related ability (Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Baddeley, 2003; Baddeley, 2012). Fluid intelligence refers to the ability to solve novel problems through reasoning and without reliance on previously acquired knowledge (Cattell & Cattell, 1959). Fluid intelligence is highly associated with working memory, both in terms of hypothesized capacity constraints, shared behavioral mechanisms, and common neural pathways in the frontal and parietal brain regions (see Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Gray, Chabris, & Braver, 2003; Halford, Cowan, & Andrews, 2007; Owen, McMillan, Laird, & Bullmore, 2005; Glascher, et al., 2010). Although highly related, working memory involves processes such as attending to, holding, and mentally manipulating information (e.g., mentally solving a verbally presented math problem) whereas fluid intelligence invokes higher cognitive abilities such as comprehension, inferential reasoning, and understanding implications of attended to information. Furthermore, working memory and fluid intelligence are each, independently, key aspects of overall intelligence, which is consistently associated with academic, social, and vocational success (Gottfredson, 1997; Gottfredson & Saklofske, 2009). Until recently, working memory and fluid intelligence were considered relatively stable, susceptible to decline but immutable to improvement after adolescence (Chuderski, 2013; Gray & Thompson, 2004). However, arguments are emerging against the belief that these abilities are fixed (Chuderski, 2013; Gray & Thompson, 2004; Lövdén, Lindenberger, Schaefer, Bäckman, & Schmiedek, 2010). Given the importance of working memory and fluid intelligence to general intelligence, and the potential plasticity of these abilities in adulthood, the concept of enhancing working memory and fluid intelligence in adults is both enticing and worthy of investigation.

Recent evidence has supported the theory of intellectual plasticity in adulthood. The mismatch model of cognitive plasticity suggests that increasing the demand on cognitive processes leads to expansion of resources associated with cognitive functioning (Lövdén et al., 2010). Based on this model, the ceiling of one's cognitive abilities can be progressively pushed upward by continually challenging the upper limits of those abilities. One particular training task, the dual n-back, has received notable attention as a training program with such characteristics, and has been associated with improved working memory and fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi et al., 2010; Jaušovec & Jaušovec, 2012; Rudebeck, Bor, Ormond, O'Reilly, & Lee, 2012; Schweizer, Hampshire, & Dalgleish, 2011).

Dual n-back working memory training is a computerized program in which audio and visual stimuli are presented simultaneously. Auditory stimuli are typically letters, and visual stimuli are blocks positioned on a 3 x 3 grid. The trainee is required to identify whether either stimulus presented in a given moment matches the stimuli presented a certain number of (i.e., "n") presentations ago. For example, in the 2-back task, the trainee identifies whether either a heard letter, or the position of a block on the grid, matches the letter or block position 2-back (i.e., two presentations previously). In line with the mismatch model, the task is adaptive, hence, as the trainee reaches 85% response accuracy, the difficulty (i.e., "n") increases. This maintains difficulty at the upper end of the trainee's ability and, in theory, expands that ability.

The specific cognitive ability expected to expand after dual n-back training is working memory, thus the goal of such training is to expand the amount of information that can be held in and/or manipulated in working memory at a given time (Morrison & Chein, 2011). Several investigations of healthy young adults revealed that training on the dual n-back task not only enhanced dual n-back performance, but also improved performance on working memory tasks that were not specifically trained (Jaeggi et al., 2008; Jaušovec & Jaušovec, 2012; Rudebeck et al., 2012; Schweizer et al., 2011). Such improvement in performance within the same cognitive domain is referred to as near transfer of training related gains. For example, the dual n-back working memory training task has been credited for post-training increases in non-trained measures of working memory, specifically, improved digit span, reading span, and recognition memory scores (Jaeggi et al., 2008; Jaušovec & Jaušovec, 2012; Rudebeck et al., 2012; Schweizer et al., 2011). Hence, dual n-back working memory training appears efficacious for inducing near transfer to working memory abilities; however, of notable interest is the potential for dual n-back training to transfer to other cognitive domains.

Far transfer refers to training related gains in a cognitive ability distinct from the ability trained, such as improvements in fluid intelligence after working memory training. Such gains have been demonstrated in healthy young adults after dual n-back training. On two occasions, Jaeggi and colleagues (2008, 2010) demonstrated far transfer of dual n-back working memory training to fluid intelligence. Similarly, individuals who trained on a dual n-back task that used emotionally laden words instead of letters performed better on fluid intelligence tasks after training (Schweizer et al., 2011). Furthermore, Rudebeck and colleagues (2012) created a version of a dual n-back task in which participants remembered pictures and locations of pictures in a three-dimensional on-screen image. Again, after training, enhanced fluid intelligence was noted (Rudebeck et al., 2012). Together, these findings support the idea that dual n-back training results not only in near transfer to domain congruent tasks, but also far transfer to tasks in a different domain, specifically, fluid intelligence.

If working memory training is indeed an effective means of enhancing fluid intelligence, the mechanisms by which working memory training results in improvement remain unclear (Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012). Working memory manipulation presents as a candidate mechanism. Working memory manipulation is defined as the ability to mentally work with information newly perceived or brought to mind, for example, formulating an answer to a verbally presented question, mentally re-arranging furniture in a room, or solving a math problem presented verbally. For these tasks, information must be remembered and mentally moved, arranged, or operated upon in order to produce a result. The ability to simply attend to and briefly remember information is the maintenance aspect of working memory. Examples of maintenance include looking at a telephone number then mentally repeating that same number in order to place a call, or mentally repeating a newly met person's name. Maintenance is necessary for manipulation to occur, although maintenance can operate independently. Working memory manipulation (i.e., maintenance plus manipulation), though not maintenance alone, is a significant predictor of fluid intelligence (Conway et al., 2002). Further, when individuals utilized strategies during working memory training (e.g., chunking or mnemonics techniques which enhance maintenance but do not benefit manipulation ability), performance on maintenance tasks were enhanced yet manipulation ability and fluid intelligence remained unchanged (Lövdén et al., 2010; Morrison & Chein, 2011). Thus, the ability to manipulate information maintained in immediate memory may underlie working memory training related improvements in fluid intelligence (Engle, Tuholski, Laughlin, & Conway, 1999). Complex working memory training tasks involving the maintenance and manipulation of information target both storage specific and processing related aspects of working memory (Cowan, 2010; Engle et al., 1999). It could be that processing related components of working memory have particular associations with fluid intelligence, such that enhanced manipulation relates to enhanced fluid intelligence. Hence, if working memory training results in far transfer, a potential mechanism in need of examination is the manipulation aspect of working memory.

Investigations that support near and/or far transfer effects of dual n-back working memory training have been criticized for several reasons. First, sample sizes were typically small (i.e., less than 20 per group) which called into question the influence of error on significant findings (Melby-Lervag & Hulme, 2012; Morrison & Chein, 2011; Shipstead et al., 2012). Also, dual n-back training studies that have demonstrated far transfer to fluid intelligence in healthy individuals utilized a convenience sample of restricted age range (i.e., participants in their 20's) and university affiliation, thus results may not generalize to the larger middle-aged adult community. In fact, little is known about whether working memory training induces cognitive plasticity in healthy middle-aged adults. This population has been comparatively overlooked in cognitive training literature (Hardy, Drescher, Sarkar, Kellett, & Scanlon, 2011), despite an ever-increasing interest by healthy middle-aged adults to improve their intellectual abilities, or potentially stave off age related cognitive decline (Fernandez, 2011). Another notable criticism of existing investigations is that matrix reasoning tasks were used as the only measure of fluid intelligence, yet fluid intelligence is comprised of more than matrix reasoning (Shipstead et al., 2012). One study that included a non-matrix based measure of fluid intelligence (mental cutting, folding, and rotation of paper) demonstrated dual n-back training related improvements in that task (Jaušovec & Jaušovec, 2012). Finally, in studies demonstrating near and far transfer, concerns have been raised regarding the quality of control groups (Shipstead et al., 2012). Specifically, control groups were often no contact groups, or groups where tasks differed enough from the training task to raise concern that factors other than working memory training (e.g., motivation, expectancy, attention to a computerized task) accounted for changes in working memory or fluid intelligence (Shipstead et al., 2012). For example, adaptive dual n-back training groups have been compared to no-contact control groups (Jaeggi et al., 2008; Jaeggi et al., 2010), groups trained with low demand computerized tasks (Schweizer et al., 2011), or social skills training groups (Jaušovec & Jaušovec, 2012).

Including active control groups where participants are blind to conditions may be useful for preventing differences in expectancy or motivation. In two separate studies of young adults assigned to a dual n-back training group, an adaptive visual search task group (active control), or a no-contact control group, training related gains were not identified in any one group relative to another for any outcome (Redick et al., 2012; Thompson et al., 2013). Similarly, undergraduate students assigned to a no-contact control, a non-adaptive 1-back training condition, or an adaptive dual n-back training condition did not demonstrate differential improvement in fluid intelligence after either 8- or 20-days of training (Chooi & Thompson, 2012). In all cases, none of the groups demonstrated near or far transfer. However, more telling would be a situation with differential improvement between compared training groups. For example, if the dual n-back group improved relative to the active control group, gains could more strongly be attributed to dual n-back training rather than expectancy or motivation.

The null findings described above may be explained by factors that have not yet been accounted for in dual n-back working memory training studies. For example, authors of studies that failed to identify between group differences in cognitive outcomes after training have suggested that individual factors prior to training may have influenced results (Redick et al., 2012; Salminen, Strobach, & Schubert, 2012; Thompson et al., 2013). For example, Thompson and colleagues' (2013) failure to enhance working memory or fluid intelligence may have been due to higher than average baseline intelligence in both the training and the active control group (i.e., Wechsler Abbreviated Scale of Intelligence means of 121 in both groups). Such high baseline abilities suggest that a ceiling effect prevented either the occurrence, or the detection, of training related change. Similarly, in Salminen's (2012) investigation, the dual n-back training group began the study with higher fluid intelligence scores than the control group, and likely reached a ceiling in the fluid intelligence measure. Thus, failure to find post-training differences in fluid intelligence improvement may have been due to pre-training differences between groups in fluid intelligence (Salminen et al., 2012). Given the potential impact of baseline intellectual abilities on training outcomes, analysis of this individual difference is essential.

A further individual difference worthy of investigation is personality. Few studies have considered relationships among personality factors and cognitive performance, and those that have reported inconsistent findings (Soubelet & Salthouse, 2011). Openness was noted as the strongest personality factor associated with crystallized and fluid intelligence, memory span, and processing speed (Soubelet & Salthouse, 2011). Agreeableness and neuroticism were negatively associated with fluid intelligence, and conscientiousness associated with higher levels of speed task performance (Soubelet & Salthouse, 2011). In an n-back training investigation, a negative correlation emerged between conscientiousness and fluid intelligence (Thompson et al., 2013). Given the limited and inconsistent research on associations between working memory, fluid intelligence, and personality, additional exploration of the relationships among personality factors and working memory training related change is warranted.

In sum, whether or not dual n-back working memory training is associated with improvements in working memory and/or fluid intelligence, and for whom and how that change occurs, remains unclear. The current study will endeavour to answer these questions while addressing methodological concerns of previous studies.

To address concerns regarding sample characteristics, we will explore whether training related change occurs in healthy adults, aged 30-60, recruited from the community. Improved cognitive performance after working memory training has been demonstrated in children (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Gibson et al., 2011; Klingberg et al., 2005), healthy young adults (Jaeggi et al., 2008; Jaeggi et al., 2010; Jaušovec & Jaušovec, 2012; Rudebeck et al., 2012; Schweizer et al., 2011) and healthy old (i.e., over 65 years) adults (Borella, Carretti, Riboldi, & De Beni, 2010; Brehmer, Westerberg, & Backman, 2012). In addition, enhanced working memory abilities have been demonstrated in middle-aged adults after cognitive, though not specifically working memory, training (Hardy et al., 2011). However, no studies to date have investigated near and far transfer of dual n-back training related change in healthy middle age-range adults.

