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To Examine the Effects of Exercise & Instructional Based Interventions on Executive Functioning, Motor Learning & Emotional Intelligence Abilities Among Older Adults

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TO EXAMINE THE EFFECTS OF EXERCISE & INSTRUCTIONAL BASED INTERVENTIONS ON EXECUTIVE FUNCTIONING, MOTOR LEARNING & EMOTIONAL INTELLIGENCE ABILITIES AMONG OLDER ADULTS

By

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Abstract

Motor skills are a vital part of our life, and there might be situations where we will be required to either learn a new skill or relearn a known one. We examined the effectiveness of two different interventions - eccentric exercise and motivation-based instructions on enhancing the ability of older adults to learn a novel motor skill. Exercise intervention studies have shown that as little as 12 weeks of exercise can lead to improvements in both physical fitness and cognitive function in older adults, particularly executive control. But it is still unclear whether those improvements translate to improvements in other domains that rely on executive control, like motor skill learning and emotional intelligence. Study 1 explored the effect of eccentric exercise on these domains, specifically the ability to handle proactive interference in motor learning. 22 healthy adults (65-85 years of age) were recruited and randomly assigned either to a non-exercise control group, or to an exercise intervention group that performed 12 weeks of low to moderate intensity eccentric leg exercise (Eccentron). Corresponding neurophysiological measures were also recorded using EEG. We found that the control group experienced more proactive interference from baseline learning to post-test compared to the exercise group. The latter also displayed a higher level of emotional processing abilities than controls. They provide preliminary evidence that the cognitive benefits of exercise for older adults can be extended to domains outside of but related to executive control and memory. In study 2, we examined the effectiveness of an intervention based on the OPTIMAL theory of motor learning and performance on skill acquisition in both younger and older adults. We recruited 39 younger adults and 30 older adults and randomly assigned them to either the experimental group or to the control group. The intervention affected the two groups differentially. It was somewhat successful at improving learning in the older adults, but not in the younger adults. In fact, the intervention may have interfered with learning in the latter.

Keywords: Aging, motor learning, proactive interference, executive function, emotional intelligence, autonomy support, enhanced expectancy, external focus, intervention

CHAPTER 1

INTRODUCTION

1.1 Introduction

The aging population is burgeoning, with the worldwide population of people over 60 years projected to be 1.4 billion by 2030 (Ehsani et al., 2015; De Luca et al., 2011). In the United States alone, people aged 65 years and over, will touch 77 million by 2034; outnumbering children for the first time (US Census Bureau, 2018). Aging is associated with numerous changes in physical and cognitive function, both of which impact motor behavior. Changes in motor behavior can be attributed not only to changes in the musculoskeletal system but also with structural atrophy and functional declines in the brain (e.g., Seidler et al., 2010). Those brain changes are especially evident in frontal lobe regions responsible for working memory and executive control (Raz, et al., 2005). The extent of age-related atrophy and cognitive decline varies between individuals and can depend on a host of factors including the environment, lifestyle, and health (Hogan, 2005). One of the main challenges for this century is to identify interventions that can improve brain function, emotional wellbeing, limit cognitive decline and enhance mobility, in order to make the later years of this rapidly growing section of aging population as healthy and productive as possible.

Cognitive declines in aging affect the ability to learn motor skills, which play a vital role across the life span-from walking, to being able to move about without assistance, or carrying out one’s daily activities independently, or even learning new skills. All these functions require a combination of gross and fine motor skills, with varying levels of motor control and coordination. Hence the importance of the ability to learn and perform a motor skill during any stage of our life, cannot be underestimated. There may be situations where we may be required to either learn a new skill or relearn a known one. These could be as part of a new task training, recreational pursuit, or even rehabilitation. But, with advanced age, there is a decline in motor learning and control abilities attributable to a multitude of factors, including declines in central nervous system, sensory receptors and musculoskeletal systems (Seidler et al., 2010). The good news is that, these declines can be attenuated by various interventions like exercise (Seidler et al., 2010; Hillman et al., 2004; Hatta et al., 2005; Hübner et al., 2018) and motor training (Seidler et al., 2010; Sawaki et al., 2003). An important aspect of motor learning is the need to overcome interference from our memory of previous motor learning, also known as anterograde or proactive interference. Aging is associated with increased susceptibility to proactive interference (PI) (Roig et al., 2014). This increased vulnerability to PI may hamper older adults from successfully learning new skills or modifying previously learned skills, both of which are crucial not only in the context of performing everyday activities but also in the implementation of neurorehabilitative training.

As the aging population rises, it is becoming imperative to discover and design diverse interventions to help individuals not only learn new skills, but also different ways of performing previously learned motor activities and ways to overcome age-related motor declines (King et al., 2017). We know that motor skills are important throughout the lifespan, and there may be situations where one requires interventions to improve their motor learning and/or motor control. This may include either learning a new skill from the beginning or relearning to perform a previous skill in a different manner (for example, after a person suffers a stroke or an accident). As step in this direction, we explored two novel approaches – a longitudinal low to moderate impact eccentric exercise program and a more immediate, short term social-cognitive-affective intervention (based on the OPTIMAL theory) to improve motor learning and skill acquisition.

Cognitive aging also has an impact on emotional intelligence (EI), a domain which plays an important role in the mental health and wellbeing during later adulthood. EI has been conceptualized in two different ways. One is the mixed model, where EI is considered to be a collection of characteristics and is typically measured using self-report instruments. The other is the ability model, where EI is believed to be a combination of abilities- perceiving, assimilating, understanding and managing emotions (Cabello et al., 2014). There are mixed findings with respect to emotional intelligence and aging. While some studies reported better scores for older adults (Galdona et al., 2018; Cabello et al., 2014; Mayer et al., 1999), others found that older adults had trouble recognizing emotions (Cabello et al., 2014; Ruffman et al., 2008). We wanted to ascertain if EI could be enhanced through exercise, as, akin to motor learning, it is also dependent on EF (Mayer and Salovey, 1997; Hurtado, et al., 2016). We were also interested in understanding if EI is a factor that contributes to motor learning and one's resilience to proactive interference. If this were the case, then including EI components and/or being mindful of their role in skill acquisition could enhance the effectiveness of motor learning and training interventions.

The overarching goal of the current research is to examine two interventions for improving cognitive function, motor learning, and EI. In our first study, we investigated if exercise-induced improvements in executive functions would generalize to other domains dependent on these cognitive mechanisms, including motor learning and resistance to proactive interference. In our second study, we examined the role of cognitive-affective processes such as enhanced expectancies (regarding one's performance), external focus of attention, and autonomy support to improve skill acquisition (Stevens et al., 2012; Wulf et al., 2014; Pascua et al., 2015; Wulf & Lewthwaite, 2016).

