COGNITIVE TRAINING WITH CASUAL VIDEO GAMES: THE EFFECTS OF WORKING MEMORY AND REASONING RELATED GAMES ON THE COGNITIVE ABILITIES OF YOUNGER AND OLDER ADULTS

BY

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DISSERTATION

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ABSTRACT

Cognitive functioning can affect one’s performance at work, quality of life and the ability to live independently, hence there are theoretical and practical implications to understanding whether cognitive training is effective, and its effects across the adult lifespan and with individual differences. There is still mixed evidence to suggest that training on a set of tasks could improve or transfer to other tasks and affect cognitive abilities, in addition to methodological limitations that affect the interpretability of many training studies. In this study, we investigated whether 15 hours of training on casual video games can broadly improve cognition by measuring pre and post-training performance on tests of attention, episodic memory, perceptual speed, reasoning and working memory. Groups of younger (Baniqued et al., 2014) and older adults were trained with casual games that were correlated with working memory and reasoning abilities. Younger adults showed better overall performance and more gains for some games at the end of training compared to the older adults. While all participants improved on the trained games, the pattern of transfer was quite sparse and differed between the younger and older adults. The older adults, unlike the younger adults, did not show differential transfer, as a function of the experimental and an active control group, to a divided attention construct. The results provide evidence that while training gains were possible over the adult lifespan, the transfer to divided attention ability appears to be limited, within the limits of the present study (e.g. given training duration, and the constructs represented in the training games) to the younger adults.

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CHAPTER 1: INTRODUCTION

There is a need to understand whether cognitive training is effective, in terms of training, transfer and retention effects, and how it may vary across the adult lifespan and with individual differences. Training or practice effects are observed when one practices on a task and improves on the performance of this practiced task. If this practice results in improvements to other untrained tasks, this is referred to as transfer. Numerous products and websites have in recent years emerged, advertising that training on their computer-based training programs, most of which were deliberately designed to look like entertainment-oriented games, would improve the users' overall cognitive performance. However, there is still mixed evidence as to whether training on a specific set of tasks can generate improvements or transfer to other tasks or to affect cognitive abilities (Boot & Kramer, 2014). Many studies (Kramer, Larish, Weber, & Bardell, 1999; Lussier, Gagnon, & Bherer, 2012; Bherer et al., 2008; Anguera et al., 2013) have shown that cognitive training regimens do develop improvement and transfer, while other studies (Ackerman, Kanfer, & Calderwood, 2010; Lee et al., 2012) however have shown little or no transfer. Researchers (Boot, Blakely and Simons, 2011; Boot, Simons, Stothart, & Stutts, 2013) have also highlighted that there are several methodological limitations plaguing many of such training studies, affecting the interpretability of these already mixed experimental results[1] . Normal aging has been associated with progressive declines in cognitive functions, not just in memory but also in perceptual speed and reasoning (Craik & Salthouse, 2000; Salthouse, 2004). Importantly, Salthouse (2004) showed that age-related differences were evident in early adulthood. Since cognitive functioning can affect one's performance at work, quality of life, and

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[1] See also: http://longevity3.stanford.edu/blog/2014/10/15/the-consensus-on-the-brain-training-industry-from-the-scientific-community-2/

the ability to live independently, the questions of whether cognitive functions can be modified across the adult lifespan and if so, the type of training regimen that is effective are important theoretically and practically.

Below I discuss some theoretical accounts for how training and transfer to untrained tasks could occur (Boot & Kramer, 2014). Firstly, task elements or components of the trained and untrained tasks can be common between the trained and untrained tasks (Thorndike, 1906). If the person practices on a task and improves on it, untrained tasks that rely on these components could benefit. On a similar line of reasoning, transfer was observed between trained and untrained task when these two tasks activated overlapping neural circuits and not for an untrained task that didn't share the overlapping brain area (Dahlin, Neely, Larsson, Bäckman & Nyberg, 2008). Thirdly, the amount of variability in stimuli, responses, and other task components during training has been shown to positively moderate the amount of transfer to untrained tasks (Gopher, Weil, & Siegel, 1989; Schmidt & Bjork, 1992). The variable practice encourages additional information processing activities about the relationship between the task variants, thereby contributing to generalizability at test. Lastly, and related to the first point, is that training could improve certain basic cognitive abilities such that it benefits untrained tasks that rely on the same abilities, such as perceptual speed or attentional control abilities. These theoretical accounts are invaluable in determining the interpretation of the numerous training studies that either showed or did not show transfer effects, as well as guiding the design of novel studies.

The literature concerning whether training can transfer to untrained tasks is a complex and mixed one. In general, such transfer is limited and rare. Improvement in trained tasks due to practice is generally attainable, and retention of these improvements to practiced tasks has also been shown to be achieved (Gopher et al., 1989; Kramer et al., 1999; Bherer et al., 2008; Boot et al., 2010; Lee et al., 2012; Anguera et al., 2013). In a recent study, Lee and colleagues (2012) trained two groups of young adults in a game (Space Fortress) that was designed for psychology research on training and transfer, and retested these groups seven months after training. When compared to the control group which did not have any training, the treatment groups showed retention of their game performance over this time period. Anguera and colleagues (2013) trained older adults in a dual-task game (Neuro Racer). After 12 hours of training, this older adults group performed at similar levels to the untrained younger adult group, and they found that this dual-task benefit persisted for six months.

Other training studies found transfer to both structurally similar (near) and dissimilar (far) tasks (Karbach and Kray, 2009). Using task-switching and dual-task paradigms, these studies found transfer beyond stimulus type (e.g. images of vehicles, fruits and animals), input (e.g. visual and auditory) and response modalities (e.g. keyboard keys, steering wheel and brake pedal)(Karbach & Kray, 2009; Bherer et al., 2008; Lussier et al., 2012). Karbach and Kray (2009), using a task-switching training paradigm found far transfer to basic cognitive functions of executive processes of inhibition, verbal and spatial working memory, and fluid intelligence.

Video games have been used to investigate training effects in multi-tasking and other cognitive functions (Gopher, 1989, 1999; Basak, Boot, Voss & Kramer, 2008; Boot, Kramer, Simons, Fabiani & Gratton, 2008; Ackerman, Kanfer and Calderwood, 2009; Boot et al., 2010; Lee et al., 2012; Strobach, Frensch & Schubert, 2012). Findings and claims using video games training have been mixed, and sometimes affected by the lack of an appropriate control condition that offers a baseline of equal motivation and expectation effects from which to compare against the treatment conditions. Unlike the earlier mentioned pure task-switching and dual-tasking paradigms, video games may contain a mixture of multiple paradigms or tasks, and depending on the type of game, may also contain other elements such as planning, decision making, working memory and fluid intelligence. Researchers using commercial entertainment-oriented first-person shooter games have claimed perceptual and attentional changes due to prolonged game play or training (Green & Bavelier, 2003, 2006, 2007). Other researchers have used commercial games that were more oriented to multi-tasking and executive control, and expanded on the range of performance measures used to track changes to other cognitive processes such as task-switching, dual-tasking and working memory. One such study (Basak et al., 2008) trained a group of older adults using Rise of Nations strategy game and found improvements in task-switching and working memory (and visual short-term memory and reasoning) when comparing the treatment to the no-training control group.

Another study (Boot et al., 2008), testing younger adults, did not find any strong evidence of transfer when they compared four groups trained with different game types or no game [Rise of Nations (strategy), Medal of Honor (first-person shooter), Tetris (active control) or no game (no-training control) group]. As these studies used subjects of different age cohorts, it is conceivable that age could be an important factor in training and transfer effects. Ackerman, Kanfer and Calderwood (2010) had older adults undergo Nintendo Wii’s Big Brain Academy game sessions and domain knowledge reading sessions for 20 hours each, and also did not find transfers to or changes in basic cognitive abilities such as crystalized and fluid intelligence and processing speed except from practice effects on 6 of their 10 ability tests administered pre- and post-training. This study highlighted at least two important points; transfer may be domain specific, and that re-test effects have to be taken into account.

Next, I will describe studies that used the Space Fortress game as a training tool. Space Fortress is a complex video game designed by cognitive psychologists as a research tool to study learning and training strategies. It incorporated diverse task demands such as memory, visual attention, manual and executive control within the gameplay. In an older study, Gopher, Weil and Bareket (1994) reported an instance of far transfer of attentional control training using the Space Fortress game, where military pilot trainees who underwent the two versions of variable priority training strategies performed better at flight school compared to those who did not train with Space Fortress (non-active control). Variable priority training is an attentional control training strategy that practices the whole task but focuses the trainee's attention on specific components of the task at different times. This contrasts with fixed priority strategy that does not require the trainees to shift the distribution of their attention, and traditional part-task training in which task components are practiced separately (Gopher, Weil & Siegel, 1989; Gopher, Weil & Bareket, 1994; Kramer, Larish, & Strayer, 1995; Kramer et al., 1999; Bherer et al., 2008; Boot et al., 2010; Lee et al., 2012). Other training studies using the Space Fortress game as a tool have found improvements to trained tasks but limited support for broader transfer. To further investigate the training and transfer effect of variable priority training with the Space Fortress game, Boot and colleagues (2010) tested young adults with a battery of cognitive and psychomotor tests before and after 20 hours of training. They found transfer specific to tasks with very similar components to those in the game itself (dual-task manual tracking and Sternberg memory tests), and limited support for broader transfer of variable priority training. Lee and colleagues (2012) included a non-active control group which took account of the history and re-test effects, and reported evidence reinforcing the domain specificity of transfer. They replicated the superior effects of variable over fixed priority training on task-specific improvements, but found no transfer to the battery of cognitive and psychomotor tests, even for the dual-task manual tracking and Sternberg memory tests, both of which had clear similarities with the Space Fortress tasks.

Literature on the potential age differences in training and transfer suggest that both younger and older adults would be likely to improve on the trained task, and if there is any transfer to untrained task, it is more likely for younger than for older adults. Studies involving both younger and older adults revealed that older adults often showed less absolute gains than younger adults (Dahlin et al., 2008; Karbach and Kray, 2009; Heinzel et al. 2014), and one study showed more relative gains for older adults (Dahlin et al., 2008). Studies that had transfer effects tend to show domain specificity, in that transfer effects were specific to tests similar to the trained task (Kramer et al. 1995, 1999; Bherer et al., 2008; Dahlin et al., 2008; Li et al., 2008; Lussier et al., 2012; von Bastian, Langer, Jäncke & Oberauer, 2013), and mostly for younger than older adults (Dahlin et al., 2008; von Bastian et al., 2013), though there were exceptions showing transfer for both age groups (Li et al., 2008; Karbach and Kray, 2009; von Bastian et al., 2013) and to other dissimilar constructs or far transfer (Karbach and Kray, 2009). In general, older adults benefit from cognitive training, with training effects relatively specific to the processes being trained. One important exception is the training of mechanisms such as executive functioning and working memory (Hertzog, Kramer, Wilson and Lindenberger, 2008), which may have transfer effects that are further, rather than specific.

Working memory is a dynamic memory system that is crucial in situations where attention must constantly shift between sources of information, and consists of several cognitive mechanisms such as active maintenance and updating of specific goals and information under distraction. Hence there is a focus on training working memory, as improvements to working memory by extension should benefit many other abilities and impact daily cognitive functioning (Shipstead, Hicks & Engle, 2012). A study (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) that showed impressive transfer to fluid intelligence measures trained their participants with dual n-back paradigm (visuo-spatial and auditory). The authors noted that gains in fluid intelligence were not related to pre-existing individual differences and gains in working memory capacity, but to the amount of training under the dual n-back paradigm. Hence they suggested that dual-tasking ability could also be influencing the measures of fluid intelligence. However, other studies (Redick et al, 2013; Thompson et al., 2013) could not replicate the effect of working memory training on fluid intelligence, and the current conclusion is that either the effect may be small and/or fragile, or that important but unknown moderators exist that determines who benefits from this type of training on transfer (Boot & Kramer, 2014). Other studies (Dahlin et al., 2008; Li et al., 2008; von Bastian et al. 2013) trained groups of younger and older adults with components of working memory such as updating and relational integration. They all found practice-related improvements for both groups but different transfer effects. Li and colleagues (2008) found limited transfer and no difference between the transfer effects of the younger and older adult groups. Dahlin and colleagues (2008) found limited transfer to the n-back task only for younger adults. Von Bastian and colleagues (2013) found both groups transferring to one of three near-transfer task (verbal complex span), and weak intermediate-transfer (binding) for younger adults group only. The trend seemed to be generally limited transfer effects, and further transfer for younger than older adults if any, which is consistent with the idea that younger adults have more plasticity (Hertzog et al., 2008). Also, only the last of these studies used active control groups, although they did not measure whether expectancies between the experimental and control groups were not different.

Baniqued and colleagues (2014) used a variety of casual video games to train cognitive functions such as working memory and reasoning on young adults (18-30 years old) who reported as being non-gamers (played less than three hours of games per week for the last six months). Casual games are a category of video games that are widely and mostly freely available on the internet. They are entertaining, relatively simple to learn and play, have short play times, and tap a range of skills in a more complex environment compared to typical laboratory neuropsychological tests. Being integrative in nature, casual games are suited for use as active control together with the treatment groups. A list of games was selected via task analysis, and validated through Principal Component Analysis (PCA) to form groups of games that varied on their correlation with neuropsychological and cognitively derived domains of working memory and reasoning (in the form of latent variables), amongst other domains such as processing speed, attention and episodic memory (Baniqued et al., 2013). The use of multiple games in each group was to discourage task-specific mastery, promote cognitive flexibility and lead to greater and broader learning (Kramer et al., 1995, 1999; Schmidt & Bjork, 1992). Two experimental groups were trained with games highly correlated (correlation coefficients of 0.3 to 0.5) with working memory and reasoning (WM-REAS) latent constructs - one with games that were mostly not adaptive across sessions (WM-REAS 1), and the other with games that were adaptive across sessions (WM-REAS 2). Across-session adaptive games here meant that the participants started their new training session at the level they stopped at on the previous session, and non-adaptive games meant that they started at the first level at every training session, regardless how well they did at their previous training session. The active control group was trained with games that were least correlated (non-significant correlation coefficients to around 0.25) with working memory and reasoning constructs. And the no-contact control group received no training but received the same pre and post-tests as the other groups. Subjects' expectations for improvement on transfer tasks were assessed through a survey upon the completion of the post-training tests. Using an extensive battery of neuropsychological tests spanning over the categories of reasoning (or fluid intelligence, gF), working memory, episodic memory, perceptual speed and attentional control, they found differential transfer in favor of the WM-REAS groups limited to a divided attention construct. The tests that comprised the divided attention construct were Trail-Making, Attentional Blink and an attention-demanding game called Dodge (Armor Games). Another important finding was that those in the experimental groups with low reasoning ability before training showed larger gains in this divided attention construct.

This study provided insights to the mixed literature of training and transfer, and a good basis for a comparative study between young and older adults to help us understand the big question about the effectiveness of cognitive training across the adult lifespan. This methodology took into consideration some of the methodological limitations that affected previous training studies. Assessment of transfer at the latent construct level improved interpretability of results (Redick et al., 2013; Schmiedek, Lövdén, & Lindenberger, 2010), through the use of multiple well-normed tests which better assess whether there was broader transfer to the related cognitive ability than single tests, as improvements to single tests may be due to task-specific improvements rather than wider improvement to the cognitive ability. Then by measuring a range of cognitive abilities, the extent and degree of transfer effects could be better understood. By comparing the experimental group with an active control group, influence due to social contact with the experimenters and other participants could be accounted for, in addition to retest and history effects that are accounted for by comparisons with a no-training control group (Boot et al., 2011, 2013). The experimental and active control groups' expectations of improvement due to their training intervention were measured, thereby having the means to account for any differential motivation and expectations (placebo effects). Multiple training tasks were used to promote broader learning and discourage training of task-specific mastery. The training tasks might produce fewer problems with adherence to the training regimen (especially for an older adult), motivation and engagement, as they were games that were simple, short, entertaining and had increasing difficulty incorporated.

In the current study, we replicated Baniqued et al. (2014) training and test methodology on a matched sample size of older adults between 60 and 85 years old. Additional eligibility criteria due to age-cohort difference included checks for cognitive impairment and neurodegenerative diseases such as Alzheimer's and Parkinson's. There was an experimental and an active control group, matching the experimental group of WM-REAS 1 and the active control group from Baniqued et al. (2014) study. The data from this previous study were combined with this current study to investigate the differences in transfer effects between younger and older adults when they were trained with casual games that are highly correlated with working memory and reasoning. Specifically we asked the following questions, 1) Are gains to the training games different for the older adults compared to the younger adults? 2) Do older adults show the same pattern for transfer as the younger adults (differential gain only in divided attention ability)? 3) Are the gains to the training games correlated with gains at transfer? The main predictions were that older adults would improve on their trained casual games, but show less or no transfer to untrained tasks compared to the younger adults. This would support the theory that while cognitive gains are still possible with older adults, the benefits are limited to trained tasks, and transfer to untrained tasks if any are less for older than younger adults (Dahlin et al., 2008; von Bastian et al. 2013), showing that neural plasticity of older adults is more limited than younger adults (Dahlin et al., 2008).