To address concerns regarding control group quality, the present study will use an active comparison group undergoing similar training in a different cognitive domain. Processing speed training was chosen as an active comparison because only weak associations have been found between processing speed and either fluid intelligence or working memory (Conway et al., 2002) and no impact of processing speed training has been found on working memory (Peng, Wen, & Wang, 2011). Including this active comparison group rather than a no-training control group allows for (1) all elements of the study with the exception of the specific games used in training (training content) to be controlled for, and (2) an investigation of dissociations among the training programs and cognitive outcomes, specifically, impacts of working memory training versus processing speed training on working memory, processing speed, and fluid intelligence.

Finally, in response to criticisms about limited measures of fluid intelligence, this study will utilize one purely matrix based task, and one task which measures both matrix and non-matrix based abstract reasoning. Overall, this study will combine an ecologically valid training paradigm with controlled experimental methodology to explore whether working memory training is beneficial relative to an active control program, how training might induce change, and what participant characteristics are associated with training related gains.

1.1 Rationale and hypotheses

The purpose of the present study is to investigate near and far transfer of working memory training related change, and factors associated with training induced enhancements in healthy, middle-aged adults. Specifically, this study will ask (1) for healthy adults, does working memory training transfer to gains in working memory (near transfer) and/or fluid intelligence (far transfer) compared to an active control training condition? A secondary goal of this study aims to discover whether a specific component of working memory is enhanced by training, therefore will ask (2) does working memory training impact working memory manipulation abilities more than maintenance abilities? Finally, this study will explore individual differences associated with change after training, thus, will ask (3) are individual differences in pre-training intelligence and personality associated with training related change in healthy adults?

Our primary hypothesis is that relative to the processing speed training group, the working memory training group will demonstrate post-training improvements in measures of working memory and fluid intelligence. Regarding our secondary goal, we anticipate that the working memory training group will experience improvements in spatial manipulation abilities, above improvements in spatial maintenance alone. Finally, we expect that individual characteristics will relate to the amount of change in cognitive outcomes. Specifically, we hypothesize that low pre-training intelligence will be associated with increased pre- to post-training change in cognitive outcomes. Regarding personality, due to inconsistent findings in previous investigations we elect to consider analyses of personality factors and training related change as exploratory.

CHAPTER 2: METHODS

2.1 Participants

Participants were healthy adults (*n*=70) aged 30-60 who self-referred to the website www.braintrainingstudy.ca after learning of the study through postings, a radio interview, and/or social media. Exclusion criteria were history of brain trauma, neurological or psychiatric illness, visual or auditory impairment, benzodiazepine or illicit drug use in the past three months, and pathologies associated with cognitive impairment (Crook et al., 1986). Individuals who used a dual n-back or processing speed training product in the previous six months were also excluded.

Seventy healthy adults participated in this study (see Figure 1 for study design flow chart). Fifty-four participants (77%) completed baseline and post-training assessments; however, participants who completed less than half the requested training sessions were excluded from analysis due to low training dosage (*n*=4). Therefore, the final analyzed sample consisted of 50 participants (working memory group *n*=23, processing speed group *n*=27).

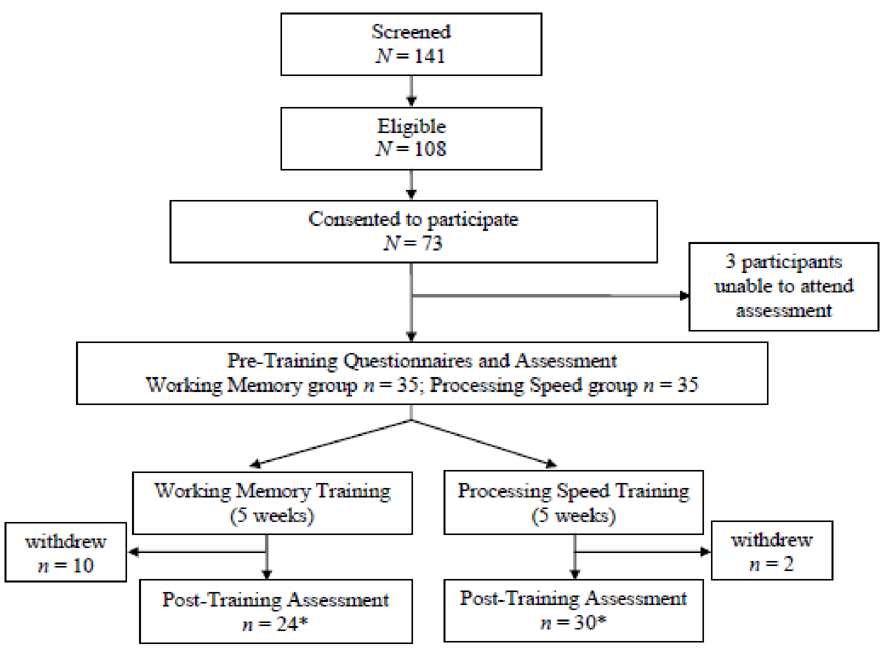

Figure 1: Flow chart of study design. *Data for one working memory training and three processing speed training participants were removed from analysis due to low (<50%) training dosage.

2.2 Training programs

Working memory and processing speed training programs were provided by Lumosity (Lumos Labs Inc., 2009) and accessed online. Examples of these programs are in Appendix A. Working memory trainees used the dual n-back, an adaptive training program that recruits auditory and visual working memory processes. Difficulty level (i.e., "n") adjusts to maintain 85% accuracy. The dual n-back training program has been used to demonstrate improved working memory and fluid intelligence in healthy young adult university samples (Jaeggi et al., 2008; Jaeggi et al., 2010) and was modified for commercial use by Lumosity (Lumos Labs Inc., 2009). Processing speed training was composed of two visual 1-back games requiring participants to quickly determine whether a given symbol matched a symbol presented immediately prior. Although speed games recruit memory processes, the focus of the training was on speed of thought and decision making rather than maintenance and/or manipulation of information in working memory. All participants were instructed to train for 20-30 minutes per day, 5-days per week, for 5 weeks at a location of their convenience.

2.3 Measures

2.3.1 Baseline measures

At baseline, participants completed an online form assessing demographics (e.g., age, gender, race, income, health status) and questionnaires assessing state characteristics potentially associated with cognitive performance. The three characteristics (mood, sleep quality, and physical activity) were measured to identify and control for confounds, if present. Mood was measured with the six dimensions (tension-anxiety, depression-rejection, anger-hostility, vigour-activity, fatigue-inertia, and confusion-bewilderment) of the Profile of Mood States-Short Form (POMS-SF; Shacham, 1983). Sleep quality was assessed with the Pittsburgh Sleep Quality Index

(PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), a highly sensitive and specific measure of sleep difficulty. The International Physical Activity Questionnaire - Last 7 Day, Short Form, Self Administered (IPAQ-S7S) was used as a valid and reliable assessment of physical activity (Craig et al., 2003). All measures have demonstrated good psychometric properties in healthy populations. Questionnaires can be viewed in Appendix B.

The HEXACO-60 (Ashton & Lee, 2009) was also administered online. The HEXACO-60 assesses six dimensions of personality: honesty-humility, emotionality, extraversion, agreeableness, conscientiousness, and openness to experience. This measure is brief yet thorough and correlates highly with other personality measures (Ashton & Lee, 2009).

Baseline intelligence was estimated with the Wechsler Abbreviated Scale of Intelligence - Second Edition (WASI-II; Wechsler, 2011) a short, standardized measure of intelligence yielding a full-scale composite score representing general intelligence. The WASI-II is an update to the original WASI, which has demonstrated convergent and structural validity with more lengthy measures of intelligence (Canivez, Konold, Collins, & Wilson, 2009). The WASI-II was administered during the in-person baseline cognitive assessment.

2.3.2 Outcome measures

At baseline and post-training, participants underwent a cognitive assessment measuring the three cognitive domains of interest: working memory, processing speed, and fluid intelligence. Examples of reproducible items are in Appendix C.

<u>2.3.2.1 Working memory</u>. Working memory was measured with three tasks. Auditory working memory was measured with the Wechsler Adult Intelligence Scale -- Fourth Edition (WAIS-IV) Digit Span subtest (Wechsler, 2008a; Wechsler, 2008b). Participants repeated verbatim a series of verbally presented digits (Digit Span Forward), recalled verbally presented

digits in backward order (Digit Span Backward), and mentally re-arranged verbally presented digits and recalled them in sequential order (Digit Span Sequencing). Visual-spatial maintenance and manipulation were measured with the Spatial Maintenance and Manipulation task provided by Glahn and colleagues (2002). This task assesses both memory span and processing ability, and has been associated with neural activation in working memory areas (Glahn et al., 2002). The spatial maintenance score was derived from participants' accuracy (% correct) at remembering the positions of circles after a short delay, and the spatial maintenance *plus* manipulation score was obtained from participants' ability (% correct) to remember the positions of circles, mentally flip the positions along a horizontal plane, and remember the new positions. Working memory was also measured with the Automated Operation Span task (Unsworth, Heitz, Schrock, & Engle, 2005) which required participants to quickly solve mathematical operations presented on screen while also remembering a series of letters. This task is highly correlated with non-automated operation span tasks (Unsworth et al., 2005) and other measures of working memory (Conway et al., 2002).

2.3.2.2 Processing Speed. Processing speed was measured using raw scores from the Symbol Search and Coding subtests of the WAIS-IV Processing Speed Index (Wechsler, 2008a; Wechsler, 2008b). Participants quickly responded to visual stimuli by either copying symbols on paper or identifying symbols that matched other symbols. Taken together, the Processing Speed Index is a reliable measure of processing speed, and individually, Symbol Search is considered "as pure a test as possible of information-processing speed" (Wechsler, 2008b).

2.3.2.3 Fluid Intelligence. Two measures of fluid intelligence were utilized in this study: Raven's Advanced Progressive Matrices (RAPM; Raven, 1975) and Cattel's Culture Fair Test (CCFT) Scale 3 (Cattell & Cattell, 1959). The RAPM has been used to demonstrate working memory training related change in fluid intelligence (Jaeggi et al., 2008; Jaeggi et al., 2010; Jaušovec & Jaušovec, 2012). For the RAPM, a 6-item practice set progressing from easy to challenging was administered to ensure the participant understood the task. As with previous studies (e.g., Jaeggi et al., 2008; Jaeggi et al., 2010; Salminen et al., 2012; Thompson et al., 2013), the 36 test items were split into parallel odd and even forms counterbalanced across participants with the opposite form delivered at post-test. Participants were allowed 20 minutes to complete the 18-item test. For the CCFT, forms A and B were also administered counterbalanced across participants. CCFT Scale 3 contains four subtests: series, classifications, matrices, and conditions providing a measure of fluid intelligence beyond matrices. The CCFT is considered a superior and more specific measure of fluid intelligence compared to measures using only matrix tasks (Colom & Garcia-Lopez, 2003; Tranter & Koutstaal, 2008) and is appropriate for the general adult population ranging from average to superior intelligence. Raw rather than scaled scores were used for analysis given that Cattel & Cattel's (1959) standardized scores and percentiles were based on administration of the forms either sequentially (A followed by B) or in isolation (A or B only) rather than counterbalanced (A followed by B for half of the sample, B followed by A for the remainder of the sample). Our use of raw scores is consistent with other studies that measured CCFT scores over multiple time points (e.g., Borella, et al., 2010).