1.2 Research Goals

Our overall objective was to enable older adults to improve their quality of life by enhancing their motor learning/skill acquisition and emotional intelligence abilities through the application of two different interventions - a long term eccentric exercise program and a more immediate, easily administered social-cognitive-affective instruction protocol. We looked at these two very different forms of techniques as two alternate approaches to enhance motor learning abilities. While the exercise program was a longer-term intervention that required a sustained commitment, the OPTIMAL theory-based intervention was a more immediate, short term mechanism to boost learning. It comprised of modifying the task instructions/directives to improve performance/skill acquisition. Our reasoning was based on the premise that exercise, though being beneficial, entails a sustained commitment over a longer period, in addition to a certain degree of physical fitness. There is a possibility that either, or both of these requirements may be a deterrent to participation and adherence. This is where the OPTIMAL theory-based intervention comes into play. It is a shorter and more immediate intervention technique that could be applicable and available to everyone. It can also be seamlessly integrated with other forms of training and interventions, including exercise programs such as ours. We anticipate that the findings from these studies have applications across domains of mental health, rehabilitation (physiotherapy, occupational therapy, etc.), education, and training. We were also interested in examining if exercise led to an improvement in EI and if EI was related to improvement in skill acquisition and resilience to proactive interference. As mentioned earlier, this knowledge could have important implications for various motor learning, training, and rehabilitation interventions.

In the first study, we addressed the research questions: Does exercise lead to improvements in EF, EI and resilience to proactive interference in motor learning? Is improvement in EF related to improvement in the other domains? Is the degree of resilience to proactive interference related to any of the emotional intelligence dimensions (emotion perception, emotional understanding, and emotional management abilities)? In the follow up study, we are investigating whether social-cognitive-affective interventions could lead to improved skill acquisition and resilience to proactive interference in both younger and older adults? Do cognitive and emotional intelligence abilities mediate the effect of this intervention? We hope to utilize the findings from these studies to enhance the learning and performance experiences of older adults across various conditions-education, recreation and/or rehabilitation.

1.3 Significance

The rationale behind these studies is to provide evidence of novel intervention methods that are both effective and simple and could be employed to enhance motor skill acquisition among older adults. The hope is, that such findings would pave way for future work on the application of these techniques across various fields including rehabilitation, therapy, training, education and sports across different age groups, populations, and health conditions. These inquiries will shed more light on the effects of exercise and intrinsic motivation-based techniques on the ability to handle proactive interference more effectively. The findings would also be directly applicable to the field of human performance.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Motor Learning

As stated in Anguera et al. (2012), "Motor learning, also referred to as skill acquisition, has been described as the processes associated with practice or experience that lead to a relatively permanent change in one's capability for responding" (Schmidt, 1988). This definition has also been emphasized in other motor learning literature (Seidler et al., 2010 Seidler, 2010). There are two main categories of motor learning: sequence learning and sensorimotor adaptation. While the former involves learning by combining isolated movements into one smooth, coherent action (like learning multiple components of a tennis serve), the latter involves learning by modifying movements in response to changes in the environment. This could be learning to change one's performance in a motor task in response to a mechanical manipulation (Shadmehr & Mussa-Ivaldi, 1994; Seidler, 2010) like a force field, perturbation or visuomotor rotation. A real-life example would be learning the mapping between the size and speed of your hand movements and the resulting movement of the cursor on the computer screen (Seidler, 2010; Seidler, 2012; Rajeshkumar & Trewartha, 2019).

Motor learning is a combination of both, conscious and unconscious processes and the interplay of both can be observed during adaptation, particularly to visuomotor transformations. While the conscious process includes the EF and PFC mediated processes like strategic intentional processes involved in selecting an action goal, the unconscious processes consists of perceptual motor integration, that is, selecting movement targets appropriate to attain the action goal, assembling the proper sequence of movement targets, and the generation of muscle activation (Bock & Girgenrath, 2006; Heuer & Hegele, 2008). For example, once the action goal to move to the target has been selected, one is generally not aware of the choice of the appropriate hand and arm movement. However, based on the dual mode principle of Willingham (1998), some of the processes like intentional strategic corrections that follow the selection of action goals, could also contribute to perceptual motor integration by consciously selecting a movement target to compensate for a visuomotor rotation (Heuer & Hegele, 2008). As we have seen, multiple cognitive mechanisms are involved in motor learning/skill acquisition and include explicit and implicit working memory resources (Trewartha, 2014; Taylor et al., 2014), spatial working memory (Anguera et al., 2009, Seidler et al., 2012), decision-making, performance monitoring, and associative memory processes (Anguera et al., 2009; Taylor and Ivry 2011; Trewartha et al. 2014; Rajeshkumar & Trewartha, 2019). Rigoli et al. (2012) emphasizes the role of executive functions in motor coordination and control-like inhibiting certain actions, monitoring, making corrections and anticipating and updating movements according to the task.

When we speak of sensorimotor adaption in motor learning, there are various aspects to it: early learning, learning to learn and transfer of learning. Early learning refers to the initial stages of motor acquisition, transfer (or generalization) of learning refers to the extent to which a newly acquired skill can be produced under different conditions and task variants. In other words, where individuals can make use of the previously acquired motor memory to learn a new task/movement. Learning to learn is when one can 'learn to learn' (Bock et al., 2001; Seidler, 2010) a new motor skill where participants exposed to different forms of motor learning tasks in succession, show a faster learning ability in the given task as compared to their naive counterparts. On examining the neural basis of these paradigms in her review, Seidler (2010), finds that early learning engages the basal ganglia thalamocortical loops, the anterior cingulate cortex, the inferior frontal gyrus, medial cerebellum, and visual and parietal cortical areas. It is hypothesized that this activation pattern most likely supports cognitive demands of the task including error detection and correction, working memory, and attention. Learning to learn is also thought to involve enhanced operations of these processes and their underlying neural systems. Later phases of motor learning have been observed to engage the lateral cerebellum, parietal and cingulate motor cortical areas and this brain activation pattern possibly supports storage and refinement of newly acquired sensorimotor representations. Transfer of learning, which involves retrieval and modification of previously acquired internal models (to complete the task at hand), shows brain activation patterns similar to those of the late phase of motor learning. There is also a possibility of engaging early learning related processes but at a comparatively reduced amplitude and timescale. As elucidated above, PFC-mediated working memory and executive control processes are essential for acquiring a new motor skill (Anguera et al., 2011; Trewartha et al., 2014; McDougle et al. 2015, 2016; Rajeshkumar & Trewartha, 2019; Seidler, 2010).

Motor learning, the ability to learn new motor skills has been observed to deteriorate in the course of aging (Bock & Girgenrath, 2006, Heuer & Hegele, 2008; McNay and Willingham 1998; Seidler, 2006, Trewartha et al., 2013; Rajeshkumar & Trewartha, 2019). This is expected, given that age-related impairments are more pronounced in the frontal lobes, and as observed, motor learning/skill acquisition (at least the conscious processes) is dependent on frontal lobe based cognitive functions (especially the dorsolateral frontal cortex, which is the major neural base of strategic and other related processes (Willingham, 1998; Heuer & Hegele, 2008). Seidler et al. (2013), explains the role of neurocognitive mechanisms, especially working memory, in the context of visuomotor adaptation (VMA). VMA, a task which is cognitively demanding (Eversheim & Bock, 2001; Taylor & Thoroughman, 2007, 2008), involves the 'recalibration of a well-learned spatial-motor association' and in addition to sensorimotor processes, it also involves explicit and implicit cognitive strategies. It is said to comprise of a cognitively powered "fast/early learning" stage marked by swift enhancements in performance and an autonomous "slow/late learning" stage with smaller performance increases evolving over longer time periods (Smith et al., 2006; Keisler & Shadmehr, 2010; Seidler et al., 2012). On examining the neural basis of VMA, the activation of DLPFC, basal ganglia, premotor, and parietal regions (Anguera et al., 2009; Inoue et al., 2000; Seidler et al., 2006; Toni et al., 1999) were observed during the early stages of adaption when participants are first exposed to the rotation and are developing adaptation strategies, while during the later stages, activity in the cerebellum, visual, parietal and temporal cortices was more predominant (Graydon et al., 2005; Imamizu et al., 2000; Inoue et al., 2000; Krakauer et al., 2004). Seidler et al. (2012) and Anguera et al. (2012) have also demonstrated that spatial working memory plays an important role in VMA and that age-related declines in this function contributes to deterioration in the performance of older adults.

