THE USE OF BILATERAL MOTOR TASK TRAINING TO AUGMENT COGNITIVE FUNCTION IN OLDER ADULTS

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by

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Abstract

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Objective: Maintaining cognitive function remains challenging in our rapidly aging society but, learning novel motor tasks may increase cognitive reserve in older adults. Bilateral tasks that combine multiple limb movements, hand-eye coordination, and object manipulation may augment shared cognitive resource function. The purpose of this study is to investigate the effectiveness of simultaneous bilateral object manipulation (SBOM) training in augmenting cognitive function in older adults.

Methods: Eighteen subjects age 50-65 were recruited to be randomly assigned into an intervention (IG) or control group(CG). The IG underwent an 8-week motor training (MT) program to practice 3-ball juggling. Cognitive and motor performance was measured by the Stroop test (Golden version), Trails Making Test (TMT) B minus A, simple and choice reaction time (RT), and 4 Dual Task (DT) tests measuring gait velocity change.

Results: The Stroop Test showed a significant increase for the for IG with a t-score of 5.44 (p=0.004). IG saw a decreased B-A Trail Making Test score from pre to post testing but findings were insignificant. Simple and choice RT decreased for all subjects but without distinction

between groups. DT 1-4 showed positive improvement pre to post in IG group and mixed results in the control suggesting a trending positive effect from training.

Discussion: Our data suggest that SBOM training may be benefitial to older subjects. This study demonstrated that increased testing performance suggests MT can preserve cognitive function. Future studies can adapt this training program to reproduce these results to a further this goal.

Chapter One

Introduction

Maintaining cognitive function remains challenging in our rapidly aging society. It has been well documented that as we age, even simple motor tasks become challenging as a function of a dimensioning neural supply while imposing the same high demand of attention and, this draws cognitive resources from neural pathways outside of the primary motor cortex (Heuninckx, Wenderoth, & Swinnen, 2008). It is the goal of our researchers to understand what is known about cognitive function and how motor training might play a role in its preservation.

Chapter Two

Literature Review

Cognitive Function and Aging

The *Cognitive Reserve Theory* suggests that on average humans will develop and retain a steady number of neural connections to draw upon during young and middle adulthood, but current research maintains that as we age our overall number of neurons typically decreases thus requiring us to share a depleting source of neural connections (Stern, 2002). It has been observed that these connections tend to realign or redistribute as a means of both normal aging and brain pathology. This rewiring of new neural pathway's functions to provide for new learning of common activities of daily living and other important communication and motor skills, and has been observed via positron emission tomography (PET) scans in acute practice of verbal and motor tasks in normal adult brains (Petersen, van Mier, Fiez, & Raichle, 1998). In normal adults, excitation in brain regions for new learning is observed in a secondary network consisting of the prefrontal cortex and anterior cingulate cortex as well as other areas specific to the task. This secondary network of neural connections are dubbed the scaffolding areas and are important for the learning of a new motor skill for all ages. Upon behavioral changes and overlearning of a skill, other task dependent areas, such as the primary motor cortex, are activated and thought of as storage areas used as a default network for skilled performance of that skill. Performance of a well-learned skill that uses the primary network, often requires less conscious effort or attention.

Current View of Compensatory Mechanisms in Cognitive Aging

In support of Petersen's finding, a group of researchers have proposed the *Scaffolding Theory of Aging and Cognition (STAC)* which states that as a compensatory mechanism neural excitability, seen as new brain circuit pathways in the areas outside of the primary network, will act to compensate the decrease in available neurons. This may be due to a decrease in total brain volume, specifically white matter, overall structural integrity as a function of age or pathology, or decreased number of dopaminergic pathways (Park & Reuter-Lorenz, 2009). STAC suggests neural pathway activation changes may be permanent changes that are a result of overused or underused areas of the brain, but the scaffolding areas of the brain could be trained or reprogrammed to be more efficient. Interventional training may help transfer the execution of simple skills back to the default primary networks, or optimize the scaffolding areas of the brain to function as proficiently as the default. Upon revisiting their theory five years later, Park and Reuter-Lorenz added the inclusion of "life-course factors" such as experience, genetics and environmental influence that may be variables that affect the early onset of the use scaffolding areas to complete simple skills (Reuter-Lorenz & Park, 2014).