In summary, the aim of this study was to provide evidence for the larger question of whether cognitive training and transfer is similar across the adult lifespan. More specifically, we investigated the effects of memory and reasoning training through playing casual video games on the cognitive abilities of younger and older adults. To ensure the results are robust, this study used a wide range of well-established psychological tests, with multiple tests (Ackerman et al. 2010) for each cognitive construct that was measured. A reasonably sizeable sample size (40 per group) was used, and an active control group was included to assess potential expectation and placebo effects. Casual games were used as training tasks because they were entertaining, pervasive, integrative in nature and hence suitable for active control, and the use of multiple games might lead to greater and broader learning. Transfer effects were found limited to divided attention ability in the previous study with younger adults, and we replicated the training and test methodology on a size-matched sample of older adults. Findings from this study contribute to our understanding of whether cognitive functions can be modified across the adult lifespan, how the effects might differ across age cohorts, and under which training regimen and conditions this be might be effective.

CHAPTER 2: METHODS

2.1 Participants

Participants were recruited from the Champaign-Urbana community through contact lists from previous experiments, flyers, printed and online newspaper postings advertising participation in a “cognitive training study” for older adults. Applicants were first screened via phone or email with a pre-screening survey that collected basic demographic information (e.g. age, sex, education, English language proficiency), and time spent playing video and board games. This survey was similar to the one used for the younger adult study, and was modified to suit the older adults (e.g. past/current occupation rather than field of undergraduate studies). The purpose of the questions regarding video game playing behavior was masked by embedding them with other lifestyle and activity questions that include the Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1997). Importantly, because we wanted to recruit as many participants as possible, extensive video game experience was not used as one of the exclusion criteria at this point in this study. If not excluded based on the survey, a phone interview was conducted to check for medical and non-medical conditions that may affect neuropsychological testing. This interview also included a TICS-M (Telephone Interview for Cognitive Status-Modified; Welsh, Breitner and Magruder-Habib, 1993) section to screen for dementia and mild cognitive impairment. A total of 387 older adults were contacted for the study, 134 were qualified at pre-screening, of which 101 were completed the study (Figure 1). After removing participants with extensive game experience or played the selected games outside study time, the final set of 86 older adults participants were entered into analysis. They were (1) between the ages 60 and 80, (2) had normal, or corrected-to-normal color vision and hearing, (3) right-handed, (4) had no medical or psychological condition that affects the central nervous system,

(5) not taking any medications that affect the brain, (6) reported playing video for 3 h or less per week in the last 6 months, and (7) not involved in other cognitive or fitness training related studies in the past 2 years. Table 1 shows the final participants' demographics. Older adult group showed higher years of education [$F(1,167) = 16.778$, $p < 0.001$, $\eta_p^2 = 0.983$], compared to the younger adult group [mean of 16.345 (0.264) and 14.828 (0.260) respectively (with standard error in parentheses)]. All participants signed an informed consent form approved by the University of Illinois Institutional Review Board. Upon study completion, participants were paid $15 an hour for laboratory visits. Participants who drop out or disqualified were paid $7.50 an hour.

2.2 Study design

All older adult participants underwent four cognitive assessment (testing) sessions in the same session and task order as that of the younger adult study (Table 2). Testing sessions were separated by alternating days to allow rest between sessions, with no more than a week's rest between any sessions. Participants were randomly assigned to one of two groups: experimental group (WM-REAS) which trained on games highly correlated with working memory and reasoning, and active control which trained on games that least correlated with working memory and reasoning. These two groups corresponded to the WM-REAS 1 and active control groups of the younger adult study. Participants were not informed of the rationale for this group assignment, and lab personnel were not blind to group assignment. All participants completed training sessions two to three times per week, for a total of 10 sessions. During each training session four games were played in pre-determined randomized order, with each game played for approximately 20 minutes each. The order of the games in each training session was the same randomized order as that for the younger adult study. Both the WM-REAS and active control groups would complete the same testing sessions in reverse session order (same as younger adult study), as soon as the next day to within a week after training was completed.

2.3 Cognitive assessment

Assessments administered before and after training were grouped into five categories: reasoning/fluid intelligence (gF), perceptual speed, episodic memory, working memory, and divided attention. In addition, two casual video games (one reasoning, one attention related; both validated in Baniqued et al. (2013) and used in Baniqued et al. (2014)) which were not used as training games, were played as part of the assessment battery. Participants also completed a series of surveys, including the Behavior Rating Inventory of Executive Function – Adult Version (Roth et al., 2005) that probed the participants for their frequency of encountering difficulties with executive functioning. At the final assessment session, participants were asked about expectations for the study, lifestyle and gaming experience in more detail. If participants reported in this post-experiment questionnaire that they played any assessment or training games outside the laboratory, their data were removed from all the analyses. If a participant had 0% accuracy (except for Attentional Blink and Task Switching), a negative d-prime score (where applicable), or scored more than four standard deviations below the mean in a task (mean and standard deviation taken separately for each session), their data will be excluded from training-related analyses of that task only.

There were some differences in the assessment sessions between this older adult study and the younger adult study, due to the fact that this older adult study did not have a Magnetic Resonance Imaging (MRI) component. In the younger adult study, the assessment tests of Matrix reasoning, Attention network test, and the two casual games were played while participants were in the MRI machine, to investigate brain activation patterns (to be reported separately by

Baniqued et al.). In this older adult study, the assessment casual games were played in the laboratory, and the tests of Matrix reasoning and Attention network test were dropped due to session time constraints imposed by additional tests and surveys that will be reported separately.

Below are descriptions of each assessment test. All tests for reasoning, episodic memory and perceptual speed constructs were taken from the Virginia Cognitive Aging Project (Salthouse and Ferrer-Caja, 2003; Salthouse, 2004, 2005, 2010).

2.3.1 Reasoning/fluid intelligence

2.3.1.1 Shipley abstract (Zachary & Shipley, 1986)

Participants were presented on a sheet of paper a progressive sequence of letters, words or numbers, and they filled in the following respective letters, words or numbers. For example, 1 2 3 4 5 _, the correct answer was 6; and lag-leg pen-pin big-bog rob-___, the correct answer was rub. The primary measure was the total number of correct answers within the 5 minutes time limit.

2.3.1.2 Paper folding (Ekstrom, French, Harman & Dermen, 1976)

Participants were shown on a computer display sequences of folds on a sheet and a hole punched through that folded sheet, and they chose from five options the resulting pattern of holes on the unfolded sheet. The primary measure was the total number of correct answers within the 10 minutes time limit.

2.3.1.3 Spatial relations (Bennett et al., 1997)

Participants were shown on a computer display a two-dimensional cut-out with folding lines, and they chose from four options the three-dimensional object that would match it. The primary measure was the total number of correct answers within the 10 minutes time limit.

2.3.1.4 Form boards (Ekstrom, French, Harman & Dermen, 1976)

Participants were shown on a computer display a two-dimensional shape, and they chose from five options of smaller shapes that would constitute together to form that bigger shape. The primary measure was the total number of correct answers within the 8 minutes time limit.

2.3.1.5 Letter sets (Ekstrom, French, Harman & Dermen, 1976)

Participants were shown on a computer display five sets of four-letter sequences and chose the one set that was not alike the other four sets. The primary measure was the total number of correct answers within the 10 minutes time limit.

2.3.2 Perceptual speed

2.3.2.1 Digit symbol (Wechsler, 1997a)

Participants were presented on a sheet of paper a coding reference table that showed each digit (from one to nine) and its corresponding symbol. They then wrote under a series of digits their corresponding symbols within a two-minute time duration. The primary measure was the total number of correct answers within the 2 minutes time limit.

2.3.2.2 Pattern comparison (Salthouse & Babcock, 1991)

Participants were presented on two sheets of paper pairs of patterns, and marked which pairs had same or different patterns. Each sheet had a time limit of 30 seconds. The primary measure was the mean number of correct answers.

2.3.2.3 Letter comparison (Salthouse & Babcock, 1991)

Participants were presented on two sheets of paper pairs of letter sets (3, 6 or 9 letters in a set), and marked which pairs had same or different letter sets. Each sheet had a time limit of 30 seconds. The primary measure was the mean number of correct answers.

2.3.3 Episodic memory

2.3.3.1 Word recall (Wechsler, 1997b)

Participants listened to a recording of lists of words and said aloud the words in any order during the recall stage. Participants listened to and recalled the words from List A for 4 consecutive rounds. Then they were introduced words and recalled from List B for the 5th round, and then asked to recall the words from List A for the final round. The primary measure was the total number of correct answers for all the rounds.

2.3.3.2 Logical Memory (Wechsler, 1997b)

Participants listened to recordings of two stories and recalled the stories with as much detail as possible. The primary measure was the total number of correct details recalled.

2.3.3.3 Paired associates (Salthouse, Fristoe & Rhee, 1996)

Participants listened to recordings of word pairs. When queried with the first word of the pair, they recalled the second word. Unlike the earlier younger adult study, lab personnel typed in the answers in order to control for anticipated slower typing ability of the older adults. There were 2 lists of 6 pairs of words. The primary measure was accuracy, which was the number of correct answers over the total number of questions.

2.3.4 Working Memory

2.3.4.1 Visual short-term memory (Luck & Vogel, 1997)

Participants were shown on a computer screen a row of four shapes of various colors for 250ms. After a delay of 900ms, a single shape was presented and the participants responded if that shape was presented earlier. This shape could differ in color, shape or both. Measures were overall accuracy, and sensitivity indexes (d’) of overall, and trials with changes in color, shape and both.

2.3.4.2 Symmetry span (Redick et al., 2013)

Participants were first presented on a computer screen with a red square on a four by four white filled grid. Next they were shown an image on another larger grid and responded if that image was symmetrical along the central vertical line. Then the second four by four grids with a different red square was displayed, followed by another symmetry judgment task. This was repeated until the end of the third symmetry judgment task, and the participants recalled the locations and sequence of the red squares on the grid. The primary measure was the total number of correct answers.

2.3.4.3 N-back(Kirchner, 1958; Kane, Conway, Miura & Colflesh, 2007)

Participants were shown on a computer display a series of letters one at a time, with 500ms stimulus-on and 2000ms inter-stimulus interval. At each presented letter, the participants responded whether this letter was presented earlier in the series. In the 1-back condition, participants compared the current letter with the previous presentation. In the 2-back condition, participants compared the current letter with the letter two presentations earlier. The measures were 2 and 3-back accuracies and sensitivity indexes (d’).

2.3.4.4 Running span (Broadway & Engle, 2010)

Participants were presented on a computer screen a series of letters (3 to 8 letters long) one at a time. At the end of the presentation, they were asked to recall the last n letters presented. Participants were told how many letters to remember before starting each block. The primary measure was the total number of correct answers.

2.3.4.5 Spatial working memory (Erickson et al., 2011)

Participants were presented with one, two or three black dots on a computer screen for 500ms. After a 3000ms delay, a probe red dot was displayed and participants responded whether this dot matched the location of one of the black dots presented in the previous array. The primary measure was the accuracy and sensitivity index (d’).

2.3.5 Attentional control

2.3.5.1 Trail making (Reitan, 1958)

Participants were presented with a sheet of paper with numbers distributed all over, and they were to connect the numbers in ascending order with a continuous pencil line trail as fast as they could. A lab personnel with a stopwatch would start timing after this sheet of paper was flipped over from its blank reverse side, and end timing when the participant completed the pencil line trail. On the second sheet, letters were included with the numbers and they were to connect them all, starting with the number 1 in ascending order and alternating between number and letter sequences. The primary measures were the time taken for each trail, and the time difference between the second and the first trail.

2.3.5.2 Attentional blink (Raymond, Shapiro & Arnell, 1992)

Participants viewed on a computer display series of rapidly presented black letters on gray background, and they were to respond with the identity of an unpredictably placed white letter, and whether an X followed sometime after the white letter. The letter series ranged from 16 to 22 letters, and each letter is presented 12ms, followed by 84ms of blank interval. The white letter was placed after either in the 7th, 10th or 13th letter, and the X could occur 2, 4, 6, or 8 letters after (lag) the white letter at 50% of the trials. Participants completed practice blocks where they only had to detect either the white letter or the X. The actual test contained 144 trials, where they had to detect both stimuli. The primary measure were the detection accuracy of the X at Lag 8 (where detection is typically high) and 2 (where detection is typically worst), and the difference between the two.

2.3.5.3 Task switching (Kramer, Hahn & Gopher, 1999; Pashler, 2000)

Participants viewed on a computer display single numbers (1-9, excluding 5) overlaid on a blue or pink background. Depending on the type of background, they responded whether the number was odd or even, or greater or less than 5. If the background was blue, they responded by pressing the X key with their left index finger for greater than 5, or pressing the Z key with their left middle finger for less than 5. If the background was pink, they responded by pressing the N key with their right index finger for odd number, or pressing the M key with their right middle finger for even number. Practice consisted of single task blocks of both types, and task-switch blocks. The primary measures were the differences in reaction time and accuracy for switch and repeat trials (Local cost), and single and repeat trials (Global cost).

2.3.5.4 Color Stroop (Stroop, 1935 & 1992)

Participants viewed on a computer display a series of colored words, and they were to respond with the color of each word. There were three trial types randomly presented, varying in terms of the color of the font and the word themselves. Congruent trials had the font color consistent with the word (e.g. ‘RED’ printed with red ink). Incongruent trials had the font color different from the word (e.g. ‘RED’ printed with blue ink). Neutral trials had words unassociated with color (e.g. ‘DOG’ printed with red ink). The primary measures were the reaction time differences between the incongruent and congruent trials (Inc-con), and between incongruent and neutral trials (Inc-neu).

2.3.6 Casual video games used for assessment

These games were selected based to the study by Baniqued et al. (2013). One game (Bloxorz) was highly correlated with performance on working memory and reasoning tasks, while the other (Dodge) was not. These games were used only as assessment tests at pre- and post-training, and not used in any of the training sessions.

2.3.6.1 Bloxorz (miniclip.com)

Participants were shown an irregularly shaped maze-platform with a target-hole on it. They were to rotate and roll a rectangular block around the maze, with the aim of dropping the block into the target-hole while trying not to roll off the maze-platform. New levels/mazes were passed once participants solved the puzzle by dropping the block into the target-hole. Participants played the first and second levels as practice. They were asked to stop when they complete level 2, or after 10 minutes had passed. Participants then resumed playing from level 3 onwards for 8 minutes, and the primary measure was the last level completed within that time.

2.3.6.2 Dodge (armorgames.com)

Participants flew a spaceship that was attacked by a variety of enemy ships with tracking missiles. The aim was to avoid getting hit, and guide the tracking missiles back into the enemy ships to destroy them. Levels were passed once participants cleared all the enemy ships on the screen. As with Bloxorz game, the participants played the first 2 levels as practice, and stopped when they completed level 2 or when 10 minutes had passed. Participants then resumed playing from level 3 onwards for 8 minutes, and the primary measure was the last level completed within that time.

2.3.7 Self-report instruments

2.3.7.1 Behavior Rating Inventory of Executive Function – Adult Version (BRIEF-A) by PAR^{TM}.

Participants used the online version of the BRIEF-A survey (Roth, Isquith & Gioia, 2005) once before and after training. This survey asked the participants the frequency that they encountered a variety of executive functioning difficulties. The example/practice question provided in the survey instruction is 'I have trouble making decisions.', and the participant would respond to all the questions by indicating 'never', 'sometimes' or 'often' (actual questions are protected by copyright laws). The dimensions covered in this 75-questions survey included Inhibit, Shift, Emotional Control, Self-monitor, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Task Monitor.

2.3.7.2 Post-experiment questionnaire

At the end of the last test session, participants completed an online questionnaire that inquired about their experience of the study, lifestyle history as well as video and board game habits. This questionnaire was similar to the one used in the younger adult study, with customization of questions to the older population. For example, the perceived improvement questions were retained and this section asked the participants to rate whether they felt that participation in the study changed the following functions (rating from scale of 1 to 10; 1=very poorly, 10=very desirably): overall intelligence, short-term or working memory, long-term memory, ability to pay attention or focus, ability to pay attention to multiple things at once (divided attention), hand-eye or visuomotor coordination, perception, vision or visual acuity, problem-solving ability, multi-tasking ability, reasoning ability, academic/workplace performance, spatial visualization ability, emotional regulation, and productivity at workplace (changed from ‘work or school’ in the younger adult study), or tendency to procrastinate. In another section, participants were asked to rate how much they liked and their effort put into each of the assigned games, and whether they used any particular strategies. They were also asked if they played any of the training or assessment games outside of the lab while their participation in the study was ongoing (with no penalty to their participation). Finally they answered questions on the nature of their knowledge and experience with video and board games. Responses from the questionnaire were used to assess whether participants in the training groups and age cohorts perceived differently the overall effect of their training.