Though older adults show some amount of deterioration in sensorimotor adaption (Seidler, 2006; Trewartha et al., 2014; Rajeshkumar & Trewartha, 2019), do they also demonstrate impaired savings in the rate of learning at transfer (the extent to which a newly acquired skill can be produced under different conditions and task variants)? Seidler explored this concept and found that older adults exhibited a normal amount of savings based on their prior learning experience. They performed as well as, and in some cases, even better that their younger counterparts in a visuomotor adaptation transfer task. This suggests that motor acquisition and transfer might be distinct processes, and differentially affected by age (Seidler, 2007). In our study, we will be looking at both, learning and transfer in older adults, particularly with reference to susceptibility to proactive interference (during transfer) in a visuomotor rotation task.

2.1.1 Motor Learning and Proactive Interference

Inhibition plays a crucial role in multiple motor functions. 'Motor inhibition is required during withdrawing, cancelation, or selection of voluntary movements' (Levin and Netz, 2015). And similar to cognitive learning, motor learning is also not free from interference. It can be affected by both proactive interference – where a previously learned skill affects the ability to learn a new skill – and retroactive interference – where retention of a previously learned skill is impaired due to learning of a new skill (Goedert & Willingham, 2002; Krakauer & Shadmehr, 2006). Compared to younger adults, older adults have been observed to be more susceptible to memory interference (Roig et al., 2014; Brashers-Krug et al., 1996). Age-related changes in brain functioning and connectivity are frequently seen in prefrontal brain areas like the dorsolateral prefrontal cortex (DLPFC), inferior frontal cortex (IFC), and/or the pre-supplementary motor area (pre-SMA) (Globe et al., 2010; Heuninckx et al., 2008) that are typically involved in the suppression of prepotent response tendencies.

During learning, when information is retrieved, irrelevant or conflicting information needs to be suppressed and relevant information enhanced. This requires recruitment of EF. Proactive interference (PI) based neuroimaging studies have observed that frontal lobe mechanisms (Badre & Wagner, 2006) like the executive control processes and working memory (Postle et.al., 2004) may play an important role in resolving PI. As we have seen, older adults appear to more susceptible to proactive interference than their younger counterparts (Dulas et.al., 2016). They also display a decline in their ability to learn new motor skill (Seidler, 2007). Bock et al. (2001) examined how sensorimotor adaptation acquired during one session influenced adaption in a subsequent session and found that when the administered sensorimotor discordances (visuomotor rotation) were in mutual conflict with each other, there was evidence of task interference and as a result, the adaptation was poorer in the subsequent session. On the other hand, when the discordances were independent (and not in opposition to each other), it facilitated adaption. Earlier studies (Shadmehr and Brashers-Krug 1997; Shadmehr and Holcomb 1999) have also demonstrated that subjects experiencing an opposite manipulation/ discordance in their second session, displayed a deterioration in their adaptation and performed substantially worse, especially if the sessions were scheduled closer to each other (less than 5 hours apart). They hypothesized that this decline could be attributed to the lack of sufficient time (between sessions) that is required for the adaptation to be consolidated in long term memory. This is because, when the two sessions are conducted in close temporal proximity, the two opposing discordances compete for the limited short-term memory (STM) capacity. They also observed that the non-compatible adapted states will interfere with memory even if they are acquired up to a month apart. According to Bock et al. (2001), interference is a competition between conflicting task requirements rather than being related to the competition for resources and fragility of representation in the short-term memory. In the visuomotor rotation (VMR) task, proactive interference (PI) happens when initial learning impairs subsequent adaptation to an opposing perturbation. The interference effects could be explained by a two-process model which suggests a fast-learning, fast-forgetting process that occurs by updating an internal model, along with a slow-learning, slow-forgetting process that does not involve updating an internal model (Huang et al., 2011; Leow et al., 2013). PI can be detrimental when trying to learn a new task or relearn a task, especially when the task is conflicting with prior learning. For example, during neurorehabilitation, when a person is required to relearn a motor task, s/he might need to overcome interference from prior learning, which may not be easy. Interventions that could reduce susceptibility to PI would be prove useful in such situations.

2.2 Emotional Intelligence

According to Mayer, Caruso and Salovey (1999, 2002; Austin, 2010), emotional intelligence (EI) consists of four branches: (1) perceiving emotions (accurate perception and expression of emotions); (2) assimilating emotions or facilitation of thought (assimilating emotional experiences into percentual perceptual and cognitive processes, reasoning with them); (3) understanding emotions (understanding the progressions of emotions across time and situations); and (4) managing emotions (effective regulation of emotions in self and others). While branches 1 and 2 are considered as the Experiential area, branches 3 and 4 form the Strategic area (Mayer and Salovey, 1997; Hurtado, et al., 2016). The above functions warrant the application of cognitive abilities to discern emotions accurately (both in self and others), manage emotions appropriately, make decisions and act accordingly. It is no surprise therefore, that emotional processing has been found to be related to attention and executive control (Etkin et al., 2012; Hurtado, et al., 2016). Hurtado explored the relationship between EF (working memory and reasoning subtests of the Wechsler Adult Intelligence Scale, Trail Making and Stroop tests, fluency and planning tasks, and Wisconsin Card Sorting Test) and EI. The findings showed a correlation between most of the EF and EI mainly in their healthy participants. Importantly, the relationship between cognitive and emotional intelligence was only significant in the Strategic area (Mayer and Salovey, 1997; Hurtado, et al., 2016), suggesting that a certain level of neurocognition is needed to understand and effectively think about one's own thoughts and those of others, in order to use proper metacognition and manage social difficulties. Executive function and self-regulation skills have said to be dependent on three types of brain function: working memory, mental flexibility, and self-control (which is also an aspect of EI - emotional management) ("Center on Developing Child", 2019). These functions are highly interrelated, and the successful application of executive function skills requires them to operate in coordination with each other. EI and EF have also shown to depend on some common brain regions like the orbital frontal cortex (OFC), and the anterior cingulate cortex (ACC) (Tarasuik et al., 2009).