Although it is recognized that compensatory neural networks assist with the computations performed by the primary or default network, the required use of compensatory networks in older adults has been observed to be less efficient than primary networks used by young adults that do the same task. Currently, researchers aim to detect if starting interventions at middle age or later adulthood are beneficial to optimize the scaffolding effect on the secondary networks to make them more efficient. This has been supported by many, including one group of researchers who specifically refer to this scaffolding management by the term, "brain maintenance" (Nyberg, Lovden, Riklund, Lindenberger, & Backman, 2012). A few relevant questions remain unanswered concerning this topic. What exactly causes these neural adaptations, are they entirely detrimental, and what can be done to prevent any cognitive decline that may be associated with these age-related adaptations?

Known Contributing Factors on Cognitive Performance

The effects of various training interventions by current researchers will answer the previous questions by determining which experiences and environmental influences are most beneficial and will provide protective support to preserve cognitive function through the aging process. Current evidence has shown that aerobic training and strength training have positive effects on increasing cognitive function and motor performance in older adults (Berryman et al., 2014). Firstly, long-term participation in aerobic training in Masters athletes has shown to attenuate the loss of regional brain volume (Tseng et al., 2013). Complimentary to these findings, research has shown that older adults with limited mobility show an accelerated progression of white matter abnormalities over a 5-year period (Wolfson et al., 2005). This reduction in white matter integrity has been linked to cognitive instability and motor deficits (Fjell, Westlye, Amlien, & Walhovd, 2011). Interestingly, Berryman and colleagues observed that in some cases, gross movement motor training yields similar beneficial effects on executive function as aerobic training. Of note, training-dependent changes to motor task training are inversely related to age (Sawaki, Yaseen, Kopylev, & Cohen, 2003), and decreased rates of training-dependent change may indicate a slower rate of cognitive plasticity in older adults than younger adults, (Cirillo, Todd, & Semmler, 2011). To date, it is unclear if a training protocol of more complex gross movement motor tasks would effectively promote and enhance performance in cognitive and motor functions in older adults.

The performance of motor coordination has already shown to require a higher cognitive demand in older adults where neural excitability has been observed to operate in both hemispheres of the motor cortex (Graziadio, Nazarpour, Gretenkord, Jackson, & Eyre, 2015), and better performance of physical tasks has been linked to excitation within the primary hemisphere for a unilateral task compared to those observed to involve both hemispheres (Cherry et al., 2010). Previous studies have measured cognitive and motor function for simple ipsilateral tasks and found that younger subjects outperformed the older subjects by expressing more motor coordination stability, while concurrently activating less brain regions than the older subjects (Heuninckx, Debaere, Wenderoth, Verschueren, & Swinnen, 2004), and this may be involved in regulating inhibitory function when simultaneous tasks are being performed; (Fujiyama, Garry, Levin, Swinnen, & Summers, 2009).

It is also important when measuring motor skill function to incorporate non-dominant hand tasks so that the task will not be one that is already overlearned or quickly learned based on previous experience, thus leaving more room for improvement in all subjects (Schaefer, Dibble, & Duff, 2015). Congruently, tasks that practice the combination of multi-limb coordination in training may offer alleviation of motor deficits for older adults (Hoff et al., 2015).

Purpose

It can be hypothesized that training older adults to complete a motor task that requires simultaneous bilateral coordination through object manipulation (classic 3-ball juggling) might be challenging enough to enhance improvements in motor performance and imply the improvement of cognitive function. The purpose of this study is to investigate the effectiveness of simultaneous bilateral object manipulation (SBOM) training in augmenting cognitive function in older adults.

Chapter Three

Methods

Subjects: Eighteen subjects were recruited (6 male/12 female) age 50-65 from the East Texas area to be randomly assigned into an intervention group or a control group. Recruitment of participants excluded individuals if they had any gait or balance issues. Also, those diagnosed with any significant orthopedic or neurological conditions that may inhibit them from completing the training protocol were excluded from recruitment. Examples include individuals with severely restricted mobility, movement disorders, epilepsy, or those who have suffered major traumatic brain injuries or recurring concussions, and lastly, individuals with major visual or hearing impairments. All criteria was assessed during a telephone or email screening and documented during the first scheduled meeting at the research facility.