2.4 Casual video games used for training

The games used for this study’s treatment and control groups were identical to those for WM-REAS 1 and Active control groups in Baniqued and colleagues’ study (2014). These games were chosen based on initial task analyses of shortlisted games, and groupings were supported with Principle Component Analysis. Details of the selection can be found in an earlier study by Baniqued and colleagues (2013). Performance on WM-REAS 1 group’s games were found to be highly correlated with participants’ performance on working memory and reasoning tasks administered through an extensive neuropsychological test battery prior to playing these games. In contrast, the games used in the active control group were not highly correlated with working memory and reasoning tasks. All games used were played on a research portal supported by Digital Artefacts company (http://www.digitalartefacts.com/). Table 3 shows the brief descriptions of each game played by the two groups and the primary measure for each game. All training sessions were recorded through screen capture software and scored offline by lab personnel. For the purpose of assessing how the participants felt about playing these games, they were asked to answer on an online survey immediately after the first, fifth and tenth (last) training sessions. The questions on this feedback survey were pertaining to each game played in their assigned group, and they responded on a scale of 1-10 (1 = least, 5 = neutral, 10 = greatest): (1) How much did you enjoy/like each game, (2) How engaging was each game, (3) How demanding/effortful was each game, and (4) How motivated were you to achieve the highest possible score on each game?

CHAPTER 3: RESULTS

3.1 Practice effects

3.1.1 Practice effectiveness

All groups improved on their training games, regardless of age group or group assignment. Repeated measures ANOVA with session (10 training sessions) as a within-subject factor and age (younger vs. older adults) as between-subject factor was conducted for the primary measure of each training game. The practice effects were robust, with significant main effects of session ($p < 0.001$) for all games (Table 4). We also found better overall performance by the younger adults compared to the older adults group, with significant main effect of age ($p < 0.001$) for all games. In addition, there was evidence of the younger group improving more than the older group over the training sessions for some games. In two of the four games of each group (WM-REAS: Silversphere and Sushi-go-round; Active control: Alphattack and Enigmata), there was significant session x age interaction (with $p = 0.001$ or less) with the younger group's game scores gradient greater than the older group's. Group averages are plotted in Figure 2, [with scores divided by the maximum average score of each game for ease of presentation].

To assess whether gains to the training games were different for the older adults compared to the younger adults, ANOVAs with age (younger vs. older adults) as between-subject factor were conducted for training gain composite score separately for each training group. Standardized training gain scores for each game were first computed by taking the difference of the performance at the later sessions (mean of sessions 9 & 10) with that of the earlier sessions (mean of sessions 1& 2), and divided it by the standard deviation of the performance at earlier sessions. Training gain composite score were then derived by averaging the standardized training gain scores for each game.

For the WM-REAS training group (Figure 3), there was main effect of age [$F(1,83) = 9.292$, $p = 0.003$, $\eta_p^2 = 0.101$], indicating a significant difference between training gain composite scores between the older and younger adults [mean of 1.065 (0.061) and 1.316 (0.055) respectively (with standard error in parentheses)]. Further analysis of each standardized training gain score showed main effects of age for the games of Silversphere [$F(1,81) = 39.927$, $p < 0.001$, $\eta_p^2 = 0.330$], with lower gains for older compared to younger adults [mean of 1.374 (0.113) and 2.257 (0.078) respectively , and Sushi-go-round [$F(1,83) = 5.669$, $p = 0.020$, $\eta_p^2 = 0.064$], with lower gains for older compared to younger adults [mean of 1.130 (0.110) and 1.448 (0.075) respectively.

For the active control training group, there was main effect of age [$F(1,85) = 64.857$, $p < 0.001$, $\eta_p^2 = 0.433$], indicating a significant difference between training gain composite scores between the older and younger adults [mean of 1.138 (0.089) and 2.307 (0.114) respectively (with standard error in parentheses)]. Further analysis of each standardized training gain score showed main effects of age for the games of Alphattack [$F(1,85) = 70.977$, $p < 0.001$, $\eta_p^2 = 0.455$], with lower gains for older compared to younger adults [mean of 3.090 (0.303) and 7.080 (0.363) respectively , and Enigmata [$F(1,85) = 5.264$, $p = 0.024$, $\eta_p^2 = 0.058$], with lower gains for older compared to younger adults [mean of 0.665 (0.081) and 1.075 (0.158) respectively.

In summary, the analysis of the training data showed robust practice effects regardless of game and age groups. The older adults also showed worse overall performance for all games, and for some games showed less gain over the 10 training sessions, compared to the younger adults group.

3.1.2 Training motivation, enjoyment, engagement and effort ratings

The four feedback questions of enjoyment, engagement, motivation and effort were entered separately into repeated measures ANOVAs with session (1^{st}, 5^{th} and 10^{th} training sessions) as within-subjects factor, and group (WM-REAS vs. active control) and age (younger vs. older adults) as between-subjects factors. Ratings for each feedback question were averaged across the four training games practiced by each participant.

For enjoyment, there was main effect of session [$F(2,322) = 11.875$, $p < 0.001$, $\eta_p^2 = 0.069$], indicating rating change over time (Figure 4). Pairwise comparison showed significant difference between the 1^{st} and 5^{th} session [mean of 6.398 (0.121) and 6.704 (0.122) respectively (with standard error in parentheses)]. There was session x age [$F(2,322) = 21.031$, $p < 0.001$, $\eta_p^2 = 0.116$]and session x group [$F(2,322) = 11.288$, $p < 0.001$, $\eta_p^2 = 0.066$] interactions, indicating differences in changes over time between the age and groups respectively. Further analysis of the session x age interaction revealed significant ($p = 0.006$ and less) enjoyment rating increase for older group [mean of 6.049 (0.170), 6.754 (0.172) and 7.109 (0.168) for 1^{st}, 5^{th} and 10^{th} session respectively], but no significant change for the younger group. Further analysis of the session x group interaction revealed significant ($p = 0.024$ and less) enjoyment rating increase for the WM-REAS group [mean of 5.980 (0.172), 6.574 (0.174) and 6.879 (0.171) for 1^{st}, 5^{th} and 10^{th} session respectively], but no significant change for the active control group. Finally, there was a session x group x age interaction [$F(2,322) = 5.745$, $p = 0.004$, $\eta_p^2 = 0.034$]. Further analysis of this 3-way interaction revealed significant ($p = 0.001$ and less) enjoyment rating increase for only the older WM-REAS group [mean of 5.378 (0.242), 6.598 (0.245) and 7.195 (0.240) for 1^{st}, 5th and 10th session respectively], but no significant change for the older active control group or the younger groups.

For engagement, there was main effect of session [$F(2,322) = 4.895$, $p = 0.008$, $\eta_p^2 = 0.03$], indicating rating change over time. Pairwise comparison showed significant difference between the 1st and 5th session [mean of 6.985 (0.132) and 7.233 (0.126) respectively (with standard error in parentheses)]. There was session x age [$F(2,322) = 27.204$, $p < 0.001$, $\eta_p^2 = 0.145$] and session x group [$F(2,322) = 4.9$, $p = 0.008$, $\eta_p^2 = 0.03$] interactions, indicating differences in changes over time between the age and groups respectively. Further analysis of the session x age interaction revealed significant ($p < 0.001$) engagement rating increase for older group between 1st and 5th sessions [mean of 6.699 (0.186) and 7.493 (0.178) respectively], but no significant change for the younger group. Further analysis of the session x group interaction revealed significant ($p = 0.02$) engagement rating increase for the WM-REAS group between 1st and 5th sessions [mean of 6.478 (0.189) and 7.157 (0.180) respectively], but no significant change for the active control group. Finally, there was a session x group x age interaction [$F(2,322) = 8.295$, $p < 0.001$, $\eta_p^2 = 0.049$]. Further analysis of this 3-way interaction revealed significant ($p = 0.01$ and less) engagement rating increase for only the older WM-REAS group [mean of 6.183 (0.265), 7.451 (0.253) and 7.982 (0.242) for 1st, 5th and 10th session respectively], but no significant change for the older active control group or the younger groups.

For effort, there was no main effect of session, but of group [$F(1,161) = 4.554$, $p = 0.034$, $\eta_p^2 = 0.028$] and age [$F(1,161) = 25.352$, $p < 0.001$, $\eta_p^2 = 0.136$], indicating rating difference between the groups and age groups. Pairwise comparison showed significant difference ($p = 0.034$) between the active control and WM-REAS groups [mean of 7.119 (0.126) and 7.502 (0.128) respectively (with standard error in parentheses)]. This meant that more effort was reported for the WM-REAS groups compared to the active control group. Pairwise comparison also showed significant difference ($p < 0.001$) between the younger and older adults groups [mean of 6.859 (0.127) and 7.763 (0.127) respectively (with standard error in parentheses)]. This meant that older adults reported more effort compared to the younger adults.

For motivation, there was no main effect of session and group, but only of age [$F(1,161) = 15.510$, $p < 0.001$, $\eta_p^2 = 0.088$], indicating rating difference between age groups. Pairwise comparison showed significant difference ($p < 0.001$) between the younger and older adults groups [mean of 7.262 (0.167) and 8.189 (0.166) respectively (with standard error in parentheses)]. There was session x age interaction [$F(2,322) = 10.182$, $p < 0.001$, $\eta_p^2 = 0.059$], indicating differences in changes over time between the age groups. Further analysis of the session x age interaction revealed significant ($p = 0.018$) motivation rating decrease for younger adults group between 1st and 5th sessions [mean of 7.514 (0.196) and 7.108 (0.195) respectively], and significant ($p = 0.015$) motivation rating increase for older adults group between 1st and 5th sessions [mean of 7.895 (0.195) and 8.309 (0.194) respectively].

In summary, the older WM-REAS group reported increasing enjoyment and engagement ratings over the entire training while the older active control group and the younger adults groups did not report significant differences in these ratings. For effort ratings, the WM-REAS groups regardless of age reported higher effort ratings overall compared to the active control groups, and the older adults reported higher effort ratings overall compared to the younger adults. For motivation ratings, the older adults regardless of training group assignment reported higher motivation ratings in general compared to the younger adults, and the older adults reported increasing motivation over the first half of the training, while the younger adults reported decreasing motivation.

3.2 Transfer of training

3.2.1 Composite-level analyses

To investigate game training effects at the level of cognitive abilities, we performed analyses at the latent construct level using composite scores. The method to calculate composite gain scores was the same as in the earlier younger adult study (Baniqued et al., 2014), that was by averaging standardized improvement scores ([post-–pre-training]/standard deviation of pre-training, averaged/collapsed across groups) from related tasks. Below is the list of composites (and the task groupings): 1) Fluid intelligence (Form Boards, Paper Folding, Spatial Relations, Shipley Abstract, Letter Sets, Bloxorz); 2) Perceptual speed (Digit Symbol, Pattern Comparison, Letter Comparison); 3) Episodic memory (Word Recall, Logical Memory, Paired Associates); 4) Divided attention (Dodge, Attention Blink, Trail Making); and 5) Working memory (Spatial WM, N-back, Visual STM, Symmetry span, Running span).

We conducted ANOVAs on the composite scores at pre-training or baseline, with group (WM-REAS vs. active control) and age (younger vs. older adults) as between-subject factors, for the purpose of checking whether the training groups within each age group are not different before training, and that the age groups are indeed different as expected (Table 5). Composite baseline scores were computed by averaging the standardized scores of primary measure at pre-training that constituted each composite. All composite baseline scores showed the main effect of age ($p < 0.001$), with younger adults scoring higher than the older adults, and no significant main effect of group or group x age interaction. This showed that the training groups within each age group were no different from each other, and the younger adults group indeed was performing better than the older adults group at pre-training.

We conducted ANOVAs on the composite gain scores with group (WM-REAS vs. active control) and age (younger vs. older adults) as between-subject factors. For the fluid intelligence composite gain scores, we found a significant main effect of age [$F(1,169) = 7.225$, $p = 0.008$, $\eta_p^2 = 0.041$], indicating a difference in gain between age groups (Figure 5, Table 6). Pairwise comparison showed a significant difference ($p = 0.008$) between the younger and older adults groups [mean of 0.380 (0.031) and 0.261 (0.031) respectively (with standard error in parentheses)]. This suggests that the younger adults group gained significantly more than the older adults in the fluid intelligence composite. For the divided attention composite gain scores, we found a significant main effect of age [$F(1,169) = 5.725$, $p = 0.018$, $\eta_p^2 = 0.033$], indicating difference in gain between age groups. Pairwise comparison showed a significant difference ($p = 0.018$) between the younger and older adults groups [mean of 0.113 (0.049) and 0.281 (0.050) respectively (with standard error in parentheses)]. This suggests that the older adults group gained significantly more than the younger adults in the divided attention composite. No main effect of group was found in any of the composites.

We also found significant age x group [$F(1,169) = 6.761$, $p = 0.010$, $\eta_p^2 = 0.038$] interaction effect for the composite gain scores of divided attention, indicating difference in gains between the age and training groups. Further analyses showed a significant difference ($p = 0.019$) between the younger WM-REAS and active control groups [mean of 0.230 (0.070) and -0.005 (0.069) respectively], indicating that within the younger adults the WM-REAS group gained significantly more than the active control group. No significant difference ($p = 0.194$) was detected across group within the older adults, indicating no difference in gain between the older WM-REAS and active control group [mean of 0.216 (0.070) and 0.345 (0.070) respectively]. There was also a significant difference ($p = 0.001$) between the younger and older adults active control groups [mean of -0.005 (0.069) and 0.345 (0.070) respectively (with standard error in parentheses)], which indicated more gain in the divided attention composite by the older adults in the active control group compared to the younger adults. These effects remained even when two older participants with MMSE (mini-mental state examination; Folstein, Folstein, & McHugh, 1975) scores less than 25 were excluded from the analyses, showing that these effects were not due to these cases of older adults performing poorly at this general test of cognitive ability at pre-training.

In summary, we found the older adults group, regardless of training group assignment, gained significantly less than the younger adults in the fluid intelligence composite, but gained more than the younger active control group in the divided attention composite. Of course, these main effects could simply be due to practice effects since subjects performed the pre-post assessment tasks twice. These main effects do not constitute differential, training group-based transfer effects. Composite gains for episodic memory perceptual speed and working memory were similar between the age groups. Only for the divided attention composite did we find training group assignment effects; the younger WM-REAS group gained significantly more than the younger active control, but the older WM-REAS and active control groups did not show a significant difference in gain. This meant that younger adults showed transfer to divided attention ability while older adults did not show transfer to any of the cognitive abilities measured.

3.2.2 Task level analysis

We performed analyses at the task level in order to investigate game training effects at the level of individual tests. To investigate the effect of transfer of training, repeated-measures ANOVAs were performed for each task, with age (younger vs. older adults) and group (WM-

REAS vs. active control) as between-subject factors and time (pre- vs. post-training) as a within-subject factor (Table 7). Time x group x age interaction effect was found only for the primary measure of Attentional Blink effect (difference in accuracies at lag 8 and lag 2) [$F(1,168) = 4.824$, $p = 0.029$, $\eta_p^2 = 0.028$]. Further analyses showed that this blink effect was significantly smaller at post-training compared to pre-training only for the older active control group [$p = 0.010$, means of 0.168 (0.050) and 0.276 (0.048) respectively], and the attentional blink effect at post-training was also significantly smaller for the older active control group than the younger active control group [$p = 0.001$, means of 0.168 (0.050) and 0.402 (0.049) respectively](Figure 6). This suggests that only the older active control group improved significantly at the attentional blink task compared to the other groups. We analyzed the older active control group's accuracy measures at lag 2 and lag 8 separately, and found that their accuracy measure at lag 2 improved significantly from pre- to post-training [$p < 0.001$, means of 0.425 (0.041) and 0.565 (0.046) respectively], but no significant difference at lag 8. Hence the significant attentional blink effect improvement shown by the older active control group over the other three groups seems to be contributed by the improvement of their accuracy at lag 2.

Main effect of age was found to be significant ($p = 0.019$ and less) for all tasks except Spatial Working Memory (accuracy and d'), and Task Switching (global cost accuracy, local cost accuracy and reaction time). Further analyses of the tasks with significance revealed better overall performance of the younger adults group over the older adults group regardless of group assignment and training (time).

Significant time x age interaction effects were found for the tasks of Pattern Comparison (perceptual speed), Bloxorz and Form Boards (Reasoning/fluid intelligence) and N-back (Working memory). For the Pattern Comparison task, we found this significant time x age interaction effect [$F(1,169) = 5.148$, $p = 0.025$, $\eta_p^2 = 0.030$], showing the younger adults improving more over time compared with the older adults regardless of group assignment [means of 21.573 (0.311) to 23.079 (0.308) and 14.930 (0.313) to 15.680 (0.310) respectively (with standard error in parentheses)]. For Bloxorz task, we found significant time x age interaction effect [$F(1,164) = 4.769$, $p = 0.030$, $\eta_p^2 = 0.028$], showing the younger adults improving more over time compared with the older adults regardless of group assignment [means of 4.361 (0.098) to 5.047 (0.105) and 3.505 (0.097) to 3.880 (0.103) respectively]. For Paper Folding task, we found significant time x age interaction effect [$F(1,168) = 14.011$, $p < 0.001$, $\eta_p^2 = 0.077$], showing the younger adults improving more over time compared with the older adults regardless of group assignment [means of 10.268 (0.418) to 12.845 (0.450) and 5.365 (0.423) to 6.109 (0.456) respectively].

For 2-back accuracy measure, we found significant time x age interaction effect [$F(1,166) = 10.314$, $p = 0.002$, $\eta_p^2 = 0.058$], showing the older adults improving significantly [$p < 0.001$, means of 0.827 (0.012) to 0.876 (0.011)] over time compared with the younger adults who showed no significant improvement [$p > 0.05$, means of 0.951 (0.012) to 0.957 (0.011)] regardless of group assignment. For 3-back accuracy measure, we found significant time x age interaction effect [$F(1,166) = 14.507$, $p < 0.001$, $\eta_p^2 = 0.080$], showing the older adults improving significantly [$p < 0.001$, means of 0.733 (0.012) to 0.791 (0.011)] over time compared with the younger adults who showed no significant improvement [$p > 0.05$, means of 0.871 (0.012) to 0.879 (0.011)] regardless of group assignment.