There have been contradictory findings in the literature related to aging and EI. While some studies state that older adults exhibit higher EI than the younger counterparts (Mayer et al., 1999; Van Rooy et al., 2004; Chapman & Hayslip, 2006; Gardner & Qualter, 2011; Mayer et al., 2000; Tsaousis & Kazi, 2013, Chen et al., 2016), others have found no significant relationships between age and the various EI branches (Farrelly and Austin, 2007, Webb et al., 2013). A few others have demonstrated that age correlates negatively with emotion perception (Day & Carroll, 2004; Palmer et al., 2005) and emotion recognition (Ruffman et al., 2008; Cabello et al., 2014). Sliter and colleagues (2012) theorize that the relationship between age and EI can be explained on the basis of lifelong learning effects. As people age, they have ample opportunities to practice EI skills all through their lifespan and through this learning, gradually improve their understanding of emotions in themselves and others (Baltes et al., 1999) and thus employ better emotion regulation strategies as compared to younger adults (Gross & John, 2003). EI is a skill that can be enhanced through practice and older adults have ample opportunities to do so. EI has also been associated with life satisfaction (James et al., 2012; Koydemir et al., 2013, Chen et al., 2016), psychological wellbeing and positive affect among older adults (Galdona, et al., 2018). Cabello et al. (2014) make a case that the as well where education can help preserve cognitive-emotional structures during aging. They found that older adults with university education had similar scores to younger adults and higher scores than their less educated counterparts.

2.3 Executive Function

Executive Function (EF) can be described as the cognitive ability to regulate behavior and the more rudimentary cognitive processes by modifying the responses based on environmental cues (Brennan et al, 1997; Welsh et al., 1995; Welsh & Pennington, 1988). It facilitates self-monitoring and goal directed activity (Brennan et al., 1997). More recent evidence indicates that executive function / executive control is a “collection of related but separable abilities” and the three most examined EFs are response inhibition (ability to inhibit dominant or automatic responses), updating working memory representations (ability to continuously monitor incoming information with reference to the present task and appropriately update by replacing irrelevant information with newer, more applicable information) and set shifting (ability to flexibly switch back and forth between tasks (Friedman et al., 2008). In addition to these most widely studied components, there are other executive functions like dual tasking (Logie et.al., 2004; Salthouse et.al., 2003; Friedman et al., 2008) and resisting proactive interference (Friedman & Miyake, 2004; Friedman et al., 2008). Like Friedman, Diamond (2013) too characterized executive function to be comprised of three main components and he described these as inhibitory control (IC: attentional inhibition and cognitive inhibition), working memory (WM) and cognitive flexibility, all of which form the basis for higher order skills such as planning, problem solving and reasoning (Collins & Koechlin 2012; Lunt et al., 2012; Diamond, 2013). Inhibitory control (IC) is the ability to control one’s attention, behavior, thought and/or emotion to override a strong internal predisposition or external temptation, and do what is more appropriate or required. Attentional inhibition/or Inhibitory control of attention refers to interference control at the perception level, and enables us to selectively attend to certain stimuli, while suppressing or ignoring others. Cognitive inhibition, another form of IC is more about the ability to resist unwanted thoughts or memories, proactive and retroactive interference. It supports working memory (WM) by keeping out/deleting irrelevant information and preventing the mental workspace from becoming cluttered (Duncan et al., 2008; Diamond 2013). It appears to correspond more with WM measures than other forms of inhibition. Self-control, another aspect of IC, involves controlling one’s emotions, resisting temptations and restricting impulsive behavior. It is also about staying on task in spite of distractions and delaying gratification (Diamond, 2013).

Inhibition is important across the lifespan, and its proficiency is connected with the development of children’s cognitive, behavioral, social, and emotional competencies (Howard et al., 2014; Riggs et al., 2004; Riggs et al., 2006). In older adults, on the other hand, a decline in inhibitory control (IC) processes interferes with memory retrieval, resisting distraction and processing speed (Hasher et al., 1991; Howard et al., 2014). Though the importance of IC mechanisms is unquestionable, there has been diversity in its conceptual and functional descriptions (Howard et al.,2014). According to Nigg (2000), inhibitory processes can be classified into four types of effortful inhibition: interference control (suppression of interference due to stimulus competition), cognitive inhibition (suppression of irrelevant information form WM), behavioral inhibition (suppression of prepotent responses) and oculomotor inhibition (suppression of reflexive saccades). His taxonomy was based on Harnishfeger's (1995) proposition that inhibitory processes can be classified along 3 dimensions: (a) intentional (conscious suppression of irrelevant stimulus) or unintentional (occurs prior to conscious awareness) (b) behavioral (inhibiting motor responses and controlling impulses), or cognitive (controls processes such as memory and attention, suppresses unwanted/irrelevant thoughts and gating irrelevant information from working memory (WM) and (c) inhibition (active suppression process that operates on the contents of WM) and resistance to interference (gating mechanism that prevents irrelevant information or distracting stimuli from entering WM). There was also the question of determining if these IC processes reflected the same cognitive abilities. While the one factor model of inhibition proposes a single inhibitory resource for interrupting task-irrelevant cognitive processes, the multi-factor model, such as the 'Theory of Constructive Operators' (TCO) model of mental attention (Im-Bolter, et al., 2015), proposes that multiple resources contribute to inhibitory function and thus involves relationships with other cognitive processes as well. The general limited-resource model of inhibition stipulates that there is a limited pool of mental resources that is allocated for ongoing cognitive processes and is not restricted to any one specific type of mental function (Engle & Kane, 2004; Wais & Gazzaley, 2011). The attentional models of inhibition assert that inhibition effects can be explained solely in terms of attention (Cohen et al., 1990; Morton & Munakata, 2002) but neuropsychological evidence from patients with frontal lobe lesions show that the deficits accompanying a frontal lobe lesion cannot be explained on the basis of attention alone (Nigg et al., 2002; Howard et al., 2014). Friedman and Miyake (2004) challenged these models of inhibition and through confirmatory factor analysis and structural equation modeling, obtained two distinct inhibition factors: The first factor corresponded to an ability to suppress pre-potent responses and resist interference from distraction, and the second factor had the ability to resist intrusions from no-longer task-relevant information ('resistance to proactive interference'). Through their evaluation of these various competing theoretical models, Howard et al. (2014) validated the distinction between automatic and effortful inhibition, the crucial role of mental attention during performance of inhibition tasks, and the role of WM in tasks involving effortful inhibition.

Given the interdependence of the IC processes, could it be a possibility that they rely on the same underlying neural processes? It is hypothesized that, while inhibitory control of attention and action appear to share the same neural substrates (Bunge et al., 2002; Cohen et al. 2012; Diamond, 2013), cognitive inhibition may be dissociable, as found by Engelhardt et al. (2008) and Friedman & Miyake (2004). But one aspect that is common to all the inhibition-related functions is that they appear to require some measure of executive control, and this involves the frontal lobes or the anterior attentional network (Posner & Raichle, 1994). An atrophy in this region (age-related or otherwise) might very well result in a decline of these functions.

The second subdomain of EF, working memory (WM), involves performing one or more mental operations while simultaneously holding information in mind that is not perceptually available (Baddeley & Hitch, 1994; Diamond, 2013). WM (holding information in mind and manipulating it) is different from short term memory (STM) (just holding information in mind). Whereas WM relies more on dorsolateral prefrontal cortex, STM shows frontal activation only in ventrolateral prefrontal cortex. WM is necessary for any activity that requires holding in mind/memory something that happened earlier and relating it to the present situation or 'working with' the earlier acquired information to complete the present task (Baddeley and Hitch, 1994; Diamond, 2013, Smith and Jonides, 1999). Another example where WM comes into play, is when we need to remember/hold a question in mind, say during a lecture or conversation, till a later time when it is appropriate to ask. Overall, WM is critical for reasoning and problem solving, understanding, holding large amounts of information in mind, organizing, combining and manipulating information in different ways. It might be compromised if interference is not handled well by the IC processes. This is because WM and inhibitory control appear to support each other and co-occur. Example of where WM supports inhibitory control is in situations where, based on the information we are holding in WM, we act counter to our initial inclination. By concentrating hard on the information held in our WM, we decrease the likelihood of an 'inhibitory error' (emitting a prepotent response). The WM-IC effect appears to be bidirectional. IC supports WM by preventing mind wandering (by avoiding distractions) and cluttering of the WM workspace (by suppressing extraneous or irrelevant thoughts) (Diamond, 2013; Duncan et al., 2008).