2.4 Procedure

Within five days of completing online consent and questionnaires, participants attended a 2.5-hour baseline cognitive assessment. To reduce carryover and fatigue effects, the administration order of cognitive tasks was counterbalanced using an eight-sequence Williams design latin square (Williams, 1949). Baseline assessments were conducted by a second-year clinical psychology master student who was blind to randomization until the baseline assessment was complete. At the conclusion of the baseline assessment, training instructions were revealed to the participant. Instructions focused on how to access the online training and the importance of playing only the games described in the instructions. Participants were told only about their training program and were not aware that processing speed and working memory programs were being directly compared, although training program names (e.g., speed mach, dual n-back) were not concealed. Game play data was monitored for compliance. Group assignment was determined by a Microsoft Excel 2010 random digit generator, and training instruction packages were assembled and provided in sealed envelopes by an individual not associated with the study. At the conclusion of the training period, participants returned for a 2-hour post-training cognitive assessment composed of the same measures (using parallel forms where indicated) excluding the WASI-II. To maintain experimenter blinding, post-assessments were conducted by undergraduate research assistants trained by the student that conducted baseline assessments. Training included one-on-one instruction, numerous practice assessments with non-study participants, and at least one participant assessment observed by the trainer to ensure competency and consistency. All assessment materials were scripted to ensure consistency of instructions to participants. Participants were asked not to discuss their training program with the research assistants, and assistants did not know specifics of the games or the target skills being trained (e.g., speed versus working memory).

2.5 Statistical Analysis

All analyses were conducted using Statistical Package for the Social Sciences (SPSS) version 20. Independent samples t-tests and chi-squared analyses were used to explore baseline differences in demographics, individual characteristics (estimated intelligence, personality, sleep quality, physical activity, and mood), and cognitive outcomes between completers and non-completers, as well as between training groups. Despite randomization, a baseline difference between training groups emerged for the spatial maintenance plus manipulation task which could not be resolved statistically.

Individual training group (working memory versus processing speed) x time (pre- and post-training) repeated measures analyses of variance (RM-ANOVAs) were conducted to test for significant differences between the working memory and processing speed training groups in working memory, processing speed, and fluid intelligence task performance over time. Cohen's *d* effect sizes of the interaction effect are reported. In anticipation that power may not be adequate to detect a statistically significant interaction, planned individual one-way RM-ANOVAs in each training group were conducted to follow-up on significant main effects of time. Cohen's *d* effect sizes are reported. To identify whether spatial manipulation abilities changed relative to spatial maintenance abilities, a training group (working memory versus processing speed) x time (pre- and post-training) x Spatial Maintenance and Manipulation task (maintenance vs. maintenance plus manipulation) RM-ANOVA was performed. Finally, correlations (two-tailed) were completed in cognitive domains demonstrating significant effects of time in order to assess participant characteristics hypothesized to be associated with training related change (i.e. baseline intelligence and personality).

CHAPTER 3: RESULTS

3.1 Participant Flow

Screening, eligibility, consent, and completion rates for the working memory training and processing speed training groups are presented in Figure 1. Of the 70 participants recruited for the study, 50 completed all components of the study (pre- and post-assessments and at least 50% of assigned training sessions). Of the participants who provided reasons for dropping out, primary reasons were being too busy to complete the daily training, and unforeseen life events (e.g., unexpected travel, injury, or illness).

Two differences were observed between participants that completed and those that did not complete the study. Relative to completers, on a baseline measure of mood state, non-completers endorsed more symptoms of confusion (M = 2.25, SD = 0.80 versus M = 1.75, SD = 0.53), $t(67) = 3.05$, $p < .01$. Additionally, in the spatial maintenance condition of the Spatial Maintenance and Manipulation task, non-completers scored higher (M = 92.50, SD = 5.00) than completers (M = 89.00, SD = 6.78), $t(68) = 2.09$, $p = .04$. No further demographic, individual, or cognitive differences were identified.

3.2 Participant Characteristics

Participants were mostly white (86%), female (70%), in a coupled relationship (74%), employed full-time (68%), had at least one university degree (64%), and incomes above $50,000 per year (70%). All participants spoke and read English fluently, although for 12% of the sample English was not their first language. Demographic characteristics are noted in Table 1.

At baseline, no significant differences in demographic variables or individual characteristics (i.e., baseline intelligence, personality, gender, age, mood, sleep quality, physical activity) were observed between the working memory and processing speed groups. Group means and standard deviations for all baseline individual characteristics are presented in Table 1.

Table 1. Participant characteristics at baseline

	Working Memory Group Mean (SD)	Processing Speed Group Mean (SD)	t-test(df)	*p*
N	23	27		
Age	46.65 (9.04)	48.44 (8.93)	$t(48)=0.70$	.49
Gender (% female)	64	78	$\chi^2(1)=1.69$	.29
Race (Caucasian: Hispanic: Asian: Other)	19: 1: 2: 1	24: 1: 1: 1	$\chi^2(3)=0.60$	.90
Marital status (% coupled)	70	78	$\chi^2(1)=0.44$	.51
Education (% post-secondary degree)	83	95	$\chi^2(1)=1.17$	.28
Employment (Full:time: part-time: not employed)	16: 4: 3	18: 2: 7	$\chi^2(2)=2.08$	.35
Income (<$50,000: $50,000-$95,000: >$95,000)	9: 6: 8	6: 7: 14	$\chi^2(2)=2.01$	.37
WASI-II Composite	104.30 (8.24)	105.07 (11.36)	$t(48)=0.27$	.79
HEXACO: Honesty-Humility	2.28 (0.51)	2.09 (0.50)	$t(48)=1.35$	.19
HEXACO: Emotionality¶	3.07 (0.63)	2.80 (0.37)	$t(48)=1.82$	.08
HEXACO: Extraversion	2.53 (0.60)	2.63 (0.51)	$t(48)=0.63$	.53
HEXACO: Agreeableness	2.85 (0.47)	2.59 (0.58)	$t(48)=1.75$	.09
HEXACO: Conscientiousness	2.37 (0.51)	2.31 (0.48)	$t(48)=0.39$	.70
HEXACO: Openness¶	2.45 (0.51)	2.52 (0.49)	$t(48)=0.45$	.66
PSQI Total Score¶	7.95 (1.65)	7.58 (2.61)	$t(48)=0.54$	.59
IPAQ Total Score	1633.96 (1325.78)	2314.11 (1877.51)	$t(48)=1.46$	.15
POMS: Vigor	2.64 (0.75)	2.71 (0.88)	$t(48)=0.33$	.74
POMS: Confusion	1.68 (0.38)	1.81 (0.63)	t(48)=0.86	.39
POMS: Tension	1.70 (0.36)	1.74 (0.46)	t(48)=0.40	.69
POMS: Anger	1.48 (0.37)	1.48 (0.34)	t(48)=0.02	.98
POMS: Fatigue	1.90 (0.65)	2.16 (0.80)	t(48)=1.24	.22
POMS: Depression	1.41 (0.39)	1.32 (0.25)	t(48)=0.96	.34

* p < .05 ** p < .01 *** p < .001
WASI-II = Wechsler Abbreviated Scale of Intelligence (2nd Edition); PSQI = Pittsburgh Sleep Quality Index; IPAQ = International Physical Activity Questionnaire; POMS = Profile of Moods State questionnaire
¶ HEXACO Emotionality and Openness data for one working memory training participant is missing; PSQI data for four working memory training participants and one processing speed participant is missing.

Regarding cognitive performance, the two groups did not differ on measures of processing speed or fluid intelligence; however, the working memory group had significantly higher scores on the maintenance plus manipulation condition of the Spatial Maintenance and Manipulation task (M = 81.96, SD = 12.95) relative to the processing speed group (M = 72.22, SD = 13.11), $t(48) = 2.63$, $p = .01$. The two groups did not differ on any other measure of working memory. Group means and standard deviations for all cognitive measures at baseline and post-training are presented in Table 2.

Table 2. Means, standard deviations, and effect sizes for the effect of time (pre- versus post-training) in the working memory (n = 23) and processing speed (n = 27) training groups, and the interaction effect between working memory and processing speed groups across time

Task	Group	Mean (SD) Time 1	Mean (SD) Time 2	*F* Test (df)	*p*	Cohen's *d*
DS	WM	29.52 (4.22)	30.09 (4.21)	$F(1,22) = 0.99$	.33	0.14
	PS	29.78 (6.04)	30.81 (6.71)	$F(1,26) = 2.69$	.11	0.16
	WMxPS			$F(1,48) = 0.30$	.59	0.16
SM	WM	87.83 (6.71)	92.83 (5.61)	$F(1,22) = 11.05$	.003**	0.81
	PS	90.00 (6.79)	92.22 (6.10)	$F(1,26) = 62.26$	<.001***	0.34
	WMxPS			$F(1,48) = 1.39$	.25	0.34
SMM	WM	81.96 (12.95)	82.61 (12.87)	$F(1,22) = 3.47$	.08	0.05
	PS	72.22 (13.11)	79.81 (12.82)	$F(1,26) = 9.56$	.01*	0.59
	WMxPS			$F(1,48) = 4.05$	.50*	0.58
Aospan ¶	WM	33.91 (20.79)	42.65 (17.16)	$F(1,22) = 8.47$	<.01**	0.46
	PS	31.08 (18.23)	38.19 (21.38)	$F(1,25) = 4.26$	.05*	0.36
	WMxPS			$F(1,47) = 0.12$	.73	0.11
SS	WM	35.22 (6.90)	37.09 (6.19)	$F(1,22) = 4.44$	.047*	0.29
	PS	34.52 (5.89)	37.85 (7.86)	$F(1,26) = 15.42$	<.001***	0.48
	WMxPS			$F(1,48) = 1.41$	.24	0.34
Coding	WM	74.13 (15.03)	79.30 (15.87)	$F(1,22) = 16.86$	<.001***	0.33
	PS	73.41 (11.77)	80.81 (11.94)	$F(1,26) = 35.52$	<.001***	0.62
	WMxPS			$F(1,48) = 1.58$	.22	0.35
RAPM	WM	11.35 (2.95)	11.61 (2.50)	$F(1,22) = 0.17$	.69	0.10
	PS	10.66 (2.41)	11.21 (2.38)	$F(1,26) = 1.35$	.26	0.23
	WMxPS			$F(1,48) = 0.14$	.71	0.11
CCFT	WM	26.22 (4.56)	28.78 (5.13)	$F(1,22) = 4.32$	.05*	0.53
	PS	26.30 (4.17)	27.85 (4.70)	$F(1,26) = 1.82$	.19	0.35
	WMxPS			$F(1,48) = 0.36$	.55	0.17

* $p \leq .05$ ** $p < .01$ *** $p < .001$
Aospan = Automated Operation Span; SM = spatial maintenance; SMM = spatial maintenance plus manipulation; DS = Digit Span; SS = Symbol Search; RAPM = Raven's Advanced Progressive Matrices, CCFT = Cattel's Culture Fair Test; WM = working memory training group, PS = processing speed training group, WMxPS = time x group interaction between WM and PS
¶Task data for one processing speed group participant's post-training scores did not record therefore processing speed group n=26 for this task

3.3 Training

Regarding training, working memory trainees spent an average of 17.18 minutes per daily training session whereas processing speed trainees spent an average of 20.41 minutes per daily training session. Although the two groups did not differ significantly in number of sessions (working memory group M = 22.74, SD = 3.39; processing speed group M = 22.81, SD = 3.28),

$t(48) = 0.08$, $p = .94$, a significant difference emerged in total hours of training, $t(48) = 3.20$, $p < .01$ with the processing speed group training more ($M = 7.76$, $SD = 1.66$) than the working memory group ($M = 6.51$, $SD = 0.93$).