In summary, we found different patterns of improvement between younger and older adults, regardless of group assignment. Older adults showed improvements to one working memory task (N-back) while younger adults did not, but showed less improvements to one of perceptual speed task (Pattern Comparison) and two of the reasoning/fluid intelligence tasks (Bloxorz and Form Boards) compared to the younger adults. The last point is in agreement with the finding in composite-level analysis that younger adults group gaining significantly more than the older adults in the fluid intelligence composite, regardless of training group assignment.

No time x group interaction effects was found for any of the assessment tasks.

Repeated ANOVAs were conducted separately for the younger and older adults, with group (WM-REAS vs. active control) as between-subject factor and time (pre- vs. post-training), as a within-subject factor, in order to analyze and contrast the effect of training type for each age group. Near significant time x group interaction effects were found for Dodge [$F(1,79) = 3.781$, $p = 0.055$, $\eta_p^2 = 0.046$] and Trails B-A [$F(1,83) = 3.867$, $p = 0.053$, $\eta_p^2 = 0.045$], with the younger WM-REAS group improving more over time than the younger active control group. Significant time x group interaction effects were found for the younger adults for Trails B [$F(1,83) = 4.291$, $p = 0.041$, $\eta_p^2 = 0.049$], and further analysis showing that the younger WM-REAS group improving more over time compared to the younger active control. No significant time x group effects were found for the older adults group, showing no detectable difference in improvement over time between the older WM-REAS and active control groups. This is in line with the finding in composite level analysis that the younger WM-REAS gained significantly more than the younger active control group, and that the older WM-REAS and active control groups showed no significant difference in gain between them. The significant difference detected between the younger and older active control groups could be explained with the latter group's significant improvement in Attentional Blink effect found in the task level analysis.

3.2.3 Perceived improvement (expectations)

To assess whether participants perceived differently the overall effect of their training due to the training group assignment and age group, analyses were carried out on their response to the improvement questions collected with the post-experiment questionnaire. For the response to whether the study had changed the way they performed their daily activities in a good way (Improve) or no change, a three-way Loglinear analysis was conducted with Age, Group and Improve as factors. The likelihood ratio of this model was χ^2 (0) = 0, $p = 1$. A second order interaction (Age x Improve) was significant (χ^2 (4) = 11.114, $p = 0.025$). To break down this effect, separate Chi-square tests were performed for Age and Improve variables, and Group and Improve variables. There was a significant association between age and whether they perceived improvement (χ^2 (1) = 7.955, $p = 0.005$). The odds of older participants perceiving improvement were 2.44 times higher than for younger adults. Also, there was no significant difference between Group and whether they perceived improvement (χ^2 (1) = 1.210, $p = 0.271$). Hence, the two training groups did not differ on their overall expectations of improvement due to the training, and the older adults group showed higher odds of perceiving improvement compared to the younger adults group.

To assess whether age and training group assignment have an effect on the participants' perceived change (rating 1=very poorly, 10=very desirably) in more specific aspects (overall intelligence, ability to pay attention or focus, etc.), two-way ANOVAs for each of the fourteen questions were performed with group and age as between-subjects factors. Significant age main effects were found for ability to pay attention or focus [$F(1,130) = 6.704$, $p = 0.011$], academic/workplace performance [$F(1,130) = 4.817$, $p = 0.030$], emotional regulation [$F(1,130) = 9.585$, $p = 0.002$], productivity at work or school, or tendency to procrastinate [$F(1,130) =$

4.037, *p* = 0.047], with higher ratings for older adults in general than for younger adults. Only for short-term or working memory did the younger adults reported higher ratings than older adults [*F*(1,130) = 4.506, *p* = 0.036]. Significant group main effects were found for long-term memory [*F*(1,130) = 4.629, *p* = 0.033], productivity at work or school, or tendency to procrastinate [*F*(1,130) = 3.990, *p* = 0.048], with higher ratings for active control group in general than for WM-REAS group. A significant age x group interaction effect was found for problem solving ability [*F*(1,130) = 9.510, *p* = 0.002]. Further analysis showed that the older active control group rated significantly higher compared to the younger active control group [*p* = 0.014, means of 7.163 (0.278) and 6.038 (0.358) respectively], and the older WM-REAS group [*p* = 0.007, means of 7.163 (0.278) and 6.093 (0.278) respectively. Hence, older adults reported higher ratings for attentional focus, academic/workplace performance, emotional regulation and productivity, and lower ratings for short-term or working memory compared to the younger adults. Active control groups reported higher ratings for long-term memory and productivity compared to the WM-REAS groups. Importantly, as divided attention and reasoning ratings were not found to be significantly different between the age groups, we concluded that the changes to these latent constructs were not likely to be driven by the participant's expectations of the effect of their training on their cognitive abilities.

3.2.4 Self-reported surveys

3.2.4.1 Behavioral rating inventory of executive function- adult version (BRIEF-A)

To investigate the effect of training on executive functioning difficulties assessed using this survey, repeated measures ANOVA were performed for each scale on the survey, with Age (younger vs. older adults) and Group (WM-REAS vs. active control) as between-subject factors and Time (pre- vs. post-training) as a within-subject factor (Table 8). Main effect of age was found for the scales of Shift [$F(1,128) = 23.431$, $p < 0.001$, $\eta_p^2 = 0.155$], Emotional Control [$F(1,128) = 8.770$, $p = 0.004$, $\eta_p^2 = 0.064$], Self-Monitor [$F(1,128) = 36.365$, $p < 0.001$, $\eta_p^2 = 0.221$], Working Memory [$F(1,128) = 21.826$, $p < 0.001$, $\eta_p^2 = 0.146$], Plan/Organize [$F(1,128) = 15.909$, $p < 0.001$, $\eta_p^2 = 0.111$] and Task Monitor [$F(1,128) = 14.935$, $p < 0.001$, $\eta_p^2 = 0.104$], with older adults reporting higher ratings than younger adults [Shift: mean of 9.809 (0.206) and 8.146 (0.275), Emotional control: mean of 14.852 (0.385) and 12.950 (0.514), Self-Monitor: mean of 9.537 (0.187) and 7.653 (0.250), Working memory: mean of 12.937 (0.262) and 10.897 (0.349), Plan/organize: mean of 15.229 (0.318) and 13.118 (0.424), and Task monitor: mean of 10.305 (0.192) and 9.069 (0.256) respectively (with standard error in parentheses)]. This meant that older adults reported higher frequencies of encountering difficulties with these tasks than younger adults. Time x Age interaction effects were found for Shift [$F(1,128) = 6.182$, $p = 0.014$, $\eta_p^2 = 0.046$], and Emotional Control [$F(1,128) = 3.951$, $p = 0.049$, $\eta_p^2 = 0.030$], with the younger adults rating increasingly more difficulties than the older adults over time. Further analyses on the Shift scale data showed that younger adults reported significant increase in difficulties in shifting over pre- and post-training tests [$p = 0.006$, mean of 7.815 (0.285) and 8.476 (0.314) respectively], while older adults showed no significant difference over the two tests ($p = 0.668$). Further analyses on the Emotional Control scale data however did not reveal any significant difference when comparing pre- and post-training tests for each younger ($p = 0.109$) and older adult ($p = 0.249$) group. No significant Time x Group interaction effect was found, which concur with composite and task level analyses that found no overall effects of group assignment. Significant Time x Age x Group interaction effects were found for the scales of Shift [$F(1,128) = 8.019$, $p = 0.005$, $\eta_p^2 = 0.059$], Plan/Organize [$F(1,128) = 4.491$, $p = 0.036$, $\eta_p^2 = 0.034$] and Task Monitor [$F(1,128) = 6.724$, $p = 0.011$, $\eta_p^2 = 0.050$]. Further analyses on the Shift scale data showed that the younger WM-REAS group reported significant increase in difficulties in shifting over pre- and post-training tests [$p < 0.001$, mean of 7.333 (0.427) increase to 8.619 (0.470)], while other groups did not show any significant differences. Further analyses on the Plan/Organize scale data however did not reveal any significant difference when comparing pre- and post-training tests for each of the four groups ($p > 0.099$). Further analyses on the Task Monitor scale data showed that younger WM-REAS and older Active Control groups reported significant increase in difficulties in monitoring tasks over pre- and post-training tests [$p = 0.025$, mean of 8.524 (0.407) increase to 9.381 (0.448); and $p = 0.037$, mean of 9.977 (0.284) increase to 10.535 (0.313) respectively], while the other two groups did not show significant differences. No significant Age x Group interaction was found when these scales' pre-training ratings were entered into separate ANOVAs. In general, older adults reported more executive functioning difficulties than the younger adults, younger adults reported more difficulties over time than the older adults, and no significant improvements to any of the scales were found for any group.

3.2.5 Exploratory analyses

Baseline reasoning ability (gF). One finding for the previous study (i.e., Baniqued et al, 2014) was that the younger adults in the WM-REAS training groups with lower baseline reasoning abilities at initial testing showed more divided attention composite transfer gain. To investigate whether this finding was evident across this study's wider age span, we correlated divided attention gain composite with baseline reasoning or gF ability, and found near significance for the younger WM-REAS ($r = -0.298$, $p = 0.053$), significance for older WM-REAS ($r = -0.301$, $p = 0.050$) groups, and non-significance for younger and older active control groups ($r = 0.131$, $p = 0.398$ and $r = -0.280$, $p = 0.069$ respectively).

Separate ANCOVAs for each age group were performed on the divided attention gain composite with group (WM-REAS vs. active control) as between-subject factor and baseline gF as a covariate. For the younger adults group, the main effect of group was significant [$F(1,84) = 7.597$, $p = 0.007$, $\eta_p^2 = 0.083$] but no there was no significant effect of baseline gF [$F(1,84) = 1.081$, $p = 0.301$]. However, for the older adults group, the main effect of group was not significant [$F(1,83) = 1.468$, $p = 0.229$, $\eta_p^2 = 0.017$] and the covariate of baseline gF had an effect on divided attention gain [$F(1,83) = 7.227$, $p = 0.009$, $r = -0.283$]. We correlated divided attention composite gain with baseline gF for each age group and found non-significance for younger adults ($r = -0.171$, $p = 0.113$) but significant result for older adults ($r = -0.278$, $p = 0.010$). Hence for older adults we found that baseline gF significantly predicted divided attention composite gain, in that lower baseline gF was correlated with higher gains, and training type was not predictive of divided attention composite gain even after controlling baseline gF as a covariate.

Separate ANCOVAs for each age group were performed on the other cognitive abilities composites (episodic memory, perceptual speed, gF and working memory) with group (WM-REAS vs. active control) as between-subject factor and baseline gF as a covariate. For younger adults, the covariate of baseline gF had an effect on gF composite gain [$F(1,84) = 6.538$, $p = 0.012$, $r = -0.269$], predicting higher composite gF gain with lower baseline gF. No other significant main effect of group or baseline gF as a covariate was found. Hence there was no evidence of transfer to episodic memory, perceptual speed, reasoning and working memory, even after controlling for baseline gF or reasoning ability.

Age, MMSE and Years of Education. Age (years old), MMSE scores and years of education were entered as covariates into separate ANCOVAs on the divided attention gain composite for the older adults group only, with group (WM-REAS vs. active control) as between-subject factor. Main effect of training group was still not significant, and there was no effect of any of the above factors as a covariate. These factors of age, MMSE scores and years of education did not have a significant effect on the magnitude of gain in divided attention composite.

Attitude toward video game effect on cognition. Attitude towards studies or media reports about the effect of video games on cognition was collected in the post-experiment survey. Participants could respond 'favorable', 'not favorable', 'mixed/neutral/skeptical' towards video game training or 'not applicable'. ANOVAs, separated by age group, were performed on divided attention gain composite with group (WM-REAS vs. active control) and attitude (favorable vs. not favorable/mixed/neutral/skeptical) towards video game training as between-subject factors. No main or interaction effects of group or attitude were significant, suggesting that attitude did not matter to divided attention game composite. However, the sample sizes within each category were very small (range between 6 and 23), which placed severe limitation on the interpretability of the analysis.

Correlation between training gain and cognitive ability gain score. To examine whether improvement on the trained task was predictive of the amount of transfer (Jaeggi et al., 2011, 2014), correlation analyses were conducted separately for each game training group and age cohort between the training gain scores (composite and standardized training gain scores for each game) and the composite gain scores for each cognitive ability. Given the exploratory nature of these correlational analyses, we only state correlations that were significant at $p < 0.01$. For the WM-REAS training groups, no significant correlations were found for either the older or younger groups [reported also in Baniqued et al. (2014)]. For the active control groups, a significant relationship was found for younger adults between the standardized training gain score for Alphattack and reasoning composite gain score ($r = 0.432$, $p = 0.003$). This suggests that more training improvement for Alphattack was associated with more reasoning composite gain for the younger adults.

Was training gain crucial to transfer in divided attention for younger and older adults? Baniqued et al. (2014) correlated composite training gain and transfer gain scores and did not find significant results, suggesting that performance improvement at training did not affect transfer to divided attention ability. In the current study, we created within each age group two groups of higher and lower training improvement by mean-splitting along the composite training gain score. ANOVAs for each age group were performed on the divided attention composite gain score with group (WM-REAS vs. active control) and training performance (higher vs. lower) as between-subject factors. If training performance was crucial, then it and group as main or interaction effects should be significant. We found the expected significant main effect of group [$F(1,82) = 8.080$, $p = 0.006$, $\eta_p^2 = 0.090$] for younger adults, but importantly non-significant results ($p > 0.174$) for training performance as a main effect, and training performance and group as interaction effect for both age groups. This showed that the amount of improvement to training games did not predict the amount of divided attention transfer for younger adults.

Correlation between training experience and cognitive ability gain. To examine whether training game experience (enjoyment, engagement, motivation and effort) was predictive of the amount of transfer, correlation analyses were conducted separately for each game training group and age cohort between each experience rating (after fifth and tenth training session) and the composite gain scores for each cognitive abilities. For the younger active control group, effort rating (tenth session) was found to be positively associated with divided attention composite gain score ($r = 0.503$, $p = 0.001$). No other significant correlations were found. This suggests that the relationship between game experience ratings and gains in cognitive abilities might not be robust.

CHAPTER 4: DISCUSSION

The aim of this study was to investigate whether widely available casual video games could broadly improve cognition over the adult lifespan. Groups of younger and older adults trained with casual games that were correlated with working memory and reasoning abilities. Using well-established psychological tests and analysis that include investigation at the latent variable construct level, appropriate active control groups and a relatively sizable sample (approximately 40 participants per group), we found that while the participants improved on the trained games, the pattern of transfer was quite sparse and differed between the younger and older adults. All participants showed robust practice effects or improvements on the trained games, and the younger adults also showed better overall performance over the total of 15 hours of training, and more gains for half the games at the end of training compared to the older adults. Pre-training checks on the measurements of cognitive abilities showed that the training and active control groups within each age cohort were similar to each other, and the younger adults group was performing better than the older adults group. Regardless of training group assignment, the older adults group gained less than the younger adults group in fluid intelligence or reasoning composite, but gained more in the divided attention composite. Importantly, unlike the younger adult group, the older adult group did not show transfer in divided attention. There was no significant difference in the divided attention gain composite between the older experimental and active control groups, in which the experimental group played casual games that were more highly correlated with working memory and reasoning abilities and the active control group played those that were least correlated.

Analysis of the participants' perceived improvement showed no difference between the training and active control groups on their overall expectations of improvement due to training groups, but the older adult group did show higher odds of perceiving overall improvement compared to the younger adults group.

Initial reasoning ability was significantly correlated with divided attention composite gains for older adults. Lower initial reasoning ability predicted higher divided attention composite gains. Neither initial reasoning ability nor training type was predictive of episodic memory, perceptual speed and working memory composite gains for both age groups. In addition for the older adult group, age, MMSE scores and years of education also were not found to be predictive of the gains in divided attention composite. Composite gains in training performance for both WM-REAS and active control groups were found to be non-predictive of any composite gain scores of cognitive constructs. Only one game's individual training gains (active control) was positively associated with gains to reasoning composite. Game experience was not found to be robustly associated with gains in cognitive abilities. Game experience ratings did not correlate with any composite gain scores, except for younger active control group's effort rating at the last session was found to be positively associated with divided attention gain score.