Cognitive flexibility, the third hub of EF, is one's ability to change perspectives, to change one's way of thinking, to come up with alternate ways of solving problems, inhibiting (and not persevering with) methods that do not work/give results and replacing them with different and more effective ones. That is, being flexible to adjust to changing demands, situations (Diamond, 2013), and readiness to selectively switch between processes to generate appropriate behavioral responses (Dajani & Uddin, 2015). It overlaps with creativity, task switching and set shifting (Diamond, 2013). An example of flexible behavior is the ability to switch between multiple tasks. A result of task switching (TS) is behavioral slowing, manifested as switch cost. The cause of this switch cost and the role of cognitive control in its resolution remains debatable. Badre & Wagner (2006) tested whether proactive interference arising from memory, places any fundamental constraints on flexible performance, and whether prefrontal control processes contribute to overcoming these constraints. Their experiments demonstrated the strong association between TS and memory. According to them, the 'control processes contributing to TS are indistinguishable from the control processes engaged to overcome interference arising during other acts of memory'. And hence, the neural mechanisms supporting interference resolution during memory retrieval, such as those subserved by mid-VLPFC, are central for successfully overcoming interference during a TS (previous studies external to the context of TS had shown that VLPFC, particularly, the left-mid-VLPFC (inferior frontal gyrus pars triangularis) has been associated with the retrieval and selection of task-relevant representations). Thus, EF/IC and memory processes appear to be intertwined.

2.3.1 Aging & Executive Function

Aging is accompanied by cognitive decline, the reasons for which could be a combination of various factors, from structural atrophy of the brain (Raz et al, 1998), to degradation of sensory faculties, visuoperceptual abilities or reduction in processing speed (Salthouse et al., 1991). But this age-related cognitive deterioration is greatly variable and is differentially affected by aging. Not everybody has the same trajectory of cognitive decline. (Christensen et al., 1997, Christensen, Mackinnon et al., 1999; Buckner, 2004; Hogan 2005; Tucker-Drob and Salthouse, 2011; Salthouse, 2017). Although this is true, the consensus is that age-related deterioration is closely related to loss of CNS functioning, and executive control/ EF processes that are dependent on it, are more susceptible to the effect of aging (Hogan, 2005; Brennan et al., 1997; Daigneault & Braun, 1993; Fisk & Warr, 1996). According to the frontal hypothesis of aging, since the prefrontal cortex (PFC) disproportionately deteriorates more rapidly and severely than the other cortical areas, cognitive dependent on this region will be among the first to start declining (McAlister and Schmitter-Edgecombe, 2016). As cognitive and motor inhibitory functions are mediated by overlapping prefrontal brain networks (Levin and Ntez, 2015), this would lead to a decline in motor functioning as well.

The changes in the frontal striatal system, with a decrease in neurotransmitters such as dopamine, serotonin and noradrenaline and degradation in the volume and function of the Pre-Frontal Cortex (PFC) contribute to a reduced EF in older adults (Hedden & Gabrieli, 2004; Raz, et al., 2004; Volkow et al., 1996). Another factor contributing to decreased EF is the damage in white matter (with frontal white matter being more vulnerable to age related changes), as evidenced through MRI based studies of white matter lesions and their link to cognition, including EF and memory (Gunning-Dixon & Raz, 2000; Buckner, 2004), and grey matter loss (Good et al., 2001; Ziegler et al., 2012; Levin & Netz, 2015). These structural declines may occur in parallel with the decline in the regional concentration levels of neurotransmitters like gamma-aminobutyric acid (GABA) (Gao et al., 2013; Levin & Netz 2015) and serotonin (Goldberg et al., 2004; Lamar et al., 2009; Sibille et al., 2007). Such declines in GABAergic activity (Fujiyama et al., 2009; Heise et al., 2013) and diminished interactions between GABAergic and cholinergic system have been observed in healthy older adults as well those with mild cognitive impairments (MCI), who in addition to MCI, also demonstrated defective motor inhibition (Levin et al., 2014).

A decline in EF also influences memory. The rationale being that, remembering is mostly dependent on controlled processing, which in turn requires sustained attention, goal setting, and effortful processing of information (for example, when learning a skill for the first time) (Schneider & Chein, 2003; Buckner, 2004). All of these are EFs. Hence, a decline in EF may in all probability contribute to deterioration in memory, over and above that contributed by general cognitive ability (Crawford, 1999; Hogan, 2005; Anderson & Craik, 2000). Inhibitory control (IC) also declines with age, as detailed by the inhibitory deficit hypothesis (Hasher & Zacks, 1988; Gamboz et al. 2002) making older adults more vulnerable to proactive and retroactive interference. Studies have demonstrated that older adults were poor at inhibiting visual and aural distractions, exhibiting poorer suppression of the stimuli that requires to be ignored (Diamond, 2013). In the motor learning literature as well, older adults have been observed to be more susceptible to memory interference (Roig et al., 2014; Shadmehr and Brashers-Krug, 1997) compared to their younger counterparts. But, although effortful inhibition declines with aging, it is uncertain if automatic inhibition (such as that seen in the attentional blink or negative priming) and which is dissociable from the volitional, effortful inhibitory control (Carr et al. 2006, Nigg et al. 2002), deteriorates too. Along these lines, the meta-analysis by Gamboz et.al. (2002) on age related differences in negative priming demonstrated that both age groups are similarly susceptible to negative priming effect, indicating that IC processes may very well be preserved in older adults.

CHAPTER 3

EFFECT OF EXERCISE INTERVENTION ON MOTOR LEARNING & EMOTIONAL INTELLIGENCE

There is evidence suggesting that brain atrophy and cognitive deterioration can be reduced or even reversed through interventions like physical exercise (Erickson & Kramer, 2009). Exercise programs, especially those that that include both aerobic and resistance training (Kelly et al., 2014) have been demonstrated to prevent age-related cognitive decline and improve brain function (Bherer et al., 2013). A number of physiological mechanisms are likely responsible for the neuroprotective and neuroplastic effects of exercise on the brain including increased blood flow, elevated neurotrophin levels, vascular improvements, facilitation of synaptogenesis and mediation of inflammation (Kirk-Sanchez & McGough, 2013; Ploughman, 2008). The prefrontal cortex (PFC) is especially impacted by exercise, with exercise-induced enhancements observed in executive functions (EF) such as attention, inhibition, working memory updating, and cognitive flexibility (Albinet et al., 2016; Chang et al., 2012). One major domain of motor behavior that is dependent on these cognitive mechanisms is motor learning / or skill acquisition.