Design: This was an 8-week interventional study that consisted of an intervention group (4males/5 female) and a control group (2males/7 females). The intervention group was asked to undergo an 8-week motor learning program to practice classic 3-ball juggling, 3 days a week for 30 minutes as a means of practicing SBOM. The experimental group was given one 30 minute introductory training session to learn the basic steps and task requirements. While a control group incorporated 10 minutes of stretching into their daily routine as well as 20 minutes of either 8 upper body or 8 lower body resistance band exercises of 1 set with 15 repetitions. Weekly phone calls and daily logbooks were given to all individuals to ensure training compliance.

Outcome Measures: Cognitive and motor performance was measured by a reaction time test, the Stroop test (Golden version), Trail Making Test (TMT) B minus A, and 4 Dual Task tests measuring gait velocity change. All tests for both groups were measured at baseline and immediately after the 8-week intervention. Comparisons were made between groups and within individuals at baseline and after training using independent and paired t-tests, respectively. Pearson correlation and multiple linear regression was used to explore demographic predictability.

Chapter Four

Results

Stroop Test: Each individuals' color-word score was subtracted by their age/education predicted score which provided a residual that was transformed to a T-score following the Golden standard handbook. The experimental group and the control averaged 44.56 and 50.44 respectively before the training sessions with no significant difference. The experimental group showed a significant increase t-score of 5.44 (p=0.004) as can be seen in Table 1. The control showed an insignificant score decrease of -1.66 (p=0.706).

Table 1: Stroop Color and Word Test

Measure	Mean	Std Dev	P-Value
A Stroop Pre	44.556	6.948	
A Stroop Post	50.000	7.810	
Difference	5.444	4.096	0.004
B Stroop Pre	50.444	8.323	
B Stroop Post	48.778	6.438	
Difference	-1.667	7.089	0.501

Table 1: Experimental group displayed improvement in executive function after training compared to their counterparts.

Trails B-A: Time to complete Trails A was subtracted from the time to complete Trails B to determine the increased amount of time to complete the harder trails making test (B). The experimental group saw a decreased B-A score from pre to post testing while the control group saw an increased B-A. However neither score was confirmed by a significant p-value.

Table 2: Trail Making Tests B-A			
Measure	**Mean Time (seconds)**	**Std Dev**	**P- Value**
A Trails Pre	38.870	14.420	
A Trails Post	35.673	15.127	
Difference	-3.197	11.611	0.433
B Trails Pre	29.927	16.176	
B Trails Post	31.349	15.537	
Difference	1.422	10.921	0.328

Table 2: A trend that may imply improved cognitive performance was observed in the experimental group using Trail Making Test.

Reaction Time: In this study, simple and choice reaction times were assessed using the ruler-drop test. 3 attempts for simple reaction time (SRT) were given to the dominant hand then the non-dominant hand where the subject was presented one ruler and simply had to catch it as soon as they perceived it had been dropped. The subjects were also given 6 attempts for a choice reaction time (CRT) where they were presented a ruler for each hand and told only one would randomly drop. Mean reaction times were recorded in centimeters as a function of consistent gravity. Both the experimental group and control group showed a decrease time to catch the rulers in SRT for dominant and non-dominant hand as well as for CRT, but not significantly as can be seen in Table 3.

Table 3: Simple & Choice Reaction Time			
Measure	**Mean Δ (CM)**	**Std Dev**	**P- Value**
A SRT Dom Δ	-1.512	4.369	0.328
A SRT Non Δ	-0.376	5.462	0.842
A CRT Δ	-1.40	4.045	0.330
B SRT Dom Δ	-1.222	5.839	0.548
B SRT Non Δ	-1.519	5.027	0.391
B CRT Δ	-2.129	3.571	0.111

Table 3: No difference was observed in simple and choice times after training in either groups.

Dual-Task Gait Velocity

An average baseline Gate velocity was taken over a 10m walk. Then each individual completed four more walks to include a second task while walking in the order of verbal fluency (DT1), reverse digit span (DT2), serial 7 subtraction (DT3), and delayed word recall and organization (DT4). Each was compared to an individual's mean to produce an average change of velocity (ΔV) to measure gait slowing. All subjects performed as expected during the baseline testing with a significant ΔV for each dual task for all subjects and when the two groups were split up. The expectations were that when the experimental group returned they would see a decreased ΔV from their baseline gait velocity. Time to complete the dual tasks decreased for the Experimental group as can be seen by Table 4 for DT1, 2, 3, and 4. The control group's ΔV only decreased for DT1 and 2 but increased for DT3 and 4.