Our main predictions stemmed from the theory of more limited neural plasticity for older adults (Dahlin et al., 2008; Hertzog et al., 2009), so that older adults would improve to a lesser extent than younger adults on their training games and also show less transfer to untrained tasks compared to the younger adults. The findings partially confirmed the main predictions both at training and at transfer. Gains in training games were not the same between younger and older adults. Older adults started and ended training at lower levels of performance on all games compared to the younger adults, and younger adults improved more on two of the four training games in each training group. This showed that training effects were also modulated by age cohort differences, extending the findings from previous studies (Dahlin et al., 2008; Karbach and Kray, 2009; Heinzel et al. 2014). However, other factors that were less cognitive in nature might have contributed to this difference in training gain. For instance, less familiarity with computer games, computer interfaces or physical circumstances (such as arthritis in hands in a few cases) might have adversely affected the ability of the older adults to show as much gain. For the transfer effects, older adults did not show transfer as the younger adults did, which was the higher composite gains to divided attention with respect to the active control group. No such differences in composite gains were found for other cognitive abilities as well. Hence we concluded that the older adults showed no transfer to untrained tasks compared to the younger adults who showed transfer to divided attention. Presently, it is worthwhile to reiterate the explanations for why divided attention ability showed gains while the other cognitive abilities did not, which were offered by Baniqued et al. (2014). They proposed that changes to cognitive abilities may follow the developmental trajectory of lower-level attention abilities to higher-level abilities such as working memory and fluid intelligence, and the duration of training was able to change only the lower-level attention abilities. The alternative explanation was that the training tasks had common elements across reasoning, working memory and other attentional control paradigms, hence practicing on these tasks led to benefits for the common elements in divided attention abilities. Both explanations may be relevant to the case for older adults; however we did not find evidence for such transfer. Perhaps the duration of training or extent of improvement might not have been sufficient to affect transfer (Dahlin et al., 2008), in this case the lower-level attention abilities of the older adults. Analysis of the training gain scores showed that the older adults improved less than the younger adults in general. It was also important to note that the older adult’s mean performance for the last training session (Figure 2) did not match up to or surpass all of the younger adults’ mean performance for first training session, except for one game (Alphattack), unlike findings from Dahlin et al. (2008). Judging from the trajectories of the mean performance curves, it was difficult to predict the extent of improvements that could be achieved with more training sessions, although more improvement seemed promising for Alphattack, Sushi-go-round and Silversphere. Future studies should include longer duration of training, or one with different durations of training in order to assess effect of duration of training on degree and extent of transfer. Perhaps longer (or shorter) duration of training would show the anticipated transfer to working memory or reasoning for the younger adults, and a different timeline and pattern of transfer for the older adults.

Did gains to the training games correlate with gains at transfer? For both the WM-REAS and active control training games, we found no significant correlation for either older or younger adults between the averaged (composite) training gain and the cognitive construct composites. This meant that training gains to this group of games that were highly correlated with working memory and reasoning abilities did not predict improvements to cognitive abilities after training. Hence this did not support the findings of Jaeggi et al. (2011, 2014) that training-related transfer is predicted by the amount of improvement in the trained task. By analyzing the gains to individual training games, we found only one positive correlation between Alphattack training gains and reasoning composite gain for younger adults. Given that the analyses did not find overwhelming evidence supporting the hypothesis that training-related transfer was predicted by the amount of improvement in the trained task, it was more likely that training gain was not robustly related to transfer gain. This absence of a relationship between improvements on trained tasks and transfer assessment tests was also reported by Thompson et al. (2013).

We explored other individual difference factors that might have an effect on gains to cognitive abilities. Lower reasoning ability at initial testing was found to be predictive of higher divided attention gain for younger WM-REAS adults (Baniqued et al., 2014), suggesting that training with games highly correlated with working memory and reasoning was more effective from participants with lower initial reasoning ability. Analysis of the data from the older adults, who were found to have lower initial reasoning ability than the younger adults, showed no effect of training game type. However, lower initial reasoning ability was predictive of higher divided attention composite gain for older adults.

Initial reasoning ability was also found to be non-predictive for gains to episodic memory, perceptual speed and working memory for both younger and older adults. It was non-predictive for gains to reasoning for older adults, but lower initial reasoning ability was associated with higher reasoning gain for younger adults, similarly reported by Baniqued et al. (2014). This correlation of lower pre-training ability with higher composite gain scores in cognitive abilities was interesting because it did not support previous finding (Stine-Morrow et al., 2014) that a more positive cognitive profile showed more cognitive growth within age cohort, but supported that hypothesis when compared across the age cohorts. More research is needed to further understand this relationship between initial reasoning ability and gains in divided attention ability. Other individual differences such as age and years of education were found to be non-predictive of gains in divided attention ability for both younger and older adults, suggesting that gains in divided attention ability is not dependent on how old one is or how many years of formal education one has received. MMSE scores were also found to be non-predictive of divided attention ability gains for older adults, at least within the score range of 23 to 30 (maximum score).

The older adults group had higher odds of perceiving overall improvement due to the intervention (WM-REAS or active control games) and did not show transfer compared to the younger adults group. Therefore, it seemed that this expectation did not have an effect on the extent of transfer, at least in this case. More importantly for this study, we found no difference between the experimental and active control groups, so we could be confident that the transfer result in younger group and no transfer result in older group were not likely to be contributed by differential motivation and expectations.

Another interesting contrast between the age groups was the difference in their experience with the casual games. While the older adults group reported higher effort ratings overall compared to the younger adults as expected, they also reported higher motivation ratings in general, and increasing motivation ratings while the younger adults reported decreasing motivation. This was accompanied by the older WM-REAS group reporting increasing enjoyment and engagement ratings while the other groups had no significant differences to these scales. The older adults were more motivated, even though they found the games more effortful. This suggests that the casual games selection may be suitable for use with the older adults on larger-scale training paradigms, and may less likely to suffer from lack of interest or compliance issues (Boot, Champion et al., 2013). Studies have shown that playing with first person shooter games could result in improvements to perceptual and attentional control (Green & Bavelier, 2003, 2006, 2007), but older adults were found to be reluctant to play or continue such games due to the violent nature of these games. The higher enjoyment and engagement ratings for the older WM-REAS group suggest that they enjoyed the games with higher correlation with working memory and reasoning more, but were not accompanied with higher gains in any cognitive abilities compared to the older active control group. Correlation analyses between game experience ratings and gains in cognitive abilities found little evidence of association. Therefore the positive game experience played a necessary role for the acceptance of training paradigms, but may not necessarily predict the amount of gain to cognitive abilities. Also, the finding that motivation was higher with the older adults assured us that they probably did not lack motivation needed for transfer to occur (Karbach, 2014), compared to the younger adults who had lower motivation ratings but showed transfer to divided attention.

One caution for this study was the contribution of retest effects to the composite gains in the assessment tasks. These effects, that are improvements in pre-post assessment performance that do not interact with training group could be the result of practice, rather than any training specific effects. Specifically, while we did not find the Age x Group interaction effect that would suggest differential benefits as a function of training type for the older adult experimental group over the older active control (or transfer), the higher but non-significantly different gains to cognitive abilities compared to the younger adult data could represent benefits for both older groups in terms of delaying age-related cognitive decline. Hertzog et al. (2009) discussed this idea of the absence of Age x Activity interactions in cross-sectional data does not preclude the presence of cognitive enrichment, and that any manipulation that raise the level of cognitive functioning defers the point in time when cognitive decline reaches levels of negative functional consequences for self and society. Since we did not have the data of a non-training control group, we could not know the effect of taking these assessment tests twice (retest), and whether the experimental and/or active control groups showed any amelioration to age-related decline in cognitive abilities. In future studies, non-training controls could be included whenever time and resources are available, if information about retest, history and social contact effects are necessary. Another caution was a possibility that not all participants were challenged fully to their maximum abilities with their training games. This was because three of the four games in each training group were non-adaptive games, which meant that the participants would have to play through completed stages from the start of each training session to get to the new and more challenging stages. Hence the training sessions might have been more effective if all the games were adaptive, so that the participants would start at their last stage reached and spend more time being challenged. However, this point may not be that worrying, as findings from Baniqued et al. (2014) did not show much difference between the adaptive and non-adaptive WM-REAS younger adults training groups (cf. Li et al., 2008; Dahlin et al., 2008; von Bastion et al., 2013). Future studies could include another adaptive active control group so as to investigate the importance of adaptive training.

In conclusion, we found that while training gains were possible over the adult lifespan, the transfer to divided attention ability was found for younger adults but not for older adults. We explored the possible explanations for this finding, and suggested future studies to explore issues such as training duration and adaptive training. We also found that casual video games may be suitable as training paradigms in terms of compliance and adherence issues, as experience ratings for these games were positive. Finally, we caution against using games as the only means to maintain or improve cognitive abilities, as there are still many unknowns about cognitive interventions, including relative effectiveness of each method, efficacy due to individual differences and the interaction of these factors.

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APPENDIX A: TABLES AND FIGURES

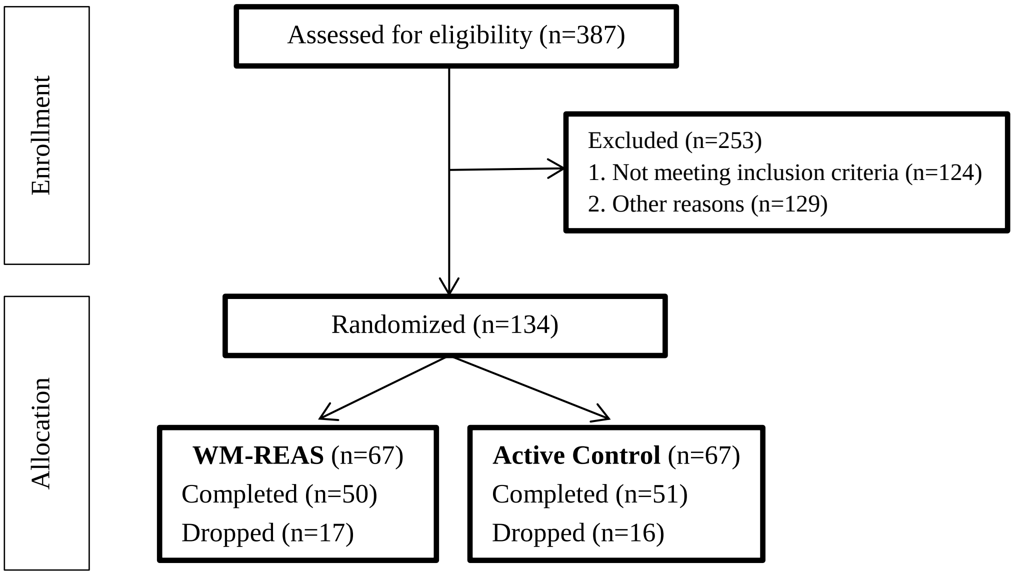


Figure 1: Consolidated Standards of Reporting Trials (CONSORT) diagram charting the follow of participants through the study. WM-REAS refers to the working memory and reasoning experimental group.

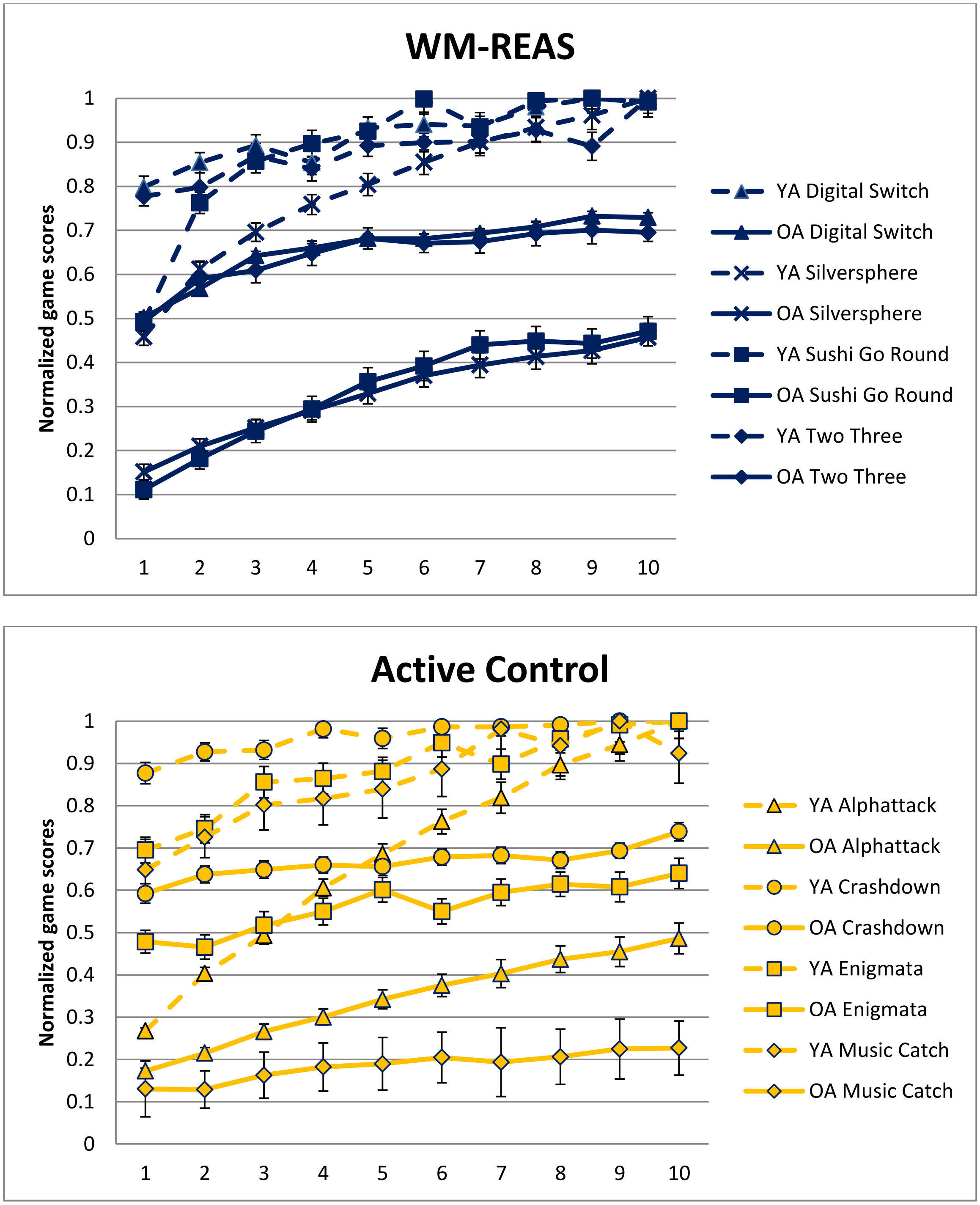


Figure 2: Mean training game performance as a function of training game, age group and session. Group average scores at each session, normalized by each game's maximum average score. YA and OA refer to younger and older adults respectively.

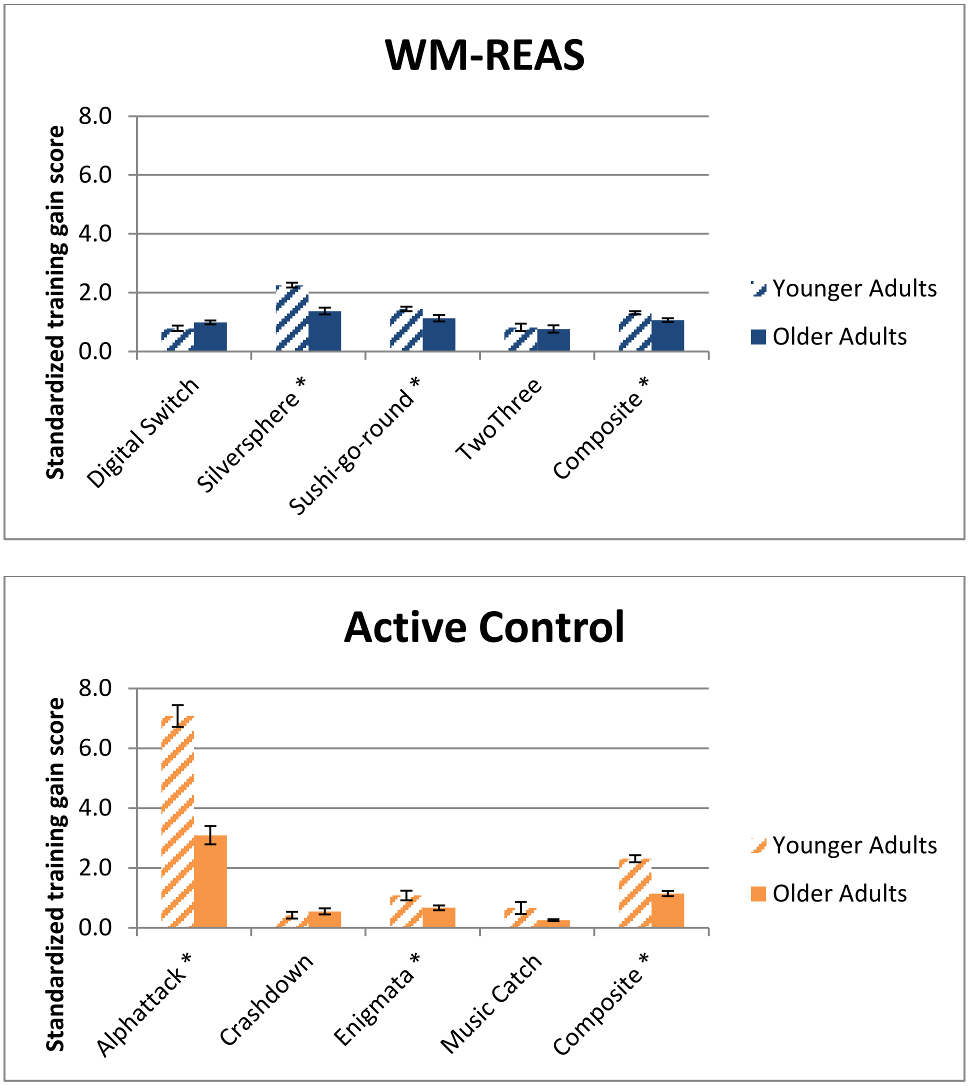


Figure 3: Standardized training gain as a function of composite and training game, age and group. Asterisks denote significant difference ($p < 0.05$) in training gain scores between younger and older adults.