Training progress in the working memory group was based on n-back level achieved. Throughout training, almost half the group (48%) reached 4-back, with many others reaching 5-back (30%). Two participants (9%) did not surpass 3-back and three participants (13%) reached 6-back. Within the working memory group, the mean average n-back level achieved on the first day of training was 1.97 ($SD = 0.32$) and on the last day of training, 3.28 ($SD = 0.56$). The difference in n-back level achieved from the first to last day of training was statistically significant, $t(22) = 13.85$, $p < .001$.

3.4 Change in working memory, processing speed, and fluid intelligence

3.4.1 Working Memory

3.4.1.1 Digit Span. The RM-ANOVA of Digit Span failed to reveal a significant time, $F(1,48) = 4.42$, $p = .07$, group, $F(1,48) = 0.11$, $p = .74$ or interaction effect, $F(1,48) = 0.30$, $p =.59$, $d = .16$.

3.4.1.2 Spatial Maintenance and Manipulation task. To identify change over time in the Spatial Maintenance and Manipulation task, and to identify whether manipulation abilities improved relative to maintenance abilities, a training group x time x task condition (maintenance versus maintenance plus manipulation) RM-ANOVA was conducted. A significant main effect of time, with improvement after training $F(1,48) = 57.70$, $p < .001$, though not group, $F(1,48) = 1.95$, $p = .17$ emerged. A significant three-way interaction between time, task, and group was revealed, $F(1,48) = 6.21$, $p = .02$. Planned RM-ANOVAs were used to further explore the interaction effect.

A time x group RM-ANOVA was conducted in each task condition. In the spatial maintenance condition, a main effect of time was revealed with higher scores after training, $F(1,48) = 9.38$, $p < .01$. Neither a main effect of group, $F(1,48) = 0.34$, $p = .57$ nor an interaction were identified, $F(1,48) = 2.39$, $p = .25$, $d = 0.34$. In the spatial maintenance plus manipulation condition, a main effect of time was present with improvement after training, $F(1,48) = 5.72$, $p = .02$. A main effect of group was not revealed, $F(1,48) = 3.73$, $p = .06$ although an interaction was noted, $F(1,48) = 4.05$, $p = .05$, $d = 0.58$ suggesting that in the spatial maintenance plus manipulation condition, processing speed trainees improved over time relative to working memory trainees.

To further explore task conditions over time, separate time x task RM-ANOVAs were conducted in each training group. In the working memory group, a main effect of time was revealed in the spatial maintenance condition, $F(1,22) = 11.05$, $p < .01$, $d = 0.81$ with higher scores post-training. A main effect of time was not found in the spatial maintenance plus manipulation condition, $F(1,22) = 3.47$, $p = .08$, $d = 0.05$. Furthermore, an interaction between the two task conditions was not revealed, $F(1,22) = 2.14$, $p = .16$ suggesting that in the working memory training group, scores in one task condition did not improve over time relative to scores in the other. In the processing speed group, a main effect of time was present for the spatial maintenance scores, $F(1,26) = 62.26$, $p < .001$, $d = 0.34$ with higher scores post-training. Similarly, a main effect of time was present for spatial maintenance plus manipulation scores, $F(1,26) = 9.56$, $p < .01$, $d = 0.59$ with higher scores post-training. An interaction between the two task conditions was revealed, $F(1,26) = 4.41$, $p = .046$, suggesting that in the processing speed group, spatial maintenance plus manipulation abilities improved over time relative to improvements in maintenance only.

3.4.1.3 Automated Operation Span Task. Analysis of the Automated Operation Span task revealed a main effect of time $F(1,47) = 11.73$, $p < .01$ with post-training scores higher than pre-training scores. Neither a main effect of group, $F(1,47) = 0.52$, $p = .48$ nor an interaction, $F(1,47) = 0.12$, $p = .73$, $d = 0.11$ were present. RM-ANOVAs, planned to follow up main effects of time, revealed a statistically significant increase in Automated Operation Span scores in the working memory group, $F(1,22) = 8.47$, $p < .01$, $d = 0.46$ and the processing speed group $F(1,25) = 4.26$, $p = .05$, $d = 0.36$.

In sum, training related improvements in working memory abilities varied. Auditory working memory scores, as measured by the Digit Span task, did not change for either training group; however both groups improved on the Automated Operation Span task. Although visual-spatial maintenance improved after training in both groups, large Cohen's *d* effect sizes were present in the working memory training group, with only small effects in the processing speed group. The opposite occurred when visual-spatial manipulation abilities were tested, with differential improvement in the processing speed group relative to the working memory training group. These findings are illustrated in Figure 2.

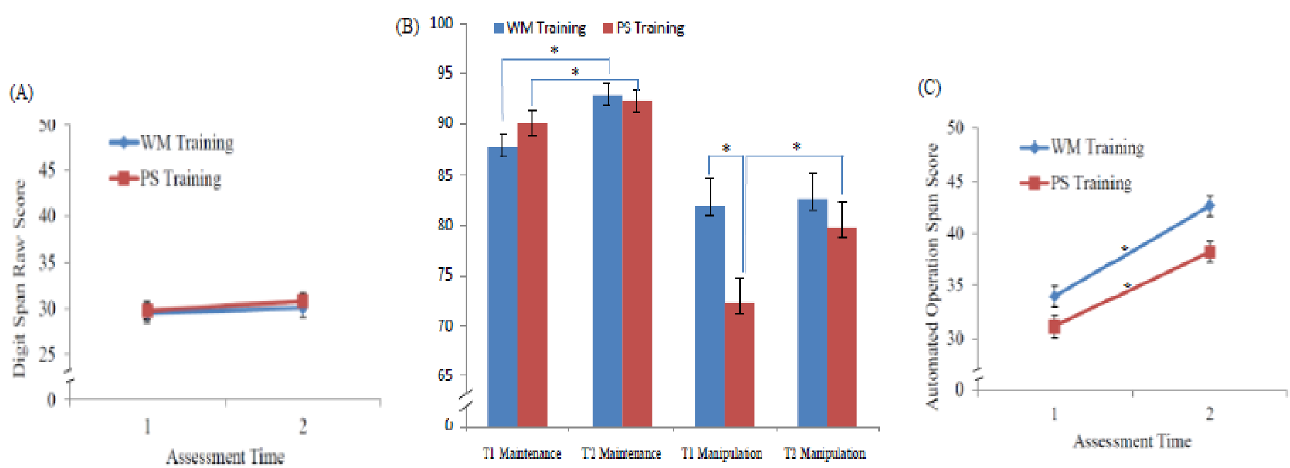

Figure 2: Mean (±S.E.) (A) Digit Span Raw Scores, (B) Spatial Maintenance and Manipulation scores, and (C) Automated Operation Span scores before (T1) and after (T2) training. *p<.05

3.4.2 Processing Speed

3.4.2.1 Symbol Search. For Symbol Search, a significant main effect of time emerged, $F(1,48) = 17.84$, $p < .001$ with higher scores after training. Analysis did not identify a main effect of group, $F(1,48) = 0.00$, $p = .99$ or an interaction effect, $F(1,48) = 1.41$, $p = .24$, $d = 0.34$. Upon individual RM-ANOVA, significant main effects of time were present in both the working memory group, $F(1,22) = 4.44$, $p = .047$, $d = 0.29$ and the processing speed group, $F(1,26) = 15.42$, $p < .001$, $d = 0.48$.

3.4.2.2 Coding. A significant main effect of time was identified for Coding, $F(1,48) = 49.99$, $p < .001$ with higher scores post-training. Neither a main effect of group, $F(1,48) = 0.01$, $p = .92$ nor an interaction effect, $F(1,48) = 1.58$, $p = .22$, $d = 0.35$ were present. Individual RM-ANOVAs revealed significant effects of time on the working memory group, $F(1,22) = 16.86$, $p < .001$, $d = 0.33$ and the processing speed group, $F(1,26) = 35.52$, $p < .001$, $d = 0.62$.

Overall, both training groups demonstrated improvements in measures of processing speed after training, although effects of training were larger in the processing speed group (i.e., medium and large cohen's *d* effect sizes) than in the working memory group (i.e., small cohen's *d* effect sizes) suggesting that processing speed training benefited processing speed tasks. Findings are visually represented in Figure 3.

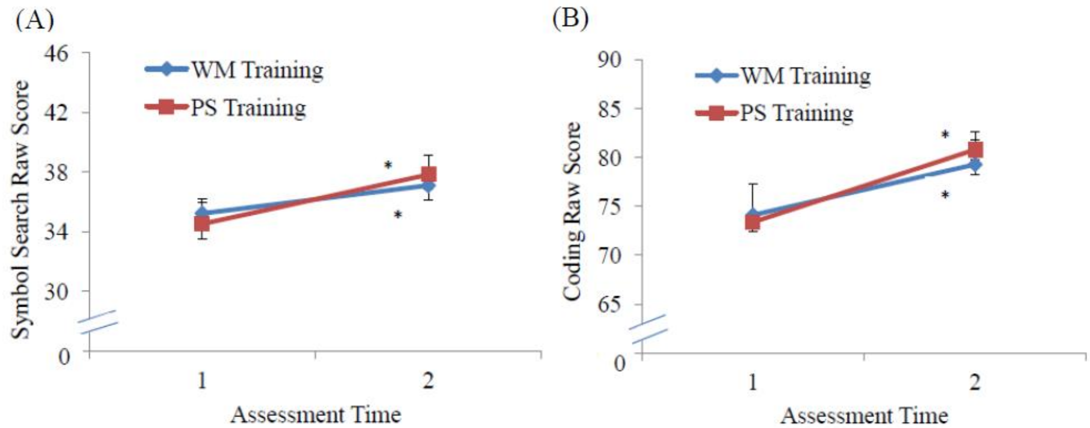

Figure 3: Mean (±S.E.) (A) Symbol Search and (B) Coding raw scores before and after training. *p<.05

3.4.3 Fluid Intelligence

3.4.3.1 RAPM. Analysis of RAPM scores failed to reveal a significant time, $F(1,48) = 1.09$, $p = .30$ group, $F(1,48) = 0.78$, $p = .38$ or interaction effect, $F(1,48) = 0.14$, $p = .71$, $d = 0.11$.

3.4.3.2 CCFT. CCFT scores resulted in a significant main effect of time, $F(1,47) = 5.93$, $p = .02$ with higher scores after training. Analyses did not identify a main effect of group, $F(1,48) = 0.18$, $p = .67$ or an interaction, $F(1,48) = 0.36$, $p = .55$, $d = 0.17$. The RM-ANOVA in the working memory group was significant, $F\,(1,22) = 4.32$, $p = .05$ with a medium effect size ($d = 0.53$). In the processing speed group, a significant effect of time was not found, $F(1,26) = 1.82$, $p = .19$, $d = 0.35$.

To summarize, only the working memory training group demonstrated training related changes in fluid intelligence. Change was limited to the CCFT. Results are showing in Figure 4.