Table 4: Dual Task GVΔ Pre-Post						
Measure	**A-Mean**	**A-%**	**B-Mean**	**B-%**	**T-test Diff**	**P-value**
DT1Δ	0.068	5.53%	0.007	0.93%	0.061	0.302
DT2Δ	0.038	2.98%	0.030	3.00%	0.008	0.922
DT3Δ	0.028	2.11%	-0.019	-1.36%	0.047	0.405
DT4Δ	0.030	2.44%	-0.010	-0.73%	0.040	0.447

Table 4: The experimental group showed improved performance in all DT conditions, suggesting augmented cognitive resources after training.

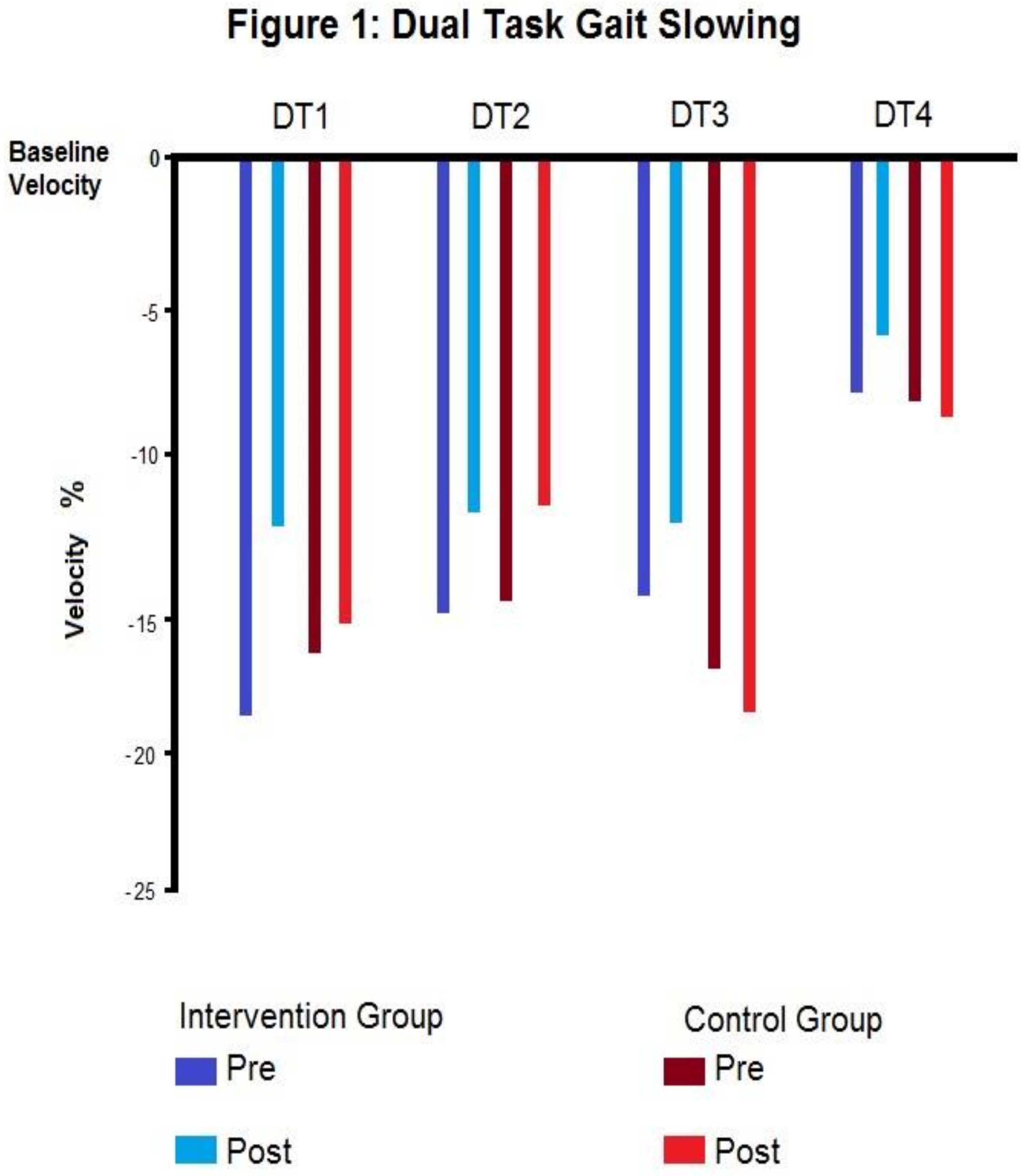

Figure 1: The control group demonstrated more pronounced gait slowing under all DT conditions, in contrast of their countrparts who underwent the SBOM training.

Chapter Five

Discussion

We anticipated to see increased performance in the Stroop Test which measured parallel processing speed and selective attention. The Stroop Test results indicated the highest quality positive change from our experimental group likely following the increased demand of parallel processing imposed on them during their 3-ball juggling task. This may be critically relevant for long-term cognitive preservation training as it is highly important for older individuals to maintain their ability to multi-task as they age. Functional magnetic resonance imaging (fMRI) data has shown that Stroop test performance may be critically relevant in denoting sensitivity to specific prefrontal brain regions during testing (Banich et al., 2000).

The TMT provides useful information regarding visual search, speed of processing, and executive function (Tombaugh, 2004). Our results indicated that a trending performance increased in the experimental group compared to the control group for the trails making test. Tombaugh's research suggested that age may be a predictive factor in TMT performance, but may be augmented by education or intelligence. However, this study found that in this sample population neither age nor education correlated with Trails B-A for all subjects pre or post. The Trail Making Tests' sensitivity to measuring visual search behavior may not have been powerful enough to decisively be effected by the inter-manual training. However, similarly researchers recently determined that visual feedback training does improve inter-manual transfer in specific tasks (Steinberg, Pixa, & Doppelmayr, 2016). This may indicate that a visual search test must be similar to the specific task they had been training for. Certainly human gaze is determined primarily by the task requirements as can be seen when researchers use virtual reality and eye tracking (Rothkopf, Ballard, & Hayhoe, 2007). However, to quantify visual search capability into the trails time of completion tasks relies on not only time to visually recognize stimuli but also movement time of the hand to complete the trails tests.