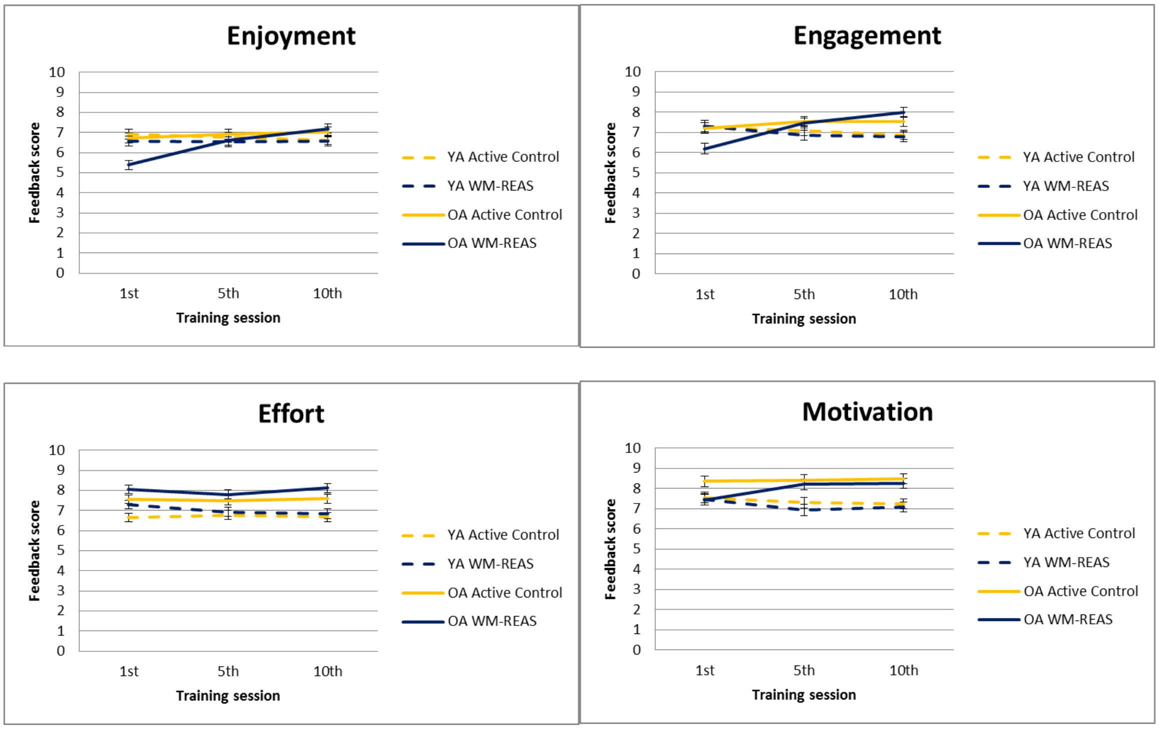


Figure 4: Training game feedback as a function of age, group and session. Feedback regarding game enjoyment, motivation, engagement and effort were collected at the end of the first, fifth and last training sessions. Feedback scale: 1 = least, 10 = greatest. YA and OA refer to younger and older adults respectively.

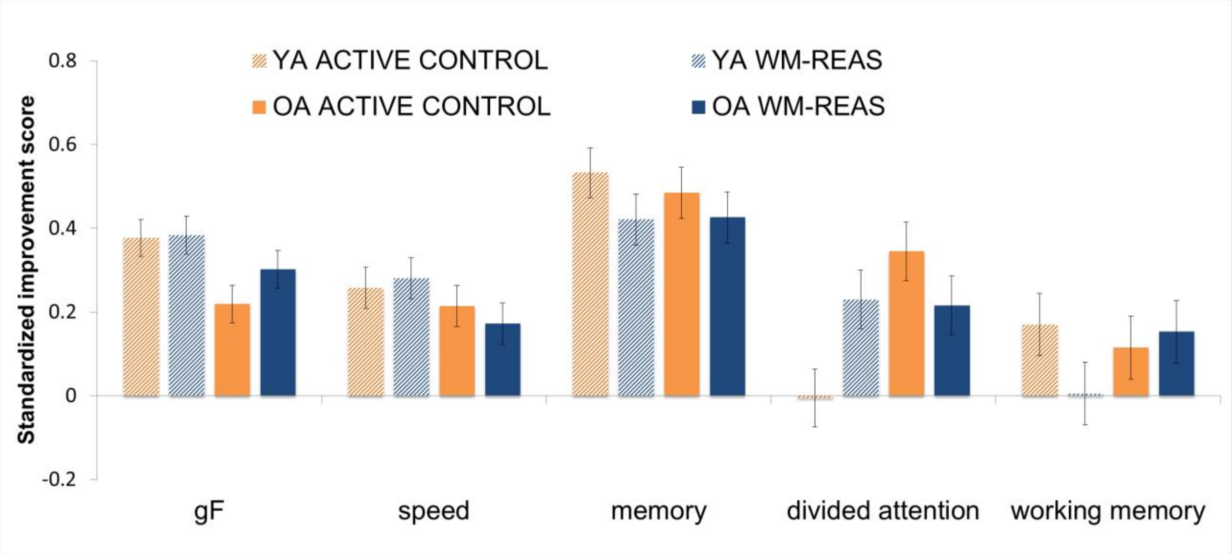


Figure 5: Transfer gain as a function of composite, group and age cohort. Error bars represent standard error. YA and OA refer to younger and older adults respectively.

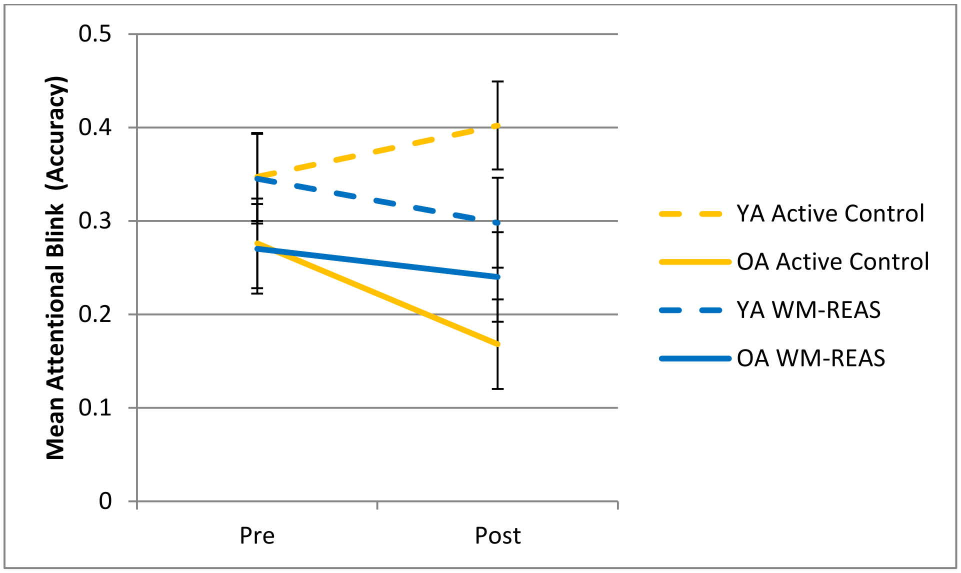


Figure 6: Mean Attentional Blink (Lag 8 accuracy – lag 2 accuracy) as a function of time, age and training group. Error bars represent standard error. YA and OA refer to younger and older adults respectively.

Table 1: Participant Demographics

	Younger adults WM-REAS	Younger adults Active control	Older adults WM-REAS	Older adults Active control
Women/men (n)	31/12	32/12	23/20	29/14
Mean age (years)	21.16 (2.25)	20.80 (2.10)	66.81 (5.70)	65.91 (5.39)
Mean years of education	14.91 (1.19)	14.75 (1.28)	16.40 (3.33)	16.29 (3.10)
Mean MMSE score	-	-	28.67 (1.57)	28.72 (1.68)

Note: Standard deivations are given in parentheses. MMSE is the Mini-Mental State Examination (Folstein et al., 1975).

Table 2: Session and order of cognitive assessment tests

Session	Assessment test	Category	Reference
1	Digit symbol substitution	Perceptual speed	Wechsler (1997a)
	Word recall	Episodic memory	Wechsler (1997b)
	Pattern comparison	Perceptual speed	Salthouse and Babcock (1991)
	Letter comparison	Perceptual speed	Salthouse and Babcock (1991)
	Logical memory	Episodic memory	Wechsler (1997b)
	Shipley abstract	Reasoning/gF	Zachary and Shipley (1986)
	Trail making	Attention	Reitan (1958)
	Paper folding	Reasoning/gF	Ekstrom, French, Harman & Dermen (1976)
	Paired associates	Episodic memory	Salthouse, Fristoe & Rhee (1996)
	Spatial relations	Reasoning/gF	Bennett et al. (1997)
	Form boards	Reasoning/gF	Ekstrom, French, Harman & Dermen (1976)
	Letter sets	Reasoning/gF	Ekstrom, French, Harman & Dermen (1976)
2	Visual short term memory	Working memory	Luck and Vogel (1997)
	Attentional blink	Attention	Raymond, Shapiro & Arnell (1992)
	Task switching	Attention	Kramer, Hahn & Gopher (1999); Pashler (2000)
	Symmetry span	Working memory	Redick et al. (2013)
3	N-back	Working memory	Kirchner (1958); Kane, Conway, Miura & Colflesh (2007)
	Color Stroop	Attention	Stroop (1935, 1992)
	Running span	Working memory	Broadway and Engle (2010)
	Spatial working memory	Working memory	Erickson et al. (2011)
4	Bloxorz	Game – reasoning/gF	miniclip.com
	Dodge	Game – attention	armorgames.com

Table 3: Training games

Training games	**Group**	**Description**	**Primary measure**	**Source**
Digital Switch	WM-REAS	In the main game, switch “digibot” positions to collect falling coins corresponding to the same “digibot” color.	Maximum level reached	miniclip.com
Silversphere	WM-REAS	Move a sphere to a blue vortex by creating a path with blocks of different features, while avoiding falling off the platform and other obstacles.	Maximum level reached	miniclip.com
Sushi Go Round	WM-REAS	Serve a certain number of customers in the allotted time by learning and preparing different recipes correctly, cleaning tables, and ordering ingredients.	Maximum money earned in a day	miniclip.com
Two Three	WM-REAS	Subtracting presented numbers to 0 by shooting units of 2 or 3, before they fall to the bottom.	Maximum level reached	armorgames.com
Alphattack	Active Control	Destroy bombs attacking the city by typing the alpha-numerals specified on the approaching bombs. There are three main stages of difficulty with levels in each.	Estimated maximum level reached (level x difficulty)	miniclip.com
Crashdown	Active Control	Click on groups of three or more same colored blocks, in order to prevent the blocks from accumulating to the top of the screen.	Maximum level reached	miniclip.com
Enigmata	Active Control	Navigate a ship while avoiding and destroying enemies, and collecting objects that provide armor or power.	Maximum level reached	maxgames.com
Music Catch 2	Active Control	Earn points by moussing over streams of colored shapes and avoiding contiguously appearing red shapes.	Mean points	reflexive.com

Table 4: Primary measure of each training game as a function of age and training session.

Training Results

Training games	Group	Primary measure	Session	Age	Session x Age	Younger adults		Older adults	
						1st	10th	1st	10th
Digital Switch	WM-REAS	Maximum level reached	$F(9, 630) = 36.719$, $p < 0.001$, $\eta_p^2 = 0.344$	$F(1, 70) = 108.259$, $p < 0.001$, $\eta_p^2 = 0.607$	$F(9, 630) = 1.527$, $p = 0.135$, $\eta_p^2 = 0.021$	6.516 (0.205)	8.097 (0.209)	4.098 (0.178)	5.951 (0.182)
Silversphere	WM-REAS	Maximum level reached	$F(9, 567) = 315.610$, $p < 0.001$, $\eta_p^2 = 0.834$	$F(1, 63) = 193.902$, $p < 0.001$, $\eta_p^2 = 0.755$	$F(9, 567) = 21.644$, $p < 0.001$, $\eta_p^2 = 0.256$	8.733 (0.362)	19.067 (0.653)	2.886 (0.335)	8.714 (0.605)
Sushi Go Round	WM-REAS	Maximum money earned in a day	$F(9, 648) = 110.116$, $p < 0.001$, $\eta_p^2 = 0.605$	$F(1, 72) = 242.809$, $p < 0.001$, $\eta_p^2 = 0.771$	$F(9, 648) = 6.989$, $p < 0.001$, $\eta_p^2 = 0.088$	2863.056 (128.537)	5762.500 (198.892)	645.263 (125.109)	2736.579 (193.587)
Two Three	WM-REAS	Maximum level reached	$F(9, 711) = 17.812$, $p < 0.001$, $\eta_p^2 = 0.184$	$F(1, 79) = 77.023$, $p < 0.001$, $\eta_p^2 = 0.494$	$F(9, 711) = 1.708$, $p = 0.083$, $\eta_p^2 = 0.021$	15.675 (0.430)	20.175 (0.405)	9.951 (0.425)	14.024 (0.400)
Alphattack	Active control	Estimated maximum level reached (level x difficulty)	$F(9, 621) = 214.434$, $p < 0.001$, $\eta_p^2 = 0.757$	$F(1, 69) = 118.621$, $p < 0.001$, $\eta_p^2 = 0.632$	$F(9, 621) = 33.794$, $p < 0.001$, $\eta_p^2 = 0.329$	13.906 (0.389)	52.000 (2.094)	8.974 (0.352)	25.282 (1.897)
Crashdown	Active control	Maximum level reached	$F(9, 639) = 11.075$, $p < 0.001$, $\eta_p^2 = 0.135$	$F(1, 71) = 205.592$, $p < 0.001$, $\eta_p^2 = 0.743$	$F(9, 639) = 0.649$, $p = 0.755$, $\eta_p^2 = 0.009$	5.848 (0.168)	6.667 (0.160)	3.950 (0.153)	4.925 (0.145)
Enigmata	Active control	Maximum level reached	$F(9, 585) = 26.993$, $p < 0.001$, $\eta_p^2 = 0.293$	$F(1, 65) = 72.793$, $p < 0.001$, $\eta_p^2 = 0.528$	$F(9, 585) = 3.330$, $p = 0.001$, $\eta_p^2 = 0.049$	2.828 (0.126)	4.069 (0.168)	1.947 (0.110)	2.605 (0.146)
Music Catch 2	Active control	Mean points	$F(9, 576) = 4.405$, $p < 0.001$, $\eta_p^2 = 0.064$	$F(1, 64) = 100.412$, $p < 0.001$, $\eta_p^2 = 0.611$	$F(9, 576) = 1.425$, $p = 0.174$, $\eta_p^2 = 0.022$	5212378.167 (582106.373)	7426197.767 (565545.257)	1047473.353 (531387.986)	1825234.326 (516269.824)

Table 5: Composite scores at pre-training as a function of age and training group.

Baseline checks Composite				**Younger adults**		**Older adults**	
Composite Pre-Training	**Age**	**Group**	**Age x Group**	**Active Control**	**WM-REAS**	**Active Control**	**WM-REAS**
Divided Attention	$F(1,169) = 13.485$, $p < 0.001$, $\eta_p^2 = 0.074$	$F(1,169) = 2.397$, $p = 0.123$, $\eta_p^2 = 0.014$	$F(1,169) = 0.293$, $p = 0.589$, $\eta_p^2 = 0.002$	0.101 (0.077)	0.179 (0.078)	-0.226 (0.078)	-0.064 (0.078)
Episodic Memory	$F(1,169) = 74.648$, $p < 0.001$, $\eta_p^2 = 0.306$	$F(1,169) = 0.002$, $p = 0.961$, $\eta_p^2 < 0.001$	$F(1,169) = 0.017$, $p = 0.897$, $\eta_p^2 < 0.001$	0.466 (0.107)	0.447 (0.109)	-0.483 (0.109)	-0.475 (0.109)
Perceptual Speed	$F(1,169) = 228.642$, $p < 0.001$, $\eta_p^2 = 0.575$	$F(1,169) = 0.468$, $p = 0.495$, $\eta_p^2 = 0.003$	$F(1,169) = 0.162$, $p = 0.688$, $\eta_p^2 = 0.001$	0.700 (0.091)	0.674 (0.092)	-0.646 (0.092)	-0.745 (0.092)
Reasoning or gF	$F(1,169) = 112.832$, $p < 0.001$, $\eta_p^2 = 0.400$	$F(1,169) = 1.924$, $p = 0.167$, $\eta_p^2 = 0.011$	$F(1,169) = 1.030$, $p = 0.312$, $\eta_p^2 = 0.006$	0.597 (0.091)	0.376 (0.092)	-0.474 (0.092)	-0.508 (0.092)
Working Memory	F $F(1,169) = 92.468$, $p < 0.001$, $\eta_p^2 = 0.354$	$F(1,169) = 1.732$, $p = 0.190$, $\eta_p^2 = 0.010$	$F(1,169) = 0.479$, $p = 0.490$, $\eta_p^2 = 0.003$	0.447 (0.084)	0.395 (0.085)	-0.306 (0.085)	-0.476 (0.085)

Table 6: Composite gain scores as a function of age and training group.