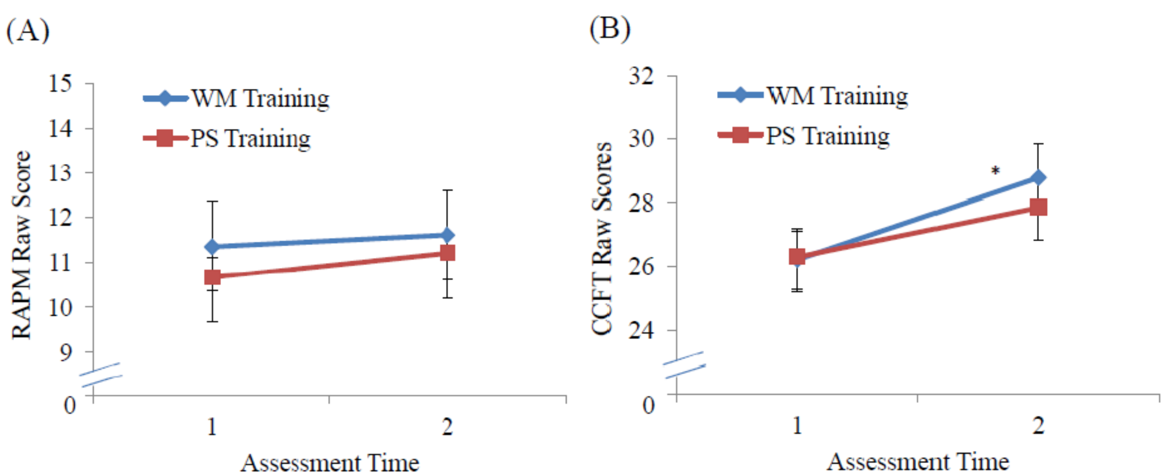

Figure 4: Mean (±S.E.) (A) Raven's Advanced Progressive Matrices and (B) Cattel's Culture Fair Test raw scores before and after training. *p<.05

3.5 Individual characteristics associated with training related change

Correlations among individual characteristics (i.e., baseline intelligence and age) and cognitive outcomes were limited to cognitive tasks with significant change over time. Thus, in the working memory training group, correlations were conducted for the spatial maintenance condition of the Spatial Maintenance and Manipulation task, the Automated Operation Span task, both measures of processing speed, and the CCFT. In the processing speed group, correlations were performed for both Spatial Maintenance and Manipulation tasks, as well as the Automated Operation Span task, and both measures of processing speed. Two-tailed correlations at alpha <.05 were utilized for WASI-II composite scores. To control for multiple analyses, alpha was adjusted to <.01 for the six dimensions of the HEXACO personality scale. Additional relationships between demographic characteristics (i.e., age and gender) and changes in cognitive outcomes are presented in Appendix D.

3.5.1 Working Memory Training Group

In the working memory training group, significant correlations were exhibited for fluid intelligence and processing speed tasks. Specifically, a negative association was present between HEXACO-Agreeableness scores and CCFT change scores, $r = -.45$, $p = .03$, as well as Symbol Search change scores, $r = -.55$, $p < .01$ indicating that less agreeable trainees performed better after training. No further associations were noted in the working memory training group.

3.5.2 Processing Speed Training Group

In the processing speed training group, significant correlations were revealed for processing speed tasks. A significant negative association emerged between baseline WASI-II scores and change in Coding, $r = -.41$, $p = .04$ indicating that processing speed trainees with lower baseline estimated intelligence benefited more from processing speed training.

CHAPTER 4: DISCUSSION

This study examined whether working memory training, relative to an active control condition, resulted in improved cognitive abilities, specifically, working memory and fluid intelligence. This investigation was conducted with healthy community adults, aged 30-60, given the increasing interest this population has in enhancing cognitive abilities, yet lack of empirical elucidation as to whether working memory training is effective. Furthermore, this study utilized an ecologically valid training paradigm, methodological controls lacking in many previous studies, and investigations of how and for whom working memory training might induce benefit.

Results suggest that healthy adults who use the dual n-back working memory training task for approximately 15-20 minutes per day for up to 25 days over a 5-week period improve on measures of working memory, fluid intelligence, and processing speed, whereas those who use a processing speed training program improve on tasks measuring working memory and processing speed but not fluid intelligence. Although the working memory group did not improve relative to the processing speed group in a statistically significant manner, effect sizes of the interaction, which represent the training related change over time between the two groups, suggest a small differential effect in favour of working memory training for performance on working memory and fluid intelligence tasks (i.e., Cohen's *d*'s = 0.11 - 0.34). Similarly, the between group effect sizes favour processing speed training for improved processing speed task performance (i.e., Cohen's *d*'s = 0.34-0.35). Given the use of an active rather than passive or no-contact control group in this study, small effect sizes between training groups were expected. Additionally, effect sizes of training related change over time were larger in the working memory group than the processing speed group for post-training working memory tasks (i.e., working memory group Cohen's *d*'s = 0.46-0.81 versus processing speed group Cohen's *d*'s = 0.35-0.59). Furthermore, the processing speed group did not improve over time in any measure of fluid intelligence whereas the working memory group demonstrated fluid intelligence improvement. A recent confirmatory factor analyses of Conway's (2002) structural equation model indicated that working memory and processing speed were associated, though moderately ($r = .27$, $p < .05$), and that working memory and fluid intelligence were notably correlated ($r = .53$, $p < .05$); however, processing speed and fluid intelligence were not related ($r = .13$; Redick, Unsworth, Kelly, & Engle, 2012). Hence, findings of the present study are in line with known associations among working memory, processing speed, and fluid intelligence. Furthermore, findings support previous dual n-back training studies in that training related effects were found in measures of both working memory and fluid intelligence (Jaeggi et al., 2008; Jaušovec & Jaušovec, 2012; Rudebeck et al., 2012; Schweizer et al., 2011).

Regarding specific fluid intelligence tasks, far transfer was demonstrated for the CCFT but not RAPM. A possible explanation for this finding is the time participants were given to complete these tasks. In this study, and other studies that failed to demonstrate training related change in fluid intelligence, participants completed the RAPM under typical time parameters (e.g., Chooi & Thompson, 2012; Jaušovec & Jaušovec, 2012; Redick et al., 2012; Salminen et al., 2012; Thompson et al., 2013). Conversely, in studies where the RAPM task was completed under time-constraints (i.e., half typical administration time), improvements in the task were found after training (Jaeggi et al., 2008; Jaeggi et al., 2010). The CCFT, by design, is more time constrained (ranging from 2.5-4.0 minutes for tasks of 10-14 items) and in the present study, working memory trainees demonstrated improvement after training. In an investigation where participants completed fluid intelligence measures in short, typical, or extended time conditions, differences between measures of working memory and fluid intelligence were "statistically indistinguishable” in the short time condition, whereas only small associations between working memory and fluid intelligence were present in the typical or extended administration time conditions (Chuderski, 2013). Furthermore, unique variance in fluid intelligence has been accounted for by both working memory and processing speed (Redick et al., 2012). In the present study, working memory training was associated with increased processing speed, and processing speed training was associated with increased working memory. Taken together, it appears that dual n-back working memory training may improve aspects of fluid intelligence requiring increased speed of thought. Future investigations could consider the potential mediating factors of processing speed on working memory and fluid intelligence after working memory training.

Regarding working memory tasks, of note is that working memory trainees improved in the Automated Operation Span task, but not the Digit Span task. Digit Span is a storage specific task whereas Automated Operation Span is a complex processing related task that requires participants to remember letters while mentally performing math operations (Shipstead et al., 2012; Unsworth et al., 2005). Similarly, the dual n-back training task is a complex processing related task as it requires participants to simultaneously remember positions of blocks and letter sounds. These two tasks may share a mechanism associated with fluid intelligence not present in digit span. However, working memory trainees also improved in spatial maintenance, a storage specific task. Hence, there may be shared qualities among the dual n-back, spatial maintenance, and Automated Operation Span tasks (e.g., visual aspects of working memory). As noted in previous reviews, mechanisms of dual n-back training related change are in need of exploration and dissemination (Morrison & Chein, 2011; Shipstead et al., 2012).

This study also explored whether working memory manipulation abilities are differentially impacted by dual n-back training, relative to working memory maintenance. Support for this hypothesis would point to manipulation ability as a potential mechanism of action in far transfer of working memory training related gains. However, findings in this sample indicated that although both training groups improved in spatial maintenance, only the processing speed group improved in spatial manipulation. Further, spatial manipulation abilities improved in the processing speed group over and above improvements in spatial maintenance. This outcome was unexpected given that working memory training was hypothesized to result in improvements in manipulation abilities. However, this result may be explained by the fact that despite randomization, the processing speed group started with significantly lower scores in the spatial manipulation task compared to the working memory training group. As with other studies reporting baseline differences between groups (e.g., Redick et al., 2012; Salminen et al., 2012; Thompson et al., 2013), in the present study, the working memory group was closer to the ceiling of the task both before and after training, whereas the processing speed group had more room to improve. However, it is also possible that by enhancing one's processing speed, the ability to mentally manipulate information improves. Further examination of the Spatial Maintenance and Manipulation task as an outcome of working memory or processing speed training, as well as exploration of associations between processing speed and working memory manipulation abilities, may inform this matter.

Finally, this study explored individual differences associated with working memory training related gain. Notable impacts of personality were demonstrated. Working memory trainees who scored highly on agreeableness were less likely to exhibit training related changes in both processing speed and fluid intelligence, with less agreeable participants garnering more benefit. This finding is consistent with an examination of personality factors and cognitive abilities, including fluid intelligence, in which a negative association emerged between agreeableness and fluid intelligence (Soubelet & Salthouse, 2011). Given that stubbornness is a quality assessed in the HEXACO measure of agreeableness (Ashton & Lee, 2009), it could be that less agreeable individuals approached training with more perseverance and as a result benefited more from training. Only one other study has attempted to investigate personality factors and dual n-back training related change (Jaeggi et al., 2010), although their study, which found a negative association between conscientiousness and fluid intelligence after dual n-back training, only assessed neuroticism and conscientiousness and did not include a measure of agreeableness. Future investigations may do well to further explore personality as an individual difference that influences working memory training related change.

Although the processing speed training group was intended as an active control group and therefore no specific hypotheses were generated regarding training related improvement, this sample demonstrated an individual difference worth mentioning. In measures of processing speed, trainees with lower estimated intelligence at baseline benefited more from processing speed training than those with higher estimated intelligence. Of note is that the measure used to estimate baseline intelligence did not include a processing speed task. In some measures of intelligence (e.g., Wechsler, 2008a; Wechsler, 2008b), processing speed is considered a component of general intelligence. For example, intelligence quotient is calculated based on the combined index scores of separate working memory, perceptual reasoning, verbal reasoning, and processing speed measures. However, other theories view processing speed as more systemic, intermingled into all aspects of intelligence (Kail, 2000). Hence, an interesting question to explore in response to our finding is whether general intelligence (rather than fluid intelligence specifically) exhibits change after processing speed training in healthy adults.

The overall findings of this study are situated midway between literature clearly indicating near and far transfer and literature undoubtedly lacking near or far transfer effects after dual n-back training. The effects found, although not as robust as hypothesized, remain noteworthy. There are many potential reasons for the blunted effects relative to studies more strongly demonstrating the benefits of training. One potential reason for the tentative finding is that healthy middle aged individuals may simply not have as much room to improve as other populations, such as clinical populations or older adults already experiencing declines. However, the finding that working memory and fluid intelligence abilities improve after dual n-back training in middle-aged adults remains important because it demonstrates that improvement is not limited to the younger (e.g., under 25) or older (e.g., over 65) groups typically studied. Rather, improvement can occur throughout the aging trajectory. Furthermore, although the purpose of this study was not to prevent age related decline, it is reasonable to assert that improving cognitive abilities at the earliest stages of cognitive decline may delay or attenuate such declines. Based on our findings, we encourage randomized, longitudinal studies to elucidate potential preventative effects of cognitive training on natural age-related decline.

Two further factors that may have influenced cognitive outcomes after training are the location and timing of training. This study was designed to be ecologically valid in that participants trained online at a time and location of their choosing, rather than in a laboratory environment. Although participants were asked to choose a training time and location in which they would not be disturbed, interruptions or other factors present in their environment may have impacted training. However, the same effects would have been present in both training conditions. Of note, additionally, is that the processing speed group, on average, spent more time training than the working memory group. Perhaps if the working memory group spent more time training, transfer effects would have been stronger. This discrepancy between groups in time spent training may suggest differences between training groups in training enjoyment, such that those who enjoyed training trained longer.