For choice reaction time, we hypothesized that the training group would find some improvement since they were practicing required quick decisive reactions to multiple stimuli. However, our results showed only an insignificant decrease in reaction time and this was no different than the control group. The order for each test always followed the same order starting with 3 dominant hand simple RT, 3 non-dominant hand, and finally, 6-random choice attempts of at least 3 for each hand. We suggest that there may be a learning curve when following this order such that by the time subjects got to the choice reaction time they were likely able to anticipate when an expected drop of the ruler would occur and were potentially more focused.

These results are directly linked to interhemispheric processing when bilateral visual fields are incorporated (Leblanc-Sirois & Braun, 2014). Similar to the expectations of previous investigators, we sought to determine if there would be a difference in hand dominance for simple reaction time, but observed no difference. This conclusion demonstrated similar results to previous researchers who have shown that hemisphere dominance for motor control does not translate to increased performance in reaction time (Nisiyama & Ribeiro-do-Valle, 2014).

The Dual-Task test measures gait velocity change by performing concurrent cognitive and motor tasks. This is a novel tool to assess cognitive reserve that has been previously established by our group (Tseng, Cullum, & Zhang, 2014). More specifically, exacerbated gait slowing has been observed under dual-task conditions in patients with mild cognitive impairment (MCI) when compared to non-MCI older adults. This has been clinically shown to exacerbate gait slowing changes in mild cognitively impaired (MCI) individuals compared to cognitively normal, education matched adults. As was predicted, all subjects in this experiment showed gait slowing during every dual task at baseline so we had them take an equivalent dual task test upon return from their training to finally capture a change in performance and translate it into a percent change. The experimental group showed an average change of 2.11-5.33% increase whereas the control group showed a -1.3- 3.00% change between pre and post. Although these changes were small there is no current literature to describe expected retest effect for this set of dual task testing but these results might provide useful insight into determining how long after a dual task gait test is given can another be taken.