3.1 Motor Learning and Exercise

It is known that an excellent physical condition may very well postpone the emergence of symptoms of an aging motor system (Statton et al., 2015), including having ameliorative effects on the symptoms of Parkinson's disease (Spirduso, 2013- Exercise and the aging brain). The benefit of staying physically active doesn’t stop there. In addition to enhancing cognitive functions and wellbeing (Kramer et al. 2007; Kaliman et al., 2011; Voelcker-Rehage et al., 2013), physical exercise has also been found to improve brain neuroplasticity and motor learning (Mang et. al., 2014, 2016; Duchesne et al., 2015; Statton et al., 2015). It appears that, while exercising prior to learning a motor skill primarily influences acquisition, exercising after acquisition positively impacts consolidation and the strengthening of the related procedural memory (Thomas et al., 2016). Multiple studies have demonstrated that an acute bout of exercise, when performed in close temporal proximity to the motor task, facilitates motor skill acquisition. (Statton et al., 2015; Roig et al., 2012, 2016). Thomas and colleagues (2016) observed a similar occurrence, where exercise-induced enhancements in procedural memory reduced as the temporal proximity of exercise from acquisition increased. The group that carried out exercise 20 minutes after motor skill acquisition displayed superior retention than both, the delayed (+2 hours) exercise group and the resting control group. Exercise seemed to amplify ‘practice-dependent plasticity’ in the area of motor skill acquisition. Dal Maso and colleagues (2018) looked at the effect of acute cardiovascular exercise (high-intensity interval training), performed immediately after the motor task (visuo-motor tracking task) on cortico-motor network functionality during the early stages of memory consolidation. Similar to other findings, they confirmed that the above protocol demonstrates beneficial effects on motor skill retention, but this effect is significant only when assessed at least 24 hours after motor practice, as demonstrated by other studies as well (Mang et al., 2014; Roig et al., 2012; Thomas et al., 2016a, 2016c).

This improvement in retention was negligible when assessed just 8 hours after motor practice. The authors state one possible reason could be the retention being assessed too close in time to the exercise, not allowing enough time for its potential effects on the later stages of memory consolidation to be captured adequately. Others too have exhibited that effects of exercise on memory are time-dependent (Roig et al., 2016) and that they may arise even long-after the termination of exercise (Berchtold et al., 2005).

Some motor memories also show stabilization (maintenance of skill level achieved during practice) and off-line improvements (gains in skill level without additional practice) after a period of sleep (King et al., 2017). This could be another reason for exercise induced improvements to manifest more strongly after the 24 hours period. Ostadan et al. (2016) examined if a single bout of exercise modified corticospinal excitability (CSE) during the early stages of memory consolidation, and if changes in CSE are associated with exercise-induced off-line gains in procedural memory. They found that the participants in the exercise group displayed larger improvements in their procedural memory and that exercise also led to an improvement in CSE which correlated with the extent of off-line increases in skill level measured in a retention test performed eight hours post motor practice. This suggests that exercise modulates short term neuroplasticity mechanisms that contribute towards motor learning. Mang et al. (2016) examined the impact of acute aerobic exercise (high-intensity cycling) on the excitability of cerebellar circuits (that have been found are known to play an important role in motor control and learning (Clenik, 2015), especially those involving visuomotor rotations (Tseng et al., 2007; Rabe et al. 2004), and the potential role of these cerebellar circuits in facilitating the effect of the exercise intervention on primary motor cortex plasticity. Their study suggests that acute aerobic exercise impacts the excitability of cerebellar circuits and provide modest evidence that these cerebellar circuits may play a role in exercise induced increases in long term potentiation-like plasticity in the primary motor cortex. Levin and Netz (2015) refer to the work of multiple research groups who have demonstrated the positive effect of aerobic exercise on inhibitory control processes.

Duchesne et al. (2015) exhibited that aerobic exercise improved cognitive inhibitory functions in both Parkinson's Disease (PD) patients and their matched control of older adults. All the studies mentioned so far employed high intensity aerobic exercise to study their impact on motor skill acquisition. Snow et al. (2016), examined the effect of a single bout of moderate intensity aerobic exercise (cycling) on motor skill acquisition and retention in healthy young adults, and found that though this form of exercise (moderate intensity aerobic exercise) facilitated the preservation of motor performance during skill acquisition, it did not influence motor learning and nor did it influence off-line motor memory consolidation. They hypothesized that intensity of exercise might be a key modulator of the effects of acute aerobic exercise on complex motor behavior like motor learning. Statton et al. (2015) found that pairing of motor practice with moderate-intensity exercise over multiple sessions, lead to an additive effect on motor skill acquisition. Thus, the combination of acute and long-term interventions could maximize the effects of cardiovascular exercise on procedural memory (Roig et al., 2013).

In our study, we are exploring the potential effect of moderate intensity eccentric exercise on the ability of older adults to handle proactive interference in a motor skill acquisition task. Our proposition is that the enhancement in EF due to the exercise intervention will result in an increased efficiency in skill acquisition/motor learning, particularly on the ability to handle proactive interference.

3.2 Motor Learning and EEG

Electroencephalography (EEG) is a non-invasive method to examine underlying neural activity. Event related potentials (ERPs) are obtained from EEG recordings by averaging selected time epochs synchronized/or time-licked to an event, in our case, the appearance of a stimulus (van Dinteren et.al., 2014; Masaki et al. 2012). The average signal derived by this process typically consists of a complex waveform with positive and negative deflections during certain time intervals and with a specific voltage distribution across the scalp/ head's surface. Based on the characteristics of the deflections and waveform/s, different components can be defined; and in most cases they can be related to underlying cognitive processes. Some of these components have found to be useful in understanding different aspects of motor learning like error detection, stimuli processing, movement preparation and motor control. Motor learning, as we have seen, can be said to comprise of motor sequence learning and motor adaptation. Our research is based on understanding the latter, which is related to compensate for/adapt to environmental changes/ manipulation (Masaki et al., 2012). The various components that are interesting to motor learning researchers include the N100 (N1), N200 (N2), N400 (N4), P300 or P3 (P3a and P3b), feedback related negativity (FRN), and slow wave negativity (SWN).

The N100 component appears as negative deflection in the ERP waveform between 125 to 200 ms following the onset of a stimulus/visual cue. It is has been associated with in a variety of stimulation conditions including visuospatial attention (and as such is related to the allocation of visuospatial attention) (Harter et al., 1989; Hillyard & Anllo-Vento, 1998; Luck et al., 1990; Krigolson et al., 2015), visual, auditory, somatic, behavioral and cognitive tasks (Du et al., 2016).

The N200 is a large negative ERP inflection between 125 and 350 ms post stimulus onset and is made up of two subcomponents- the anterior N200 and posterior N200. While the former is associated with conflict monitoring, stimulus frequency and aspects of language characterization (Krigolson et al., 2015**,** Patel & Azzam, 2005**)**, the latter is sensitive to stimulus frequency and is usually seen in concordance with the posterior P300 component that is evoked during oddball tasks. The posterior N200 has also been associated with allocation of visuospatial attention (Folstein & Van Petten, 2008). N200 in general is suggested to have even more subdivisions related to error evaluation (FRN) and attention (N2pc) (Luck, 2005).