In line with the idea that one training program may have been more enjoyable than the other, is the observation that more working memory trainees than processing speed trainees withdrew from this study. It could be that working memory participants found the dual n-back training task too difficult or frustrating to truly push their limits and expand their abilities. It is possible that increasing the difficulty of the task immediately after the participant performs well prevents a motivating sense of achievement. In other words, the participants' triumph after a difficult task is rewarded with an even more difficult task. As noted in the mismatch model of cognitive plasticity, if a training task is too difficult, the trainee may become overwhelmed and give up (Lövdén et al., 2010). It is possible that the dual n-back training program utilized in this study progressed too quickly in difficulty. Future studies may consider including either a quantitative or qualitative assessment of perceived dual n-back training task difficulty throughout the training process.

In sum, the present study suggests that dual n-back working memory training, when administered in a natural web-based (as opposed to laboratory) environment, results in both near and far transfer of training related gain in healthy adults. However, statistical results are not as robust as desired when the working memory training group is directly compared to a processing speed training group. Individual difference such as personality likely had an impact on the effects, although further investigation is warranted to dissect the influence of individual factors on training related change. Further, methodological decisions such as the amount of time participants have to complete matrix-based tasks of fluid intelligence, the amount of time working memory trainees spend training relative to comparison groups, and the inclusion of measures of frustration or perceived difficulty regarding the n-back training task may enlighten future studies.

4.1 Limitations

The most notable limitation of the present study is the inability to statistically control for practice effects. Although both training groups were expected to improve across time in all measures due to practice, we hypothesized that the working memory group would improve relative to the processing speed group in measures of working memory and fluid intelligence. Had such an interaction between time and group been present in the cognitive measures, a strong claim could be made that working memory training improved working memory and fluid intelligence abilities beyond the practice effects experienced by both groups. However, Cohen's *d* effect sizes were reported and indicate medium and large effects of working memory training on working memory outcomes, and small effects of processing speed training on working memory outcomes. It is conceivable that the small effect represents the practice effect. This suggestion is supported by the effect sizes of the interactions which favour working memory training relative to processing speed training for improved working memory and fluid intelligence task performance.

An additional limitation is that multiple comparisons were performed, specifically, separate analyses within each training group for each cognitive measure. Multiple comparisons may have inflated the likelihood of detecting a training effect in each group. It is possible that with a larger sample size, the differential impacts of the two training programs may be more clearly revealed even after controlling for multiple comparisons. Future studies should include a larger sample and both an active and no-contact control condition in order to statistically account for practice effects.

4.2 Conclusion

Findings from this study point to the tentative conclusion that dual n-back working memory training, when studied under rigorous methodological controls (i,e., utilizing randomization, blinding, and an active control group) yet in an ecologically valid manner, is effective at generating near and far transfer of working memory training related gain. Such findings are exciting as this is the first study to explore transfer of dual n-back training to middle age-ranged adults, a population particularly interested in not only enhancing their cognitive abilities, but preventing or slowing potential future cognitive declines as they move through the aging trajectory. Intelligence and its components (e.g., working memory) have practical and psychosocial benefits in every-day life and are associated with enhanced overall quality of life (Gottfredson, 1997; Gottfredson & Saklofske, 2009). Hence the prospect of enhancing intelligence through working memory training is enticing. However, given that the results of the present study were not robust, caution is recommended regarding dual n-back training related claims, and additional exploration is warranted into factors associated with training related change.

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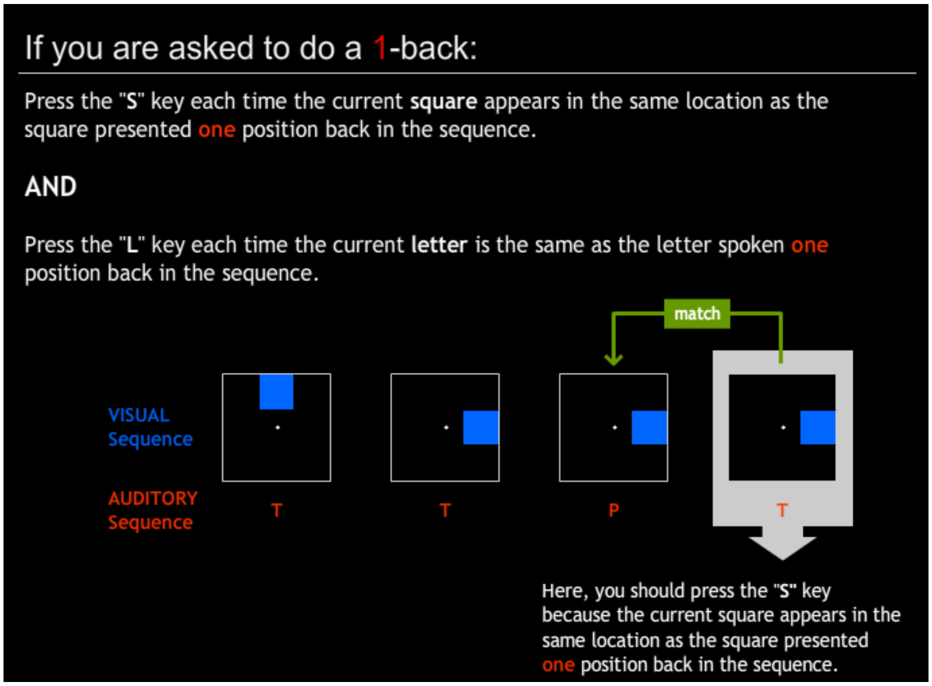
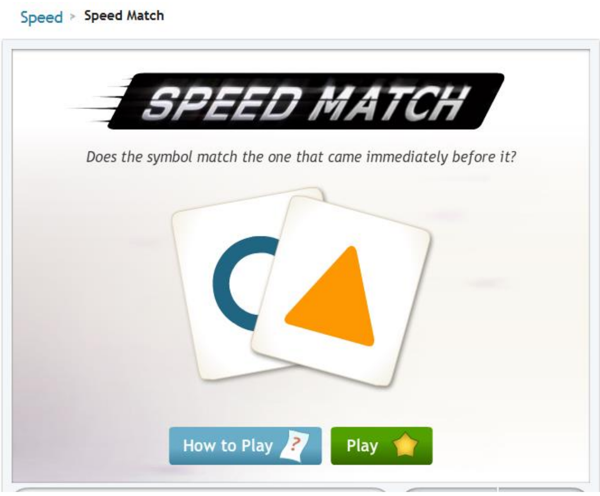
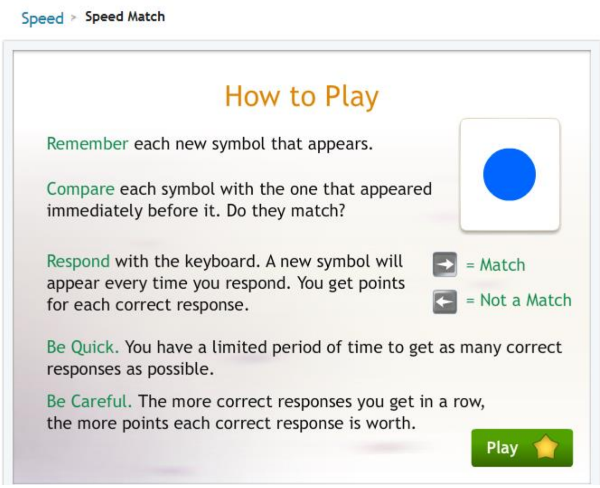
Appendix A: Training Tasks

Example of Dual N-back Working Memory Training Task



Example of a Processing Speed Training Task





From Lumos Labs, 2009

Appendix B: Questionnaires

Demographic Information

1. **Gender:** Male / Female

2. **Birth date:** __day__ /__month__/__year__

3. **Self Identified Ethnic Origin**: ____________________________

4. **Is English your primary language?** Yes / No
   If no, are you able to speak, read, and write fluently in English? Yes / No

5. **Current Marital Status** (circle one number):
   1 = Single (never married)
   2 = Married
   3 = Common-Law
   4 = Divorced (not remarried)
   5 = Widowed
   6 = Other: _______________please briefly describe _____________

6. **Current employment status** (circle one number):
   1 = Full-time paid work outside the home for an organization
   2 = Full-time paid work for self-owned business (self-employed)
   3 = Part-time (less than 30 hours / week) paid work outside the home for an organization
   4 = Part-time (less than 30 hours / week) paid work for self-owned business (self-employed)
   5 = Not currently employed but looking for work
   6 = On temporary leave but planning to return to employment (leave type: ______________)
   7 = Full-time parent / homemaker
   8 = Retired
   9 = Other: _______________please briefly describe _____________

7. **What is your present occupation?** ____

8. **Total Years of Education**: ______
(Including elementary, secondary, high school, technical, and university)

9. **Highest level of education completed** (circle one number):
1 = Less than grade 8
2 = Grade 8
3 = Grade 12
5 = Some college / technical school
6 = College / technical school
7 = Some university
8 = Undergraduate Degree
9 = Master's degree
10 = Ph.D.
11 = Other: ______________please briefly describe ____________

10. Annual Income: Average annual household income in past 5 years (circle one number):
(Gross income based on tax returns.)

1 = Under $10,000
2 = $10,000 – $20,000
3 = $20,000 – $30,000
4 = $30,000 – $50,000
5 = $50,000 – $95,000
6 = $95,000 and up

Health Information

11. Are you aware of any complications that occurred during your birth? Yes / No
If yes, describe:

12. Have you ever suffered from a concussion? Yes / No
If yes, date of concussion: ___Month__ / __Year___
Treatment received:

13. Have you ever suffered from any other form of head trauma? Yes / No
If yes, type of trauma:
Date of trauma: ___Month__ / __Year___
Treatment received:

14. Have you ever suffered from a brain fever? Yes / No

15. Have you ever been diagnosed with a neurological illness? Yes / No
If yes, type of illness:

16. Have you ever been diagnosed with a psychiatric illness? Yes / No
If yes, type of illness:

17. Do you now, or have you in the past three months, used benzodiazepines? Yes / No

18. Do you now, or have you in the past three months, used illicit drugs (e.g., narcotics, stimulants, depressants / sedatives, hallucinogens, cannabis). Yes / No

19. Do you currently have difficulties with your vision or hearing? Yes / No
If yes, please describe:

20. Do you currently have a cardiovascular condition or breathing problems? Yes / No
If yes, please describe:

Please list any current medical or psychological conditions you have been diagnosed with, the approximate date of diagnosis, and what current treatments you are receiving (if any).

Diagnosis:	Date of Diagnosis:	Current Treatment:
e.g. Hypertension	November 1997	Eprosartan, 600mg once daily

Please list any other medications, vitamins, dietary supplements, and herbs you are currently taking (including dosage / frequency).

Medication / Vitamin / Supplement / Herb:	Taking since:	Current Dosage / Frequency:
e.g. St. John's Wort	January 2008	One 300 mg pill twice daily

Please list any complementary therapies you have used in the past month, when you began using that therapy, and the frequency of use.

Examples of complementary therapies: meditation, acupuncture, acupressure, chiropractic, relaxation therapy, spiritual healing (e.g. Reiki, Distance), reflexology, yoga, massage, homeopathy, prayer, naturopathy

Complementary therapy:	Using since:	Frequency:
e.g. Massage therapy	June 2010	Once every two months

Please list any psychological therapies you have used in the past month, when you began using that therapy, and the frequency of use.

Examples of psychological therapies: individual counseling or therapy, group therapy, couple/family counseling or therapy, hypnosis, behavior therapy, self-help books.

Complementary therapy:	Using since:	Frequency:
e.g. Marriage counseling	July 2011	Once per month

Cognitive Training Experience:

Do you currently, or have you in the last six months, used a computerized “brain training”, “brain fitness”, “brain exercise”, “brain gym” or “cognitive training” programs or exercises?