Future Implications

The total number of subjects seems to be the most outstanding limiting factor in this study. This sample population included almost all right handers with only 1 subject identified as left hand dominant. No preference was made towards hand dominance in recruitment as all tests were selected to equally measure all individuals.Two-thirds of the subjects in this study have a master's degree or higher. Fortunately, correlation indicated no direct relation between any variable studied to education level.

An unexpected limitation was observed when it came to the results of the experimental subjects. Upon return from 8 weeks training, subjects were to report what their highest run of consecutive catches was and, they were asked to demonstrate an attempt to validate their response. Only two individuals were able to perform relatively endlessly proving they had successfully transformed the discrete subcomponents of juggling into a continuous motion. The remaining 7 reported an average of 4.86 consecutive catches and when asked to demonstrate were still struggling to maintain a fluid movement pattern.

Future investigations may consider a few implications that might be successfully adjusted to further this study. Firstly, object manipulation training may be adapted to a visual feedback program such as using a Kinect or VR to change the skill level of the task and let learners gradually progress. We speculate that their might be a learning curve that could be adjusted with advancing difficulty levels using a modifiable task.

Also, working directly with the learners during every training session could guide subjects to increased skill performance progression. Lastly, and most importantly, we would like to recruit at least twice as many more subjects to expand and normalize data points with greater validtity. A long term study could potentially show an increased potential to combat the cognitive detriments of aging beyond what was observed in this experiment.

Conclusion

Our pilot data suggest that inter manual gross motor training may be benefitial for older subjects. As demonstrated in this study, 3-ball juggling is a very complex skill that challenges subjects to meet a high standard of multi-tasking. We found that a modified, computer operated version of this training might more easily be used to adjust to a learners initial abilities. This training application could provide older adults a cognitive challenge to physically incorporate gross motor training into their daily lives as a way to augment or preserve cognitive function. Promoting cognitive vilatity and maintaining the functional operation of daily activites remains a serious goal in our aging population. Our researchers will continue exploring the potential of gross motor training and motor learning programs in order to further preserve cognitive function in older adults.

Literature Citations

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

Berryman, N., Bherer, L., Nadeau, S., Lauziere, S., Lehr, L., Bobeuf, F., . . . Bosquet, L. (2014). Multiple roads lead to Rome: combined high-intensity aerobic and strength training vs. gross motor activities leads to equivalent improvement in executive functions in a cohort of healthy older adults. *Age (Dordr), 36*(5), 9710. doi: 10.1007/s11357-014-9710-8

Cherry, B. J., Yamashiro, M., Anderson, E., Barrett, C., Adamson, M. M., & Hellige, J. B. (2010). Exploring interhemispheric collaboration in older compared to younger adults. *Brain Cogn, 72*(2), 218-227. doi: 10.1016/j.bandc.2009.09.003

Cirillo, J., Todd, G., & Semmler, J. G. (2011). Corticomotor excitability and plasticity following complex visuomotor training in young and old adults. *Eur J Neurosci, 34*(11), 1847-1856. doi: 10.1111/j.1460-9568.2011.07870.x

Fjell, A. M., Westlye, L. T., Amlien, I. K., & Walhovd, K. B. (2011). Reduced white matter integrity is related to cognitive instability. *J Neurosci, 31*(49), 18060-18072. doi: 10.1523/JNEUROSCI.4735-11.2011

Fujiyama, H., Garry, M. I., Levin, O., Swinnen, S. P., & Summers, J. J. (2009). Age-related differences in inhibitory processes during interlimb coordination. *Brain Res, 1262*, 38-47. doi: 10.1016/j.brainres.2009.01.023

Graziadio, S., Nazarpour, K., Gretenkord, S., Jackson, A., & Eyre, J. A. (2015). Greater intermanual transfer in the elderly suggests age-related bilateral motor cortex activation is compensatory. *J Mot Behav, 47*(1), 47-55. doi: 10.1080/00222895.2014.981501

Heuninckx, S., Debaere, F., Wenderoth, N., Verschueren, S., & Swinnen, S. P. (2004). Ipsilateral coordination deficits and central processing requirements associated with coordination as a function of aging. *J Gerontol B Psychol Sci Soc Sci, 59*(5), P225-232.