The N400 (a negative ERP deflection occurring approximately 400 ms after a meaningful stimulus onset) has largely been associated with semantic processing and reflect neurocognitive mechanisms related to construction of meaning based on expectancies created past experiences and current contextual information. But similar effects have also been observed for non-linguistic material involving meaningful actions (Amoruso et al., 2013; Sitnikova et al., 2003, Hanslmayr et al., (2008) where action-elicited N400 waveforms were observed to be more frontally distributed, as compared to the linguistic N400 which had maximum peaks over central and parietal regions (Amoruso et al., 2013). Some of these non-linguistic studies like Hanslmayr et al. (2008) and others (Markela-Lerenc et al., 2004; Liotti et al., 2000; Rebai et al., 1997) found the N400 component to be related to interference elicited by the Stroop incongruent trials resulting from the activation of the frontal central areas, particularly the ACC (MacDonald et al., 2000; Botvinick et al., 2004) as revealed by dipole localization (Hanslmayr et al., 2008). Another component called Late negativity (LN) at the 600-800 ms interval has also been observed exhibit a N400-like effect reflecting interference detection in addition to the elicitation of executive control/central executive processes.

The P300 ERP component is a large positive waveform that peaks at approximately 300 ms after stimulus onset and has been linked to cognitive information processing (e.g., memory, attention, executive function) (van Dinteren et.al., 2014). P300 is measured by assessing its amplitude and latency. The amplitude (µV) s defined as the "difference between the mean pre-stimulus baseline voltage and the largest positive-going peak of the ERP waveform within a time window" (the range of which can vary depending on stimulus modality, task conditions, subject age, etc.). The latency is defined as the "time from stimulus onset to the point of maximum positive amplitude withing a time window". The scalp distribution is defined as the change in amplitude over the midline electrodes (Fz, Cz, Pz) which usually increases in magnitude from frontal to parietal sites (Johnson, 1993; Polich, 2007).

The classical P300 component P3b, occurs in the range of 300-600 ms (Bledowski et al., 2004) and is elicited by novel events (like an infrequently appearing target stimuli in the 'oddball task'). It has a centroparietal distribution on the scalp and has been linked to cognitive processes like context updating (Donchin & Coles, 1988; Kok, 2001) (updating of one's internal model of the environment based on new information), event categorization, context closure (Polich, 1997; Bledowski et al., 2004), executive function (Dichter et al., 2006), speed of information processing (O'Brien et al., 2011; Amin et al., 2015) and stimulus change detection (Polich, 2007). In addition to the traditional P300 (P3b), that is associated with responding to infrequent target stimuli, a slightly earlier P3 peak has also been observed with marginally shorter latencies and larger amplitudes (scalp distribution) over the frontal and central electrode sites. This component has been labeled as P3a (Squires et.al., 1975; Polich, 1997) and appears to reflect an initial alerting process (Polich, 1997) and not necessarily to the generation of responses (van Dinteren et.al., 2014). Bledowski et al. (2004) also made similar observations, where the parietal and inferior temporal regions were associated with P3b, and P3a with the frontal areas and insula. They theorized that most likely, the two components engage different attentional subsystems which in turn depends on the type of task involved (Bledowski et al., 2004). For our study on motor learning, we will be considering the classical/traditional P300 or P3b.

With respect to adaptation in motor learning, MacLean et al. (2016) found P300 to be modulated by phase (early, middle, late stages of adaptation), where it became smaller as the task progressed, or in other words, as learning improved. A related observation was that the P300 amplitude decreased with a reduction in error size. Palidis et al. (2019) also had similar findings in their VMR task, where P300 was correlated to learning rate and its amplitude increasing with sensory error induced by the perturbed visual feedback. Both these studies reflect well the theory of context updating where the P300 response is triggered by an element of surprise (on encountering the manipulation) and consistently having to modify their internal model in order to adapt to the changing environment/conditions. The P300 component appears to have a significant visual and sensory/proprioceptive association.

In addition to the P300, there are more tonic components with less distinct peaks and predominantly negative polarity which last for at least a couple of hundred ms. These long lasting sustained potential shifts, or slow waves seem to exist as long as the system is engaged in a particular processing task. Slow waves have been observed in a variety of tasks like selective and directive attention (Nd) (Hansen & Hillyard, 1983;1988), motor preparation (Bereitschaftspotential, or BP) performance related negativity (Kornhuber & Deecke, 1965; Lang et al., 1988), during associative learning (Lang et al., 1987), and when anticipating a stimulus presentation (CNV and SPN) (Brunia & Damen, 1988; Walter et al., 1964). Their topography is task specific and covaries with the nature of a task. It has also been observed that their amplitude covaries with task difficulty (the amplitude becomes larger when the task becomes more difficult/or when more effort is needed to complete the task). And hence these topographically distinct slow wave patterns can be used to discriminate between the different stages of information processing within a task (Rosler et al., 1997)

3.3 Emotional Intelligence & Exercise

There have been a few studies investigating the association of EI and health related behaviors (Saklofske et al., 2015, 2007; Tsaousis & Nikolaou, 2005), and even fewer studies to examine the effect of exercise on EI, which were mostly done on animals (rats). And though there may not be much research done exclusively on the effect of exercise on EI, but there have been studies demonstrating that in addition to enhancing learning, memory, executive function and cognitive control (Voss et al., 2011; Gomez-Pinilla & Hillman, 2013; Donnelly et al., 2016), exercise also reduces incidence of stress related psychiatric illnesses like depression (Zheng, et al., 2006; Greenwood, et al., 2003; Blumenthal, et al, 2007; Lloyd et al., 2017) and anxiety (Herring et al., 2010; Powers et al., 2015, Mika et al., 2015). It also enhances memory for extinction when performed in close temporal proximity to the extinction ("decay of a fear response following repeated presentation of the fear-evoking conditioned stimulus in the absence of the aversive unconditional stimulus") session (Siette et al., 2014). Now it appears that exercise may be effective in preventing relapse of fear as well. Mika and colleagues (2015) demonstrated that exercising during fear extinction diminishes relapse through a physiological mechanism involving striatum and its direct pathway. One reasoning is that a positive affective state (generated through exercise by recruitment of the dopaminergic system) could become associated with the conditioned stimulus (CS) during extinction, thus resulting in a relapse-resistant extinction memory. Mammalian target of rapamycin (mTOR) is a translation regulator essential for cell growth, propagation, and survival. It has been associated with enhancing learning and memory as well as antidepressant effects. Exercise appears to activate mTOR in brain regions involved in cognition and emotion (Lloyd et al., 2017). More recently, a study by Giles et al. (2018) demonstrated that endurance exercise akin to 90 minutes of moderate intensity running exercise increases positive emotion during exercise, and the cognitive control of emotion using reappraisal after exercise in younger adults.

Based on previous findings and the association between the EI and EF, we hypothesize that exercise induced improvement in EF will translate to/or be reflected in, an improvement in EI as well, particularly in the areas of emotion perception and emotion management.

3.4 Executive Function & Exercise

The importance of executive functions cannot be undervalued. They are necessary to support several essential functions in our everyday lives, including planning a complex sequence of tasks, organizing, multitasking, learning a new skill/task, initiating goal directed behavior and sustaining attention while overcoming distractions and/or interference (McAlister & Schmitter-Edgecombe, 2016). EFs have also been found to play a mediating role between age and memory (Brennan et al., 1997; Troyer et al.,1994). Hence, various interventions are being studied that could help older adults maintain and enhance their EFs, and thus provide them an opportunity to live independent and fully functioning lives for as long as possible. One such intervention proven to be effective in enhancing EF and other cognitive abilities like memory in older adults is exercise.