Examples of these programs include Brain Age, Brain Metrix, Cogfit, Cogmed, Lumosity, PositScience.

Please list any computerized cognitive training programs or exercises you have used regularly in the last six months. If you are not sure if a computer game you play is considered a part of cognitive training or a mental exercise please list it anyway.

Exercise:	Program:	Frequency:
e.g. Triangle Math	Nintendo Brain Age	Once a week since May 2012

Pittsburgh Sleep Quality Index (PSQI)

INSTRUCTIONS: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the **past month**. Please answer all questions.

During the past month, what time have you usually gone to bed at night?
BED TIME: _______

During the past month, how long (in minutes) has it usually taken you to fall asleep each night?
NUMBER OF MINUTES: ________

During the past month, what time have you usually gotten up in the morning?
GETTING UP TIME: __________

During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed).
HOURS OF SLEEP PER NIGHT: ________

For each of the remaining questions, check the one best response. Please answer all questions.

During the past month, how often have you had trouble sleeping because you …

Cannot get to sleep within 30 minutes

not during the past month _________	less than once a week ________	once or twice a week _________	three or more times a week ________

Wake up in the middle of the night or early morning

not during the past month _________	less than once a week ________	once or twice a week _________	three or more times a week ________

Have to get up to use the bathroom

not during the past month _________	less than once a week ________	once or twice a week _________	three or more times a week ________

Cannot breathe comfortably

not during the past month _________	less than once a week ________	once or twice a week _________	three or more times a week ________

Cough or snore loudly

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

Feel too cold

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

Feel too hot

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

Had bad dreams

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

Have pain

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

Other reason(s), please describe ____

How often during the past month have you had trouble sleeping because of this?

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

During the past month, how would you rate your sleep quality overall?

Very good _____ Fairly good _____ Fairly bad _____ Very bad _____

During the past month, how often have you taken medication (prescribed or "over the counter") to help you sleep?

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

not during the past month ________	less than once a week ________	once or twice a week ________	three or more times a week ________

During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

no problem at all________	only a very slight problem ________	somewhat of a problem ________	a very big problem ________

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Profile of Mood States-Short Form:

Below is a list of words that describe feelings that people have. Please read each one carefully. Then circle ONE number corresponding to the adjective phrase which best describes HOW YOU HAVE BEEN FEELING DURING THE **PAST WEEK** INCLUDING TODAY.

Not at all	***A Little***	***Moderately***	***Quite a Bit***	***Extremely***
0	***1***	***2***	***3***	***4***

1.	Tense	0	1	2	3	4
2.	Angry	0	1	2	3	4
3.	Worn-out	0	1	2	3	4
4.	Unhappy	0	1	2	3	4
5.	Lively	0	1	2	3	4
6.	Confused	0	1	2	3	4
7.	Peeved	0	1	2	3	4
8.	Sad	0	1	2	3	4
9.	Active	0	1	2	3	4
10.	On edge	0	1	2	3	4
11.	Grouchy	0	1	2	3	4
12.	Blue	0	1	2	3	4
13.	Energetic	0	1	2	3	4
14.	Hopeless	0	1	2	3	4
15.	Uneasy	0	1	2	3	4
16.	Restless	0	1	2	3	4
17.	Unable to concentrate	0	1	2	3	4
18.	Fatigued	0	1	2	3	4
19.	Annoyed	0	1	2	3	4
20.	Discouraged	0	1	2	3	4
21.	Resentful	0	1	2	3	4
22.	Nervous	0	1	2	3	4
23.	Miserable	0	1	2	3	4
24.	Cheerful	0	1	2	3	4
25.	Bitter	0	1	2	3	4
26.	Exhausted	0	1	2	3	4
27.	Anxious	0	1	2	3	4
28.	Helpless	0	1	2	3	4
29.	Weary	0	1	2	3	4
30.	Bewildered	0	1	2	3	4
31.	Furious	0	1	2	3	4
32.	Full of pep	0	1	2	3	4
33.	Worthless	0	1	2	3	4
34.	Forgetful	0	1	2	3	4
35.	Vigorous	0	1	2	3	4
36.	Uncertain about things	0	1	2	3	4
37.	Bushed	0	1	2	3	4

HEXACO-PI-R

(SELF REPORT FORM)

DIRECTIONS

On the following pages you will find a series of statements about you. Please read each statement and decide how much you agree or disagree with that statement. Then write your response in the space next to the statement using the following scale:

5 = strongly agree
4 = agree
3 = neutral (neither agree nor disagree)
2 = disagree
1 = strongly disagree

Please answer every statement, even if you are not completely sure of your response.

Please provide the following information about yourself.

1 _____ I would be quite bored by a visit to an art gallery.
2 _____ I plan ahead and organize things, to avoid scrambling at the last minute.
3 _____ I rarely hold a grudge, even against people who have badly wronged me.
4 _____ I feel reasonably satisfied with myself overall.
5 _____ I would feel afraid if I had to travel in bad weather conditions.
6 _____ I wouldn't use flattery to get a raise or promotion at work, even if I thought it would succeed.
7 _____ I'm interested in learning about the history and politics of other countries.
8 _____ I often push myself very hard when trying to achieve a goal.
9 _____ People sometimes tell me that I am too critical of others.
10 _____ I rarely express my opinions in group meetings.
11 _____ I sometimes can't help worrying about little things.
12 _____ If I knew that I could never get caught, I would be willing to steal a million dollars.
13 _____ I would enjoy creating a work of art, such as a novel, a song, or a painting.
14 _____ When working on something, I don't pay much attention to small details.
15 _____ People sometimes tell me that I'm too stubborn.
16 _____ I prefer jobs that involve active social interaction to those that involve working alone.
17 _____ When I suffer from a painful experience, I need someone to make me feel comfortable.
18 _____ Having a lot of money is not especially important to me.
19 _____ I think that paying attention to radical ideas is a waste of time.
20 _____ I make decisions based on the feeling of the moment rather than on careful thought.
21 _____ People think of me as someone who has a quick temper.
22 _____ On most days, I feel cheerful and optimistic.
23 _____ I feel like crying when I see other people crying.
24 _____ I think that I am entitled to more respect than the average person is.
25 _____ If I had the opportunity, I would like to attend a classical music concert.
26 _____ When working, I sometimes have difficulties due to being disorganized.
27 _____ My attitude toward people who have treated me badly is “forgive and forget”.
28 _____ I feel that I am an unpopular person.
29 _____ When it comes to physical danger, I am very fearful.
30 _____ If I want something from someone, I will laugh at that person's worst jokes.

Continued…

31 ______ I’ve never really enjoyed looking through an encyclopedia.
32 ______ I do only the minimum amount of work needed to get by.
33 ______ I tend to be lenient in judging other people.
34 ______ In social situations, I’m usually the one who makes the first move.
35 ______ I worry a lot less than most people do.
36 ______ I would never accept a bribe, even if it were very large.
37 ______ People have often told me that I have a good imagination.
38 ______ I always try to be accurate in my work, even at the expense of time.
39 ______ I am usually quite flexible in my opinions when people disagree with me.
40 ______ The first thing that I always do in a new place is to make friends.
41 ______ I can handle difficult situations without needing emotional support from anyone else.
42 ______ I would get a lot of pleasure from owning expensive luxury goods.
43 ______ I like people who have unconventional views.
44 ______ I make a lot of mistakes because I don’t think before I act.
45 ______ Most people tend to get angry more quickly than I do.
46 ______ Most people are more upbeat and dynamic than I generally am.
47 ______ I feel strong emotions when someone close to me is going away for a long time.
48 ______ I want people to know that I am an important person of high status.
49 ______ I don’t think of myself as the artistic or creative type.
50 ______ People often call me a perfectionist.
51 ______ Even when people make a lot of mistakes, I rarely say anything negative.
52 ______ I sometimes feel that I am a worthless person.
53 ______ Even in an emergency I wouldn’t feel like panicking.
54 ______ I wouldn’t pretend to like someone just to get that person to do favors for me.
55 ______ I find it boring to discuss philosophy.
56 ______ I prefer to do whatever comes to mind, rather than stick to a plan.
57 ______ When people tell me that I’m wrong, my first reaction is to argue with them.
58 ______ When I’m in a group of people, I’m often the one who speaks on behalf of the group.
59 ______ I remain unemotional even in situations where most people get very sentimental.
60 ______ I’d be tempted to use counterfeit money, if I were sure I could get away with it.

Appendix C: Cognitive measures

Automated Operation Span task:

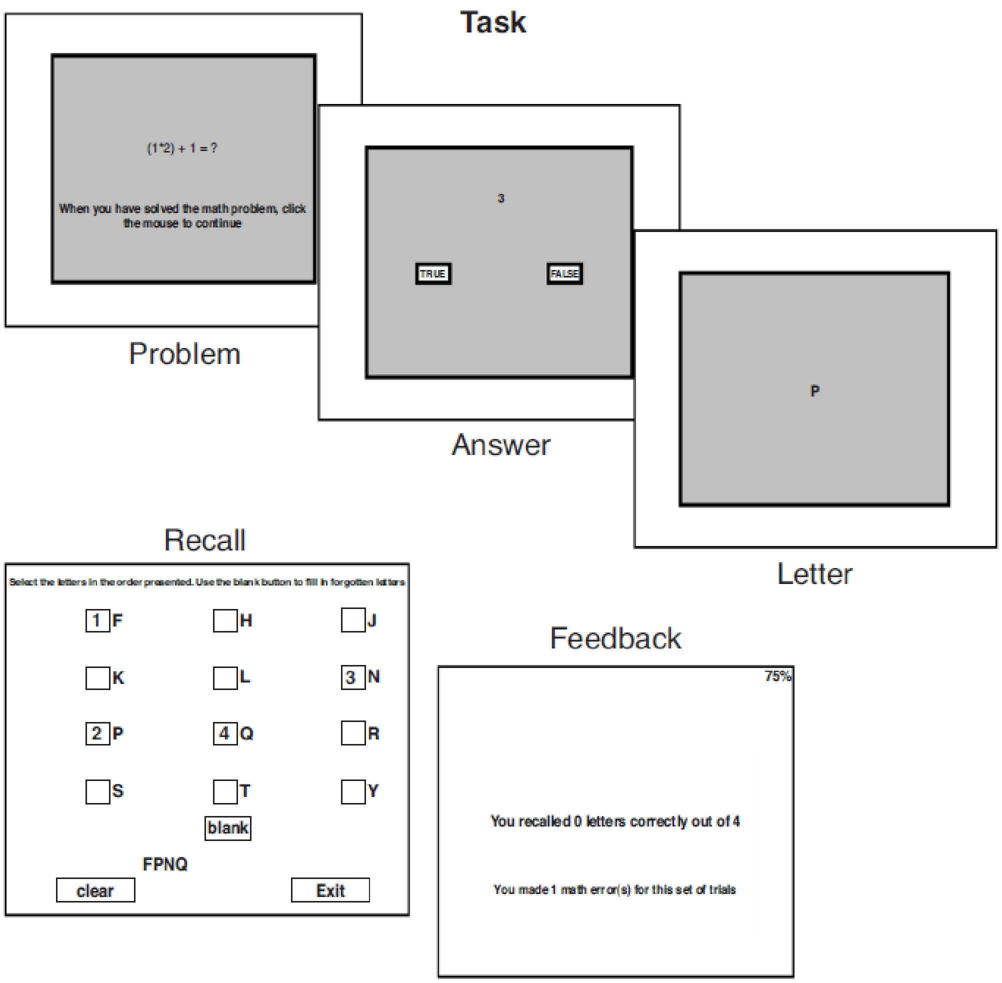
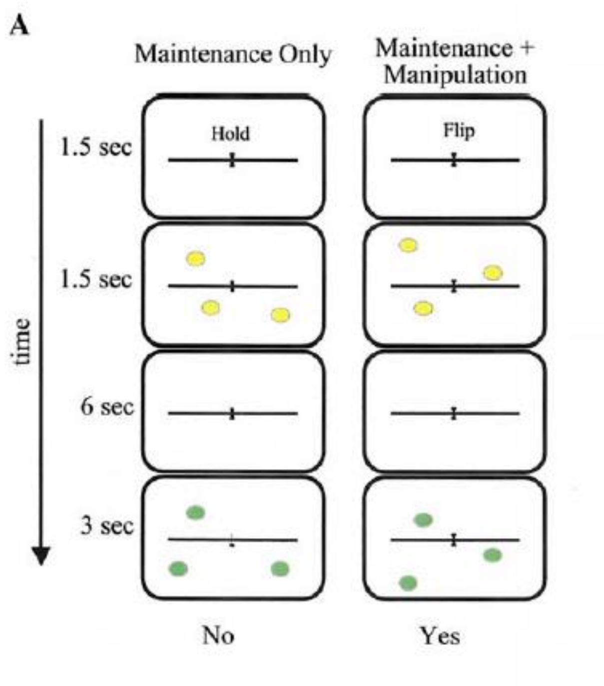


Figure 1. Illustration of the automated operation span task. In the task, first a math operation is presented. After it is solved, participants click the mouse and a digit is presented, which is judged to be either the correct or incorrect answer to the math operation. This is followed by a letter for 800 msec. For recall, the correct letters from the current set are selected in the correct order. After recall, feedback is presented for 2,000 msec.