Heuninckx, S., Wenderoth, N., & Swinnen, S. P. (2008). Systems neuroplasticity in the aging brain: recruiting additional neural resources for successful motor performance in elderly persons. *J Neurosci, 28*(1), 91-99. doi: 10.1523/JNEUROSCI.3300-07.2008

Hoff, M., Trapp, S., Kaminski, E., Sehm, B., Steele, C. J., Villringer, A., & Ragert, P. (2015). Switching between hands in a serial reaction time task: a comparison between young and old adults. *Front Aging Neurosci, 7*, 176. doi: 10.3389/fnagi.2015.00176

Leblanc-Sirois, Y., & Braun, C. M. (2014). Intra and inter hemispheric dynamics revealed by reaction time in the Dimond paradigm: a quantitative review of the literature. *Neuropsychologia, 58*, 1-13. doi: 10.1016/j.neuropsychologia.2014.03.012

Nisiyama, M., & Ribeiro-do-Valle, L. E. (2014). Relative performance of the two hands in simple and choice reaction time tasks. *Braz J Med Biol Res, 47*(1), 80-89. doi: 10.1590/1414-431X20132932

Nyberg, L., Lovden, M., Riklund, K., Lindenberger, U., & Backman, L. (2012). Memory aging and brain maintenance. *Trends Cogn Sci, 16*(5), 292-305. doi: 10.1016/j.tics.2012.04.005

Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: aging and neurocognitive scaffolding. *Annu Rev Psychol, 60*, 173-196. doi: 10.1146/annurev.psych.59.103006.093656

Petersen, S. E., van Mier, H., Fiez, J. A., & Raichle, M. E. (1998). The effects of practice on the functional anatomy of task performance. *Proc Natl Acad Sci U S A, 95*(3), 853-860.

Reuter-Lorenz, P. A., & Park, D. C. (2014). How does it STAC up? Revisiting the scaffolding theory of aging and cognition. *Neuropsychol Rev, 24*(3), 355-370. doi: 10.1007/s11065-014-9270-9

Rothkopf, C. A., Ballard, D. H., & Hayhoe, M. M. (2007). Task and context determine where you look. *J Vis, 7*(14), 16 11-20. doi: 10.1167/7.14.16

Sawaki, L., Yaseen, Z., Kopylev, L., & Cohen, L. G. (2003). Age-dependent changes in the ability to encode a novel elementary motor memory. *Ann Neurol, 53*(4), 521-524. doi: 10.1002/ana.10529

Schaefer, S. Y., Dibble, L. E., & Duff, K. (2015). Efficacy and Feasibility of Functional Upper Extremity Task-Specific Training for Older Adults With and Without Cognitive Impairment. *Neurorehabil Neural Repair, 29*(7), 636-644. doi: 10.1177/1545968314558604

Steinberg, F., Pixa, N. H., & Doppelmayr, M. (2016). Mirror Visual Feedback Training Improves Intermanual Transfer in a Sport-Specific Task: A Comparison between Different Skill Levels. *Neural Plast, 2016*, 8628039. doi: 10.1155/2016/8628039

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *J Int Neuropsychol Soc, 8*(3), 448-460.

Tombaugh, T. N. (2004). Trail Making Test A and B: normative data stratified by age and education. *Arch Clin Neuropsychol, 19*(2), 203-214. doi: 10.1016/S0887-6177(03)00039-8

Tseng, B. Y., Cullum, C. M., & Zhang, R. (2014). Older adults with amnestic mild cognitive impairment exhibit exacerbated gait slowing under dual-task challenges. *Curr Alzheimer Res, 11*(5), 494-500.

Tseng, B. Y., Uh, J., Rossetti, H. C., Cullum, C. M., Diaz-Arrastia, R. F., Levine, B. D., . . . Zhang, R. (2013). Masters athletes exhibit larger regional brain volume and better cognitive performance than sedentary older adults. *J Magn Reson Imaging, 38*(5), 1169-1176. doi: 10.1002/jmri.24085

Wolfson, L., Wei, X., Hall, C. B., Panzer, V., Wakefield, D., Benson, R. R., . . . Guttmann, C. R. (2005). Accrual of MRI white matter abnormalities in elderly with normal and impaired mobility. *J Neurol Sci, 232*(1-2), 23-27. doi: 10.1016/j.jns.2004.12.017