Transfer Results

				Younger adults		**Older adults**	
Composite Gain	**Age**	**Group**	**Age x Group**	**Active Control**	**WM-REAS**	**Active Control**	**WM-REAS**
Divided Attention	$F(1,169) = 5.725$, $p = 0.018$, $\eta_p^2 = 0.033$	$F(1,169) = 0.565$, $p = 0.453$, $\eta_p^2 = 0.003$	$F(1,169) = 6.761$, $p = 0.010$, $\eta_p^2 = 0.038$	-0.005 (0.069)	0.230 (0.070)	0.345 (0.070)	0.216 (0.070)
Episodic Memory	$F(1,169) = 0.128$, $p = 0.721$, $\eta_p^2 = 0.001$	$F(1,169) = 1.973$, $p = 0.162$, $\eta_p^2 = 0.012$	$F(1,169) = 0.191$, $p = 0.663$, $\eta_p^2 = 0.001$	0.533 (0.060)	0.421 (0.061)	0.485 (0.061)	0.426 (0.061)
Perceptual Speed	$F(1,169) = 2.361$, $p = 0.126$, $\eta_p^2 = 0.014$	$F(1,169) = 0.040$, $p = 0.841$, $\eta_p^2 < 0.001$	$F(1,169) = 0.418$, $p = 0.519$, $\eta_p^2 = 0.002$	0.258 (0.049)	0.280 (0.049)	0.214 (0.049)	0.172 (0.049)
Reasoning or gF	$F(1,169) = 7.225$, $p = 0.008$, $\eta_p^2 = 0.041$	$F(1,169) = 1.003$, $p = 0.318$, $\eta_p^2 = 0.006$	$F(1,169) = 0.762$, $p = 0.384$, $\eta_p^2 = 0.004$	0.377 (0.044)	0.383 (0.045)	0.219 (0.045)	0.302 (0.045)
Working Memory	$F(1,169) = 0.392$, $p = 0.532$, $\eta_p^2 = 0.002$	$F(1,169) = 0.721$, $p = 0.397$, $\eta_p^2 = 0.004$	$F(1,169) = 1.859$, $p = 0.175$, $\eta_p^2 = 0.011$	0.170 (0.074)	0.005 (0.075)	0.115 (0.075)	0.153 (0.075)

Table 7: Mean task performance as a function of age, training group and test session.

Transfer Results				**Younger adults**				**Older adults**			
				ACTIVE CONTROL		**WM-REAS**		**ACTIVE CONTROL**		**WM-REAS**	
Task	**Time x Group**	**Time x Age**	**Time x Group x Age**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Attentional Blink Lag 2 (Accuracy)	$F(1, 168) = 0.057$, $p = 0.812$, $\eta_p^2 < 0.001$	$F(1, 168) = 2.162$, $p = 0.143$, $\eta_p^2 = 0.013$	$F(1, 168) = 2.736$, $p = 0.100$, $\eta_p^2 = 0.016$	0.444 (0.041)	0.475 (0.045)	0.424 (0.041)	0.504 (0.046)	0.425 (0.041)	0.565 (0.046)	0.481 (0.041)	0.554 (0.046)
Attentional Blink Lag 8 (Accuracy)	$F(1, 168) = 0.621$, $p = 0.432$, $\eta_p^2 = 0.004$	$F(1, 168) = 0.744$, $p = 0.390$, $\eta_p^2 = 0.004$	$F(1, 168) = 1.644$, $p = 0.202$, $\eta_p^2 = 0.010$	0.792 (0.032)	0.876 (0.027)	0.769 (0.032)	0.802 (0.027)	0.701 (0.033)	0.733 (0.028)	0.751 (0.032)	0.795 (0.027)
Attentional Blink Effect, Lag 8 - Lag 2 (Accuracy)	$F(1, 168) = 0.073$, $p = 0.788$, $\eta_p^2 < 0.001$	$F(1, 168) = 3.188$, $p = 0.076$, $\eta_p^2 = 0.019$	$F(1, 168) = 4.824$, $p = 0.029$, $\eta_p^2 = 0.028$	0.347 (0.047)	0.402 (0.049)	0.345 (0.048)	0.298 (0.050)	0.276 (0.048)	0.168 (0.050)	0.270 (0.048)	0.240 (0.050)
Dodge (Last level completed)	$F(1, 163) = 0.059$, $p = 0.809$, $\eta_p^2 < 0.001$	$F(1, 163) = 3.876$, $p = 0.051$, $\eta_p^2 = 0.023$	$F(1, 163) = 2.877$, $p = 0.092$, $\eta_p^2 = 0.017$	8.929 (0.236)	9.167 (0.195)	8.897 (0.245)	9.538 (0.202)	6.047 (0.234)	7.047 (0.192)	6.047 (0.234)	6.744 (0.192)
Trail Making, Trails A (s)	$F(1, 165) = 0.633$, $p = 0.427$, $\eta_p^2 = 0.004$	$F(1, 165) = 0.860$, $p = 0.355$, $\eta_p^2 = 0.005$	$F(1, 165) = 0.483$, $p = 0.488$, $\eta_p^2 = 0.003$	26.497 (1.448)	22.222 (1.200)	27.592 (1.465)	23.434 (1.214)	34.239 (1.483)	30.233 (1.229)	34.884 (1.448)	32.601 (1.200)
Trail Making, Trails B (s)	$F(1, 165) = 0.503$, $p = 0.479$, $\eta_p^2 = 0.003$	$F(1, 165) = 0.123$, $p = 0.726$, $\eta_p^2 = 0.001$	$F(1, 165) = 1.143$, $p = 0.287$, $\eta_p^2 = 0.007$	47.737 (3.688)	42.368 (2.507)	54.549 (3.731)	44.297 (2.537)	73.214 (3.731)	63.944 (2.537)	80.664 (3.731)	72.384 (2.537)
Trail Making, Trails B - A (s)	$F(1, 166) = 0.821$, $p = 0.366$, $\eta_p^2 = 0.005$	$F(1, 166) = 0.212$, $p = 0.646$, $\eta_p^2 = 0.001$	$F(1, 166) = 0.620$, $p = 0.432$, $\eta_p^2 = 0.004$	21.241 (3.275)	20.146 (2.352)	26.958 (3.313)	20.863 (2.380)	36.721 (3.313)	31.942 (2.380)	47.142 (3.275)	42.015 (2.352)
Logical Memory (Total correct)	$F(1, 169) = 0.063$, $p = 0.803$, $\eta_p^2 < 0.001$	$F(1, 169) = 0.019$, $p = 0.891$, $\eta_p^2 < 0.001$	$F(1, 169) = 0.087$, $p = 0.768$, $\eta_p^2 = 0.001$	48.227 (1.361)	52.977 (1.300)	48.535 (1.376)	52.721 (1.315)	42.326 (1.376)	46.628 (1.315)	43.535 (1.376)	47.884 (1.315)
Paired Associates (Accuracy)	$F(1, 156) = 1.750$, $p = 0.188$, $\eta_p^2 = 0.011$	$F(1, 156) = 2.941$, $p = 0.088$, $\eta_p^2 = 0.019$	$F(1, 156) = 0.365$, $p = 0.547$, $\eta_p^2 = 0.002$	0.661 (0.038)	0.807 (0.037)	0.618 (0.038)	0.701 (0.037)	0.348 (0.039)	0.419 (0.038)	0.359 (0.039)	0.406 (0.038)
Word Recall (Total correct)	$F(1, 169) = 1.363$, $p = 0.245$, $\eta_p^2 = 0.008$	$F(1, 169) = 1.876$, $p = 0.173$, $\eta_p^2 = 0.011$	$F(1, 169) = 0.321$, $p = 0.572$, $\eta_p^2 = 0.002$	53.341 (1.150)	58.636 (1.063)	53.651 (1.163)	58.512 (1.076)	43.674 (1.163)	50.372 (1.076)	42.674 (1.163)	48.116 (1.076)
Digit Symbol Substitution (Total correct)	$F(1, 164) = 1.914$, $p = 0.168$, $\eta_p^2 = 0.012$	$F(1, 164) = 0.266$, $p = 0.606$, $\eta_p^2 = 0.002$	$F(1, 164) = 0.126$, $p = 0.723$, $\eta_p^2 = 0.001$	96.093 (2.224)	103.093 (2.168)	93.881 (2.250)	99.690 (2.194)	69.209 (2.224)	76.023 (2.168)	65.875 (2.306)	70.675 (2.248)

(Continued)

Table 7: Continued

Transfer Results				**Younger adults**				**Older adults**			
				ACTIVE CONTROL		**WM-REAS**		**ACTIVE CONTROL**		**WM-REAS**	
Task	**Time x Group**	**Time x Age**	**Time x Group x Age**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Letter Comparison (Mean correct)	$F(1, 169) = 0.272$, $p = 0.603$, $\eta_p^2 = 0.002$	$F(1, 169) = 0.073$, $p = 0.787$, $\eta_p^2 < 0.001$	$F(1, 169) = 0.230$, $p = 0.632$, $\eta_p^2 = 0.001$	12.977 (0.330)	13.523 (0.353)	13.302 (0.334)	13.570 (0.357)	9.616 (0.334)	9.953 (0.357)	9.442 (0.334)	9.767 (0.357)
Pattern Comparison (Mean correct)	$F(1, 169) = 1.497$, $p = 0.223$, $\eta_p^2 = 0.009$	$F(1, 169) = 5.148$, $p = 0.025$, $\eta_p^2 = 0.030$	$F(1, 169) = 2.585$, $p = 0.110$, $\eta_p^2 = 0.015$	21.682 (0.438)	22.716 (0.433)	21.465 (0.443)	23.442 (0.438)	15.000 (0.443)	15.814 (0.438)	14.860 (0.443)	15.547 (0.438)
Bloxorz (Last level completed)	$F(1, 164) = 0.583$, $p = 0.446$, $\eta_p^2 = 0.004$	$F(1, 164) = 4.769$, $p = 0.030$, $\eta_p^2 = 0.028$	$F(1, 164) = 1.332$, $p = 0.250$, $\eta_p^2 = 0.008$	4.405 (0.137)	5.119 (0.147)	4.317 (0.139)	4.976 (0.149)	3.452 (0.137)	3.690 (0.147)	3.558 (0.136)	4.070 (0.145)
Form Boards (Total correct)	$F(1, 168) = 0.393$, $p = 0.532$, $\eta_p^2 = 0.002$	$F(1, 168) = 14.011$, $p < 0.001$, $\eta_p^2 = 0.077$	$F(1, 168) = 0.017$, $p = 0.897$, $\eta_p^2 < 0.001$	10.909 (0.588)	13.364 (0.633)	9.628 (0.594)	12.326 (0.641)	5.302 (0.594)	5.860 (0.641)	5.429 (0.602)	6.357 (0.648)
Letter Sets (Total correct)	$F(1, 166) = 0.006$, $p = 0.939$, $\eta_p^2 < 0.001$	$F(1, 166) = 0.447$, $p = 0.505$, $\eta_p^2 = 0.003$	$F(1, 166) = 0.447$, $p = 0.505$, $\eta_p^2 = 0.003$	12.884 (0.372)	13.140 (0.330)	12.095 (0.376)	12.571 (0.334)	11.000 (0.372)	11.651 (0.330)	10.905 (0.376)	11.381 (0.334)
Paper Folding (Total correct)	$F(1, 169) = 0.015$, $p = 0.903$, $\eta_p^2 < 0.001$	$F(1, 169) = 0.094$, $p = 0.760$, $\eta_p^2 = 0.001$	$F(1, 169) = 0.228$, $p = 0.633$, $\eta_p^2 = 0.001$	8.932 (0.353)	9.773 (0.356)	7.953 (0.357)	8.698 (0.360)	5.372 (0.357)	6.000 (0.360)	4.953 (0.357)	5.744 (0.360)
Spatial Relations (Total correct)	$F(1, 168) = 0.008$, $p = 0.930$, $\eta_p^2 < 0.001$	$F(1, 168) = 0.105$, $p = 0.746$, $\eta_p^2 = 0.001$	$F(1, 168) = 0.383$, $p = 0.537$, $\eta_p^2 = 0.002$	13.395 (0.655)	14.674 (0.683)	11.535 (0.655)	13.023 (0.683)	6.512 (0.655)	8.163 (0.683)	7.256 (0.655)	8.628 (0.683)
Shipley Abstract (Total correct)	$F(1, 169) = 0.811$, $p = 0.369$, $\eta_p^2 = 0.005$	$F(1, 169) = 0.781$, $p = 0.378$, $\eta_p^2 = 0.005$	$F(1, 169) = 2.107$, $p = 0.148$, $\eta_p^2 = 0.012$	15.909 (0.431)	17.114 (0.402)	15.814 (0.436)	16.860 (0.407)	12.535 (0.436)	13.070 (0.407)	11.442 (0.436)	12.651 (0.407)

(Continued)

Table 7: Continued

Transfer Results				**Younger adults**				**Older adults**			
				ACTIVE CONTROL		**WM-REAS**		**ACTIVE CONTROL**		**WM-REAS**	
Task	**Time x Group**	**Time x Age**	**Time x Group x Age**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
N-back, 2-back accuracy	$F(1, 166) = 0.055$, $p = 0.815$, $\eta_p^2 < 0.001$	$F(1, 166) = 10.314$, $p = 0.002$, $\eta_p^2 = 0.058$	$F(1, 166) = 0.458$, $p = 0.499$, $\eta_p^2 = 0.003$	0.955 (0.017)	0.964 (0.015)	0.947 (0.017)	0.951 (0.016)	0.832 (0.017)	0.874 (0.016)	0.823 (0.017)	0.877 (0.015)
N-back, 3-back accuracy	$F(1, 166) = 0.139$, $p = 0.710$, $\eta_p^2 = 0.001$	$F(1, 166) = 14.507$, $p < 0.001$, $\eta_p^2 = 0.080$	$F(1, 166) = 1.029$, $p = 0.312$, $\eta_p^2 = 0.006$	0.861 (0.017)	0.878 (0.015)	0.882 (0.017)	0.880 (0.015)	0.745 (0.017)	0.799 (0.015)	0.722 (0.017)	0.784 (0.015)
N-back, 2-back d'	$F(1, 159) = 0.198$, $p = 0.657$, $\eta_p^2 = 0.001$	$F(1, 159) = 2.858$, $p = 0.093$, $\eta_p^2 = 0.018$	$F(1, 159) = 0.711$, $p = 0.400$, $\eta_p^2 = 0.004$	4.725 (0.294)	5.263 (0.361)	4.552 (0.298)	4.591 (0.366)	2.636 (0.305)	3.502 (0.375)	2.751 (0.313)	3.772 (0.384)
N-back, 3-back d'	$F(1, 158) = 1.673$, $p = 0.198$, $\eta_p^2 = 0.010$	$F(1, 158) = 1.379$, $p = 0.242$, $\eta_p^2 = 0.009$	$F(1, 158) = 1.429$, $p = 0.234$, $\eta_p^2 = 0.009$	2.590 (0.202)	2.454 (0.191)	2.354 (0.205)	2.672 (0.194)	1.506 (0.212)	1.803 (0.201)	1.496 (0.215)	1.810 (0.204)
Running Span (Total correct)	$F(1, 167) = 0.321$, $p = 0.572$, $\eta_p^2 = 0.002$	$F(1, 167) = 3.849$, $p = 0.051$, $\eta_p^2 = 0.023$	$F(1, 167) = 3.403$, $p = 0.067$, $\eta_p^2 = 0.020$	20.721 (0.914)	22.814 (1.005)	21.833 (0.925)	21.952 (1.017)	18.349 (0.914)	17.326 (1.005)	15.140 (0.914)	15.163 (1.005)
Spatial Working Memory, accuracy	$F(1, 166) = 1.364$, $p = 0.245$, $\eta_p^2 = 0.008$	$F(1, 166) = 0.030$, $p = 0.862$, $\eta_p^2 < 0.001$	$F(1, 166) = 0.818$, $p = 0.367$, $\eta_p^2 = 0.005$	0.883 (0.011)	0.892 (0.019)	0.882 (0.011)	0.852 (0.020)	0.872 (0.011)	0.867 (0.020)	0.844 (0.011)	0.834 (0.019)
Spatial Working Memory, d'	$F(1, 163) = 0.047$, $p = 0.829$, $\eta_p^2 < 0.001$	$F(1, 163) = 1.560$, $p = 0.213$, $\eta_p^2 = 0.009$	$F(1, 163) = 3.455$, $p = 0.065$, $\eta_p^2 = 0.021$	2.846 (0.153)	3.065 (0.187)	2.941 (0.158)	2.807 (0.193)	2.800 (0.158)	2.915 (0.193)	2.557 (0.158)	2.952 (0.193)
Symmetry Span (Total correct)	$F(1, 128) = 0.169$, $p = 0.682$, $\eta_p^2 = 0.001$	$F(1, 128) = 2.298$, $p = 0.132$, $\eta_p^2 = 0.018$	$F(1, 128) = 2.280$, $p = 0.134$, $\eta_p^2 = 0.018$	21.080 (1.459)	25.560 (1.586)	18.190 (1.592)	20.476 (1.730)	7.186 (1.113)	8.209 (1.209)	6.395 (1.113)	8.674 (1.209)
Visual STM, overall accuracy	$F(1, 168) = 0.367$, $p = 0.545$, $\eta_p^2 = 0.002$	$F(1, 168) = 2.483$, $p = 0.117$, $\eta_p^2 = 0.015$	$F(1, 168) = 0.059$, $p = 0.809$, $\eta_p^2 < 0.001$	0.812 (0.008)	0.806 (0.008)	0.795 (0.008)	0.795 (0.008)	0.723 (0.008)	0.731 (0.008)	0.704 (0.008)	0.714 (0.008)
Visual STM, overall d'	$F(1, 168) = 0.547$, $p = 0.461$, $\eta_p^2 = 0.003$	$F(1, 168) = 1.289$, $p = 0.258$, $\eta_p^2 = 0.008$	$F(1, 168) = 0.028$, $p = 0.868$, $\eta_p^2 < 0.001$	1.840 (0.057)	1.813 (0.061)	1.741 (0.057)	1.761 (0.061)	1.278 (0.057)	1.318 (0.061)	1.118 (0.057)	1.187 (0.061)