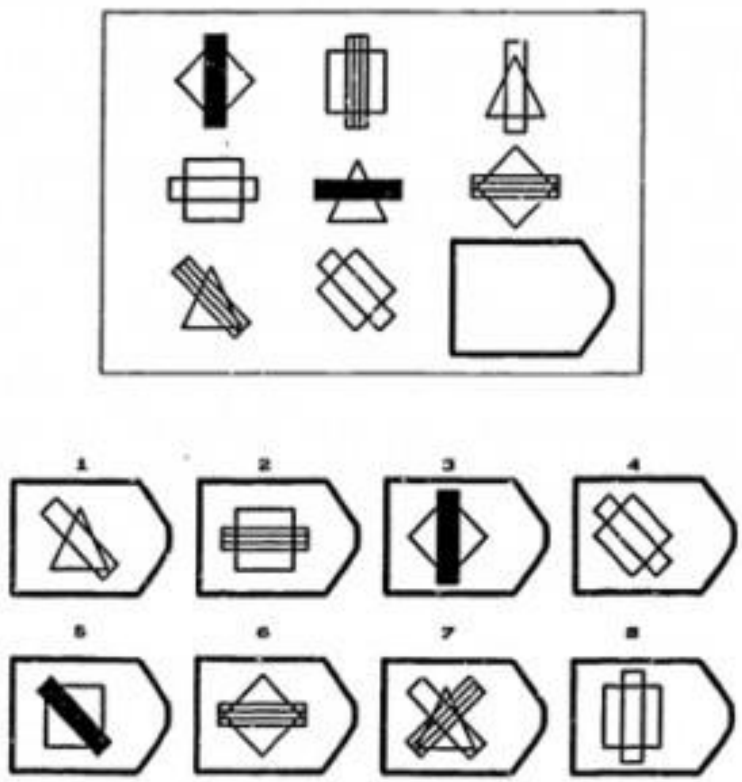
From Unsworth, et al., 2005

Spatial Maintenance and Manipulation task:



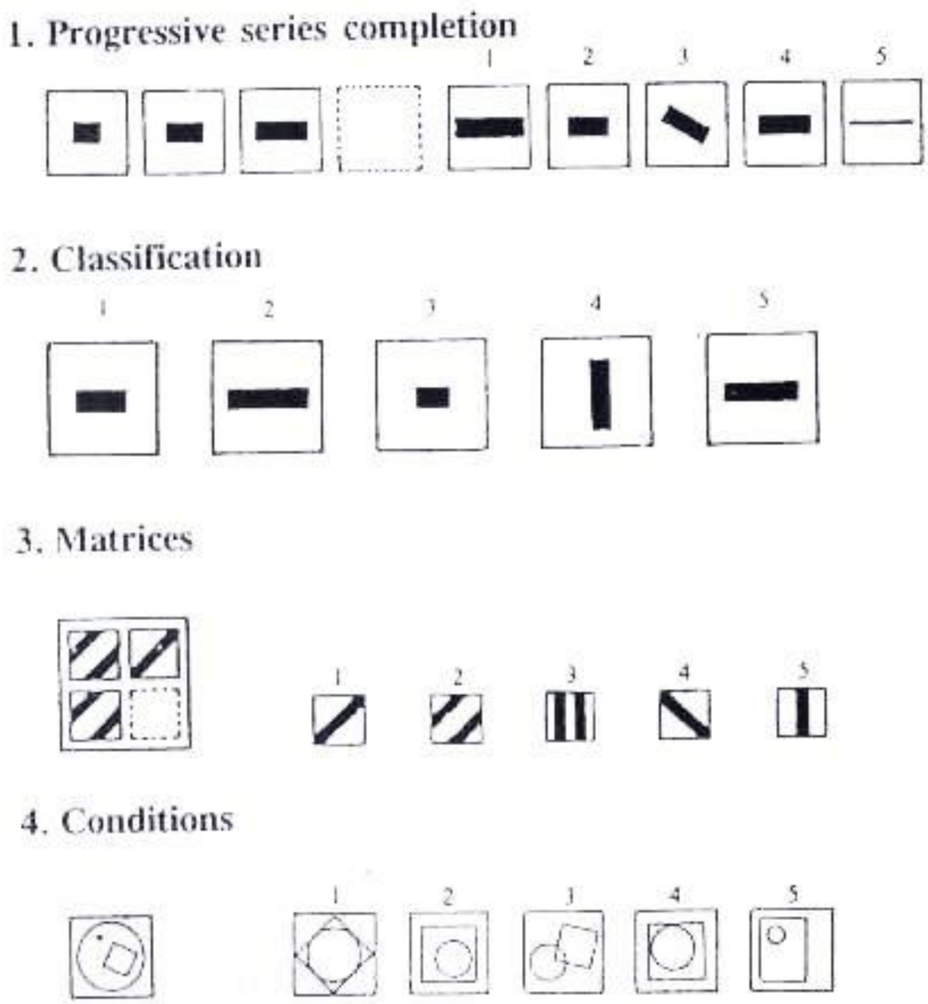
From Glahn et al., 2002

Example of a matrix item as would be found in the Raven's Advanced Progressive Matrices task:



From: http://www.highiqpro.com/iq-brainteasers-puzzles-iq-tests/matrix-iq-brain-teasers

Example items as would be found in the Cattell's Culture Fair Test:



From Cattell & Cattell, 1959

Appendix D: Demographic characteristics and change in cognitive outcomes

Additional exploratory analyses were conducted regarding age and gender as potential demographic characteristics associated with working memory training related change. Working memory training has been associated with improved cognitive task performance in a number of healthy individuals (Beck, et al., 2010; Borella, et al., 2010; Brehmer, Westerberg & Backman, 2012; Gibson et al., 2011; Jaeggi et al., 2008; Jaeggie et al., 2010; Jausovec & Jausovec, 2012; Klingberg et al., 2005; Redick et al., 2012; Rudebeck et al., 2012); however, the 30-60 age range has not been investigated in a dual n-back training context. Regarding gender, differences in cognitive abilities between genders are consistently found, with females more successful in verbal tasks and males more adept at visual-spatial tasks, although no gender differences have been found in dual n-back task performance (Schmidt, Jogia, Fast, Christodoulou, Haldane, Kumari, & Frangou, 2009). To our knowledge, no studies have included gender as a potential predictor of dual n-back training related change.

Analyses

To explore associations between age and change in cognitive outcomes after training, correlations were conducted for all change scores for each training group. To assess the relationship between gender and change in cognitive outcomes after training, t-tests were conducted for all change scores in each training group. All analyses were two-tailed with alpha <.05.

Results

In the working memory training group, correlations revealed a significant association between age and spatial maintenance change scores, suggesting that older working memory trainees experienced more gain in spatial maintenance ability after training than younger trainees, $r = .69$, $p <.001$. Further, males were more likely to improve in Coding scores (mean change score = 8.44, $SD = 3.28$) than females (mean change score 3.07, $SD = 6.56$), $t(21) = 2.27$, $p = 03$.

In the processing speed training group, a significant negative correlation was present between age and Symbol Search change scores, $r = -.68$, $p < .001$, and between age and Coding change scores, $r = -.43$, $p = .02$, suggesting that younger trainees benefited more than older trainees on processing speed tasks. An additional negative correlation emerged between age and CCFT change scores, $r = -.49$, $p < .01$ implying that younger trainees experienced more fluid intelligence gains after processing speed training than older trainees.

Discussion

In this study we explored associations among demographic characteristics (i.e., age and gender) and change in cognitive performance for healthy adults after 5-weeks of either working memory or processing speed training. Associations between age and cognitive outcomes were identified in both training groups, while gender was only related to outcomes in the working memory training group.

Regarding age, older working memory trainees performed better on a working memory maintenance task than younger trainees, suggesting that older individuals may experience more working memory training related benefit. This finding is consistent with literature demonstrating working memory training related change in older adults (e.g., over 65; Borella, Carretti, Riboldi, & De Beni, 2010; Brehmer, Westerberg, & Backman, 2012; Redick et al., 2012), and could explain lack of consistent findings in studies of young adults. An investigation of cognitive abilities across the life span indicated that fluid intelligence abilities peak in the mid-20’s with declines noticeable by the mid-30’s, thus it may be more difficult to induce further cognitive improvements in younger mean populations than older mean populations (Li et al., 2004). It may be that older populations have more room to grow in cognitive ability compared to younger populations already near their peak abilities.

In the processing speed training group, correlations revealed that younger participants benefited more from training than older participants on processing speed tasks as well as one fluid intelligence measure. In a recent investigation using visual speed of processing training in adults over 50, no differences were found in post-training abilities in those aged 50-64, and those above 65, prompting a call for trials of processing speed training in earlier life stages (Wolinsky, Vander Weg, Howren, Jones, & Dotson 2013). It is possible that processing speed training benefits speed of thought in younger individuals.

Regarding gender, male working memory trainees improved more than females in the Coding measure of processing speed. Significant gender differences have been noted for a previous version of this task (Longman, Saklofske, & Fung, 2007) although baseline differences were not revealed in the present sample. In general, males reportedly perform better on speeded tasks requiring physical dexterity (e.g., finger tapping, grooved pegboard) whereas females perform better on paper-pencil copying tasks (Roivainen, 2011). Although speculative, there may be a component of the dual n-back task, such as attending to and remembering spatial positions of blocks, that transfers to enhanced abilities to quickly relate abstract marks to numbers. This finding points to a need for further exploration of gender differences in working memory training related gains in processing speed.

Limitations

A key limitation of the present analysis is multiple comparisons. Given the number of correlations conducted, it is possible that the ability to detect significant relationships was inflated.

Conclusion

In summary, age and gender seem to be associated with changes in cognitive abilities after working memory or processing speed training. Most notably, older working memory trainees improved in working memory performance more than younger trainees, and younger processing speed trainees experienced more gains in fluid intelligence than older trainees. Furthermore, male working memory trainees demonstrated more post-training enhancement on a processing speed task relative to female trainees. Further exploration in this age group is necessary to elucidate who benefits most from what type of training.