(Continued)

Table 7: Continued

Transfer Results				**Younger adults**				**Older adults**			
				ACTIVE CONTROL		**WM-REAS**		**ACTIVE CONTROL**		**WM-REAS**	
Task	**Time x Group**	**Time x Age**	**Time x Group x Age**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Visual STM, both d'	*F*(1, 159) = 0.361, *p* = 0.549, $\eta_p^2 = 0.002$	*F*(1, 159) = 0.187, *p* = 0.666, $\eta_p^2 = 0.001$	*F*(1, 159) = 0.368, *p* = 0.545, $\eta_p^2 = 0.002$	1.281 (0.098)	1.384 (0.098)	1.308 (0.098)	1.411 (0.098)	0.927 (0.108)	1.135 (0.107)	0.866 (0.101)	0.951 (0.101)
Visual STM, color d'	*F*(1, 168) = 1.642, *p* = 0.202, $\eta_p^2 = 0.010$	*F*(1, 168) = 0.660, *p* = 0.418, $\eta_p^2 = 0.004$	*F*(1, 168) = 0.744, *p* = 0.390, $\eta_p^2 = 0.004$	2.943 (0.136)	3.008 (0.153)	3.029 (0.136)	2.757 (0.153)	1.937 (0.136)	1.993 (0.153)	1.713 (0.136)	1.703 (0.153)
Visual STM, shape d'	*F*(1, 168) = 1.420, *p* = 0.235, $\eta_p^2 = 0.008$	*F*(1, 168) = 0.034, *p* = 0.854, $\eta_p^2 < 0.001$	*F*(1, 168) = 0.072, *p* = 0.789, $\eta_p^2 < 0.001$	1.979 (0.111)	1.884 (0.122)	1.857 (0.111)	1.887 (0.122)	1.417 (0.111)	1.311 (0.122)	1.032 (0.111)	1.122 (0.122)
Stroop, Incongruent - congruent (ms)	*F*(1, 165) = 0.300, *p* = 0.585, $\eta_p^2 = 0.002$	*F*(1, 165) = 0.006, *p* = 0.939, $\eta_p^2 < 0.001$	*F*(1, 165) = 0.003, *p* = 0.958, $\eta_p^2 < 0.001$	80.306 (8.647)	80.088 (7.938)	82.642 (8.958)	78.122 (8.223)	118.296 (8.958)	119.211 (8.223)	110.835 (8.747)	106.521 (8.030)
Stroop, Incongruent - neutral (ms)	*F*(1, 165) < 0.001, *p* = 0.997, $\eta_p^2 < 0.001$	*F*(1, 165) = 0.304, *p* = 0.582, $\eta_p^2 = 0.002$	*F*(1, 165) = 1.111, *p* = 0.293, $\eta_p^2 = 0.007$	62.070 (7.680)	47.242 (7.502)	51.439 (7.956)	45.966 (7.772)	92.353 (7.956)	91.815 (7.772)	85.329 (7.769)	75.378 (7.589)
Task Switch, Single - Repeat (accuracy)	*F*(1, 163) = 0.098, *p* = 0.754, $\eta_p^2 = 0.001$	*F*(1, 163) = 1.882, *p* = 0.172, $\eta_p^2 = 0.011$	*F*(1, 163) = 0.256, *p* = 0.613, $\eta_p^2 = 0.002$	0.014 (0.027)	0.029 (0.016)	0.023 (0.027)	0.032 (0.016)	0.026 (0.027)	-0.015 (0.016)	0.040 (0.027)	0.023 (0.016)
Task Switch, Repeat - Single (ms)	*F*(1, 162) = 0.245, *p* = 0.621, $\eta_p^2 = 0.002$	*F*(1, 162) = 2.025, *p* = 0.157, $\eta_p^2 = 0.012$	*F*(1, 162) = 2.108, *p* = 0.148, $\eta_p^2 = 0.013$	180.445 (16.601)	180.937 (16.195)	192.300 (16.802)	172.870 (16.392)	258.017 (16.601)	198.654 (16.195)	208.203 (16.802)	189.372 (16.392)
Task Switch, Repeat - Switch (accuracy)	*F*(1, 163) = 0.083, *p* = 0.774, $\eta_p^2 = 0.001$	*F*(1, 163) = 0.131, *p* = 0.718, $\eta_p^2 = 0.001$	*F*(1, 163) = 0.032, *p* = 0.859, $\eta_p^2 < 0.001$	0.015 (0.009)	0.015 (0.007)	0.021 (0.009)	0.016 (0.007)	0.013 (0.009)	0.014 (0.007)	0.021 (0.009)	0.021 (0.007)
Task Switch, Switch - Repeat (ms)	*F*(1, 162) = 1.334, *p* = 0.250, $\eta_p^2 = 0.008$	*F*(1, 162) = 2.369, *p* = 0.126, $\eta_p^2 = 0.014$	*F*(1, 162) < 0.001, *p* = 0.996, $\eta_p^2 < 0.001$	246.059 (18.801)	258.306 (18.480)	267.731 (19.029)	259.396 (18.704)	237.071 (18.801)	221.851 (18.480)	288.430 (19.029)	252.426 (18.704)

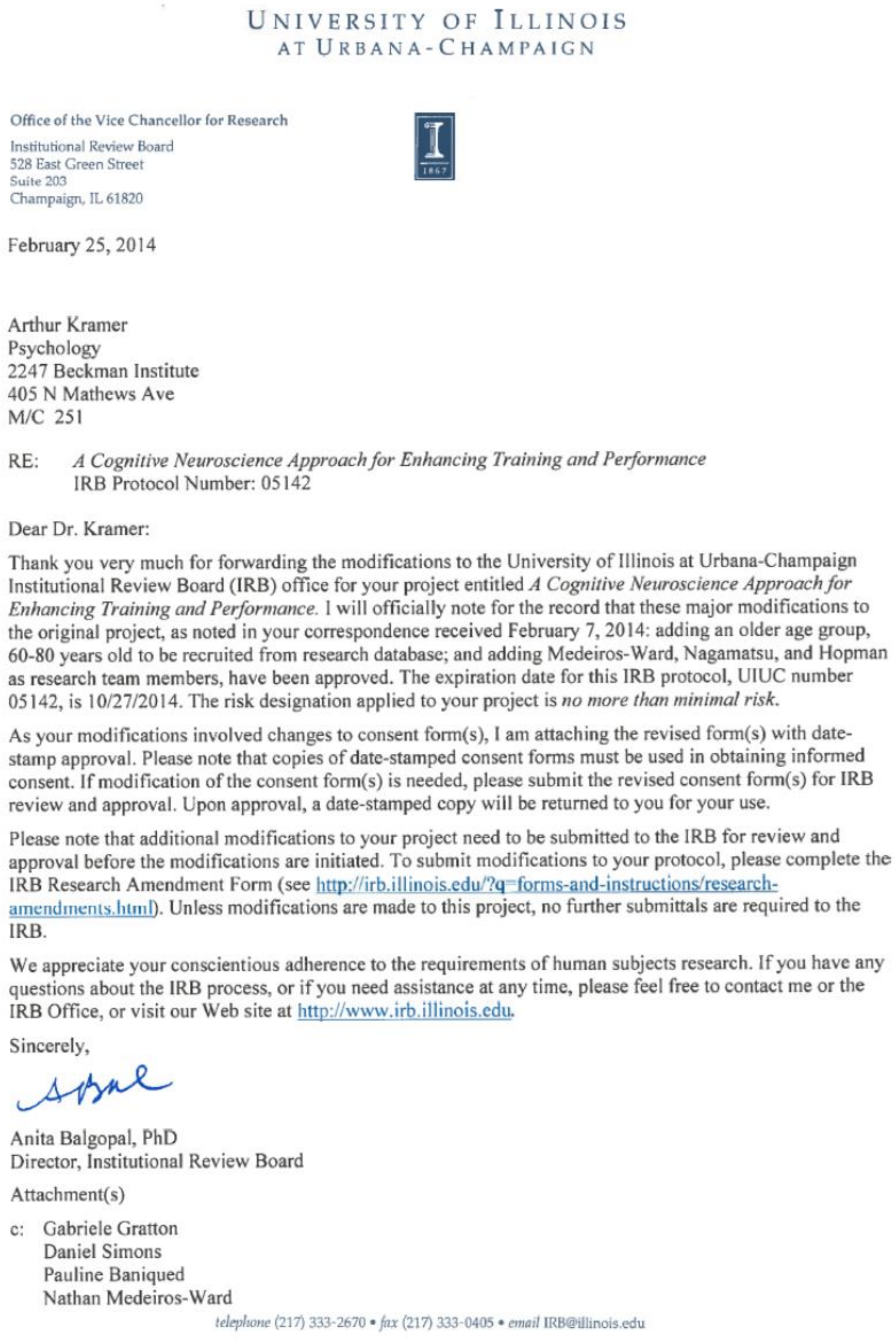
ANOVA results showing interaction effects. Parentheses indicate ± SEM.

Table 8: Mean BRIEF-A survey ratings as a function of age and training group.

BRIEF				**Younger adults**				**Older adults**			
				ACTIVE CONTROL		**WM-REAS**		**ACTIVE CONTROL**		**WM-REAS**	
Task	**Time x Group**	**Time x Age**	**Time x Group x Age**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Inhibit	$F(1, 128) = 0.792$, $p = 0.375$, $\eta_p^2 = 0.006$	$F(1, 128) = 1.173$, $p = 0.281$, $\eta_p^2 = 0.009$	$F(1, 128) = 1.134$, $p = 0.289$, $\eta_p^2 = 0.009$	11.519 (0.479)	12.222 (0.471)	11.476 (0.543)	12.238 (0.534)	11.814 (0.379)	12.512 (0.373)	12.049 (0.389)	12.098 (0.382)
Shift	$F(1, 128) = 1.892$, $p = 0.171$, $\eta_p^2 = 0.015$	$F(1, 128) = 6.182$, $p = 0.014$, $\eta_p^2 = 0.046$	$F(1, 128) = 8.019$, $p = 0.005$, $\eta_p^2 = 0.059$	8.296 (0.377)	8.333 (0.415)	7.333 (0.427)	8.619 (0.470)	9.744 (0.298)	9.884 (0.329)	9.951 (0.306)	9.659 (0.337)
Emotional Control	$F(1, 128) = 0.108$, $p = 0.743$, $\eta_p^2 = 0.001$	$F(1, 128) = 3.951$, $p = 0.049$, $\eta_p^2 = 0.030$	$F(1, 128) = 0.057$, $p = 0.811$, $\eta_p^2 < 0.001$	12.296 (0.673)	12.741 (0.736)	13.143 (0.763)	13.619 (0.835)	14.512 (0.533)	14.163 (0.584)	15.439 (0.546)	15.293 (0.598)
Self-monitor	$F(1, 128) = 0.639$, $p = 0.426$, $\eta_p^2 = 0.005$	$F(1, 128) = 0.363$, $p = 0.548$, $\eta_p^2 = 0.003$	$F(1, 128) = 2.594$, $p = 0.110$, $\eta_p^2 = 0.020$	7.741 (0.347)	7.444 (0.377)	7.524 (0.393)	7.905 (0.428)	9.326 (0.275)	9.651 (0.299)	9.537 (0.282)	9.634 (0.306)
Initiate	$F(1, 127) = 0.111$, $p = 0.739$, $\eta_p^2 = 0.001$	$F(1, 127) = 1.078$, $p = 0.301$, $\eta_p^2 = 0.008$	$F(1, 127) = 0.291$, $p = 0.591$, $\eta_p^2 = 0.002$	11.407 (0.488)	11.667 (0.518)	10.750 (0.567)	11.300 (0.602)	11.907 (0.387)	12.000 (0.410)	12.366 (0.396)	12.390 (0.420)
Working Memory	$F(1, 128) = 0.366$, $p = 0.546$, $\eta_p^2 = 0.003$	$F(1, 128) = 2.879$, $p = 0.092$, $\eta_p^2 = 0.022$	$F(1, 128) = 0.291$, $p = 0.590$, $\eta_p^2 = 0.002$	10.926 (0.476)	11.185 (0.509)	10.619 (0.540)	10.857 (0.577)	12.907 (0.378)	12.791 (0.403)	13.268 (0.387)	12.780 (0.413)
Plan/Organize	$F(1, 128) = 0.675$, $p = 0.413$, $\eta_p^2 = 0.005$	$F(1, 128) = 0.016$, $p = 0.900$, $\eta_p^2 < 0.001$	$F(1, 128) = 4.491$, $p = 0.036$, $\eta_p^2 = 0.034$	13.630 (0.590)	13.222 (0.619)	12.381 (0.669)	13.238 (0.702)	14.814 (0.467)	15.372 (0.491)	15.366 (0.478)	15.366 (0.503)
Task Monitor	$F(1, 128) = 0.351$, $p = 0.555$, $\eta_p^2 = 0.003$	$F(1, 128) = 0.126$, $p = 0.723$, $\eta_p^2 = 0.001$	$F(1, 128) = 6.724$, $p = 0.011$, $\eta_p^2 = 0.050$	9.259 (0.359)	9.111 (0.395)	8.524 (0.407)	9.381 (0.448)	9.977 (0.284)	10.535 (0.313)	10.390 (0.291)	10.317 (0.321)
Organization of Materials	$F(1, 128) = 0.286$, $p = 0.593$, $\eta_p^2 = 0.002$	$F(1, 128) = 1.997$, $p = 0.160$, $\eta_p^2 = 0.015$	$F(1, 128) = 1.115$, $p = 0.293$, $\eta_p^2 = 0.009$	12.815 (0.628)	13.222 (0.657)	11.667 (0.712)	11.905 (0.745)	13.349 (0.497)	12.953 (0.520)	12.390 (0.509)	12.512 (0.533)

ANOVA results showing interaction effects. Parentheses indicate ± SEM.

APPENDIX B: INSTITUTIONAL REVIEW BOARD APPROVAL LETTER



UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Office of the Vice Chancellor for Research
Institutional Review Board
528 East Green Street
Suite 203
Champaign, IL 61820

February 25, 2014

Arthur Kramer
Psychology
2247 Beckman Institute
405 N Mathews Ave
M/C 251

RE: *A Cognitive Neuroscience Approach for Enhancing Training and Performance*
IRB Protocol Number: 05142

Dear Dr. Kramer:

Thank you very much for forwarding the modifications to the University of Illinois at Urbana-Champaign Institutional Review Board (IRB) office for your project entitled *A Cognitive Neuroscience Approach for Enhancing Training and Performance.* I will officially note for the record that these major modifications to the original project, as noted in your correspondence received February 7, 2014: adding an older age group, 60-80 years old to be recruited from research database; and adding Medeiros-Ward, Nagamatsu, and Hopman as research team members, have been approved. The expiration date for this IRB protocol, UIUC number 05142, is 10/27/2014. The risk designation applied to your project is *no more than minimal risk*.

As your modifications involved changes to consent form(s), I am attaching the revised form(s) with date-stamp approval. Please note that copies of date-stamped consent forms must be used in obtaining informed consent. If modification of the consent form(s) is needed, please submit the revised consent form(s) for IRB review and approval. Upon approval, a date-stamped copy will be returned to you for your use.

Please note that additional modifications to your project need to be submitted to the IRB for review and approval before the modifications are initiated. To submit modifications to your protocol, please complete the IRB Research Amendment Form (see http://irb.illinois.edu/?q=forms-and-instructions/research-amendments.html). Unless modifications are made to this project, no further submittals are required to the IRB.

We appreciate your conscientious adherence to the requirements of human subjects research. If you have any questions about the IRB process, or if you need assistance at any time, please feel free to contact me or the IRB Office, or visit our Web site at http://www.irb.illinois.edu.

Sincerely,

Anita Balgopal, PhD
Director, Institutional Review Board

Attachment(s)

c: Gabriele Gratton
Daniel Simons
Pauline Baniqued
Nathan Medeiros-Ward

telephone (217) 333-2670 • *fax* (217) 333-0405 • *email* IRB@illinois.edu