The link between exercise and cognitive improvement has been established in several research studies (Spirduso, 1975; Colcombe & Kramer, 2003; Bherer et al., 2013;

Voelcker-Rehage & Niemann, 2013; Basso & Suzuki, 2017). The exact neurophysiological and behavioral basis of this effect are not yet clear. It could be due to the increase in brain derived neurotropic factor (BDNF), alleviated capacity for neuroplastic change, increased cognitive abilities, other behavioral variables, or a combination of one or more of these. There have also been few inconsistencies in these assertions, where a few studies like that of Kimura et al. (2010) did not display a significant effect of exercise on cognition. But by and large, the evidence is in favor of exercise enhancing cognitive abilities (Colcombe & Kramer, 2003; Hillman et al., 2008; Kramer & Erickson, 2007; Sibley & Etnier, 2003). Though exercise benefits cognitive functions in general, its effect is more pronounced on executive functions (Colcombe & Kramer, 2003). It has also been observed that cognitive improvement is greater for those tasks/exercise interventions that require executive control and are correlated with improvement in cardiovascular function (Bherer et al., 2013). Duration, frequency and dose (length of each exercise session) seem to influence level of cognitive improvement: the more time spent practicing, the better the cognitive improvement (Diamond, 2013). Voelcker-Rehage & Niemann (2013) reviewed multiple studies on how different forms of exercise (cardiovascular, resistance, coordinative exercises) affect the brain. They acknowledged that exercise induced changes in metabolism, like higher oxygen supply (as established in cardiovascular studies) and changes in information processing, occurring due to the cognitive demands of the exercise (like coordination training), are crucial to induce molecular, cellular changes and improve functional connectivity in the brain. This in turn, results in improved cognitive functioning (Colcombe & Kramer, 2003; Voelcker-Rehageetal, 2011; Voelcker-Rehage & Niemann, 2013). These studies have thus demonstrated that exercise, especially those that are cognitively demanding and involve higher metabolism and cardiovascular function have a positive effect on cognitive functioning, especially on EF. In physical activities with very low metabolic or cognitive demands, no such improvement can be expected. For example, aerobic or resistance exercise (like running on a treadmill or riding a stationary bike) that do not include a substantial cognitive component/or that do not require any EF skills do not lead to improvement in executive control (Hillman et al., 2008; Diamond, 2013; Diamond 2016). It appears that the intensity of aerobic exercise determines the scale and direction of exercise's effect on emotion and cognitive control, with high and low intensity exercises affecting cognitive and emotional processing in differential ways (Dietrich, 2006; Giles et al., 2018). While some studies have shown that acute bouts of high intensity aerobic exercises benefit cognitive functioning, a few others have proven otherwise (Basso and Suzuki, 2017). Despite this variability, three of the most consistent effects reported are improvements in prefrontal cortex dependent cognitive tasks (Basso et al., 2015), improvements in mood state (Reed & Ones, 2006; Maroulakis et al., 1993), and decrease in stress level (Ebbesen, et al. 1992; Basso and Suzuki, 2017). More recently, in their meta-analysis, Sanders et al. (2019) found that, though exercise did appear to yield a small positive effect on executive function and memory (d = 0.25 and d = 0.24 respectively), the dose parameters (duration of the exercise program, duration of individual sessions and frequency of sessions) may not predict the magnitude of this effect.

There have been several studies highlighting the positive relationship between physical fitness/exercise and aging (Hogan, 2005; Yang et al., 2020; Zang et al., 2014; Kroll & Clarkson, 1978; Spirduso, 1980). Exercise is an important and a much-researched intervention for older adults and has proven to be beneficial to them on many fronts. It has been found to improve cardiovascular health, retain mobility/reduce inactivity, reduce risk of falling and improve cognitive resilience (Hogan, 2005; Bherer et al., 2013; Voelcker-Rehage & Niemann, 2013). Physically active older adults have shown to demonstrate superior physiological response times than their inactive counterparts (Hogan, 2005; Kroll & Clarkson, 1978). In some cross-sectional studies, the response times of highly fit older participants have even been found to be comparable to that of participants even 30 to 40 years younger than them. Exercise has also shown to postpone deterioration observed in motor systems by maintaining the nigrostriatal DA system. The author goes on to say that exceptional physical condition may in all probability delay the emergence of symptoms of an aging motor system and may ameliorate the symptoms of Parkinson's disease (Hogan, 2005; Spirduso et al., 1988). Another example is that of mind-body exercises like Tai Chi Chuan (TCC), that has been proven to enhance an individual’s cardiopulmonary function and cognitive capabilities (Yang et al., 2020; Miller & Taylor-Piliae, 2014, Nguyen & Kruse, 2012). Yang and colleagues (2020) examined the potential effects of TCC specifically on inhibitory control in older people using a functional near-infrared spectroscopy (fNIRS) technique and found that the intervention group performed significantly better in the flanker test (faster reaction times in the incongruent flanker trials) after the TCC exercise intervention.

Even though there have been multiple studies exploring the direct relationship between exercise and EF, the benefits of exercise for improving other cognitive abilities that are dependent on EF abilities are less well understood. Two such candidate domains that we are interested in understanding more about, are motor learning/skill acquisition and emotional intelligence abilities.

3.5 Research Question

Several studies have documented a positive relationship between motor learning, executive function, exercise and aging, especially when the involved exercise has a cognitive component to it. However, is the improvement in EF connected to improvement in motor learning and emotional intelligence or are the improvements orthogonal? Does improvement in EF translate improvement in handing proactive interference in motor learning among older adults? What are other factors might contribute to this improvement? Is the degree of susceptibility to proactive interference related to any of the emotional intelligence dimensions (emotion perception, emotional understanding and emotional management abilities)?

We designed a 12-week eccentric exercise intervention as an attempt to answer the above questions and to test the prediction that exercise leads to improvement in EF, the ability to handle proactive interference in motor learning, and EI abilities. In addition, we are also assessing changes in physical and cardiovascular measures, but the latter two will not be the primary focus areas of this dissertation.

3.6 Method

Twenty-two older adult participants between 60 and 85 years old were recruited from the Houghton, MI area to participate in this study. Participants were screened either over the phone or in person using a health questionnaire to ensure that they met our inclusion criteria outlined in Figure 2.1. They were all high functioning individuals without any kind of neurological, cardiovascular, or orthopedic condition that would compromise their ability and efficiency to do the assigned tasks in the study. The participants were randomly assigned either to the exercise group or a non-exercise control group. The exercise group included 9 females and 2 males, average age 70.6 years (+/- 3.53 years) with an average BMI of 26.34 and the control group included 8 females and 3 males, with an average age of 71.8 years (+/- 6.08 years) and an average BMI of 23.77. For the baseline measures (Figure 3.1), participants were requested to come in on 3 separate days. On day 1 they completed the cognitive and motor learning (VMR) tasks, on day 2 they had their physical fitness and arterial stiffness measures taken and on day 3 they completed their second round of physical measures and were administered the personality and emotional intelligence questionnaires. The same protocol was followed for the post measures twelve weeks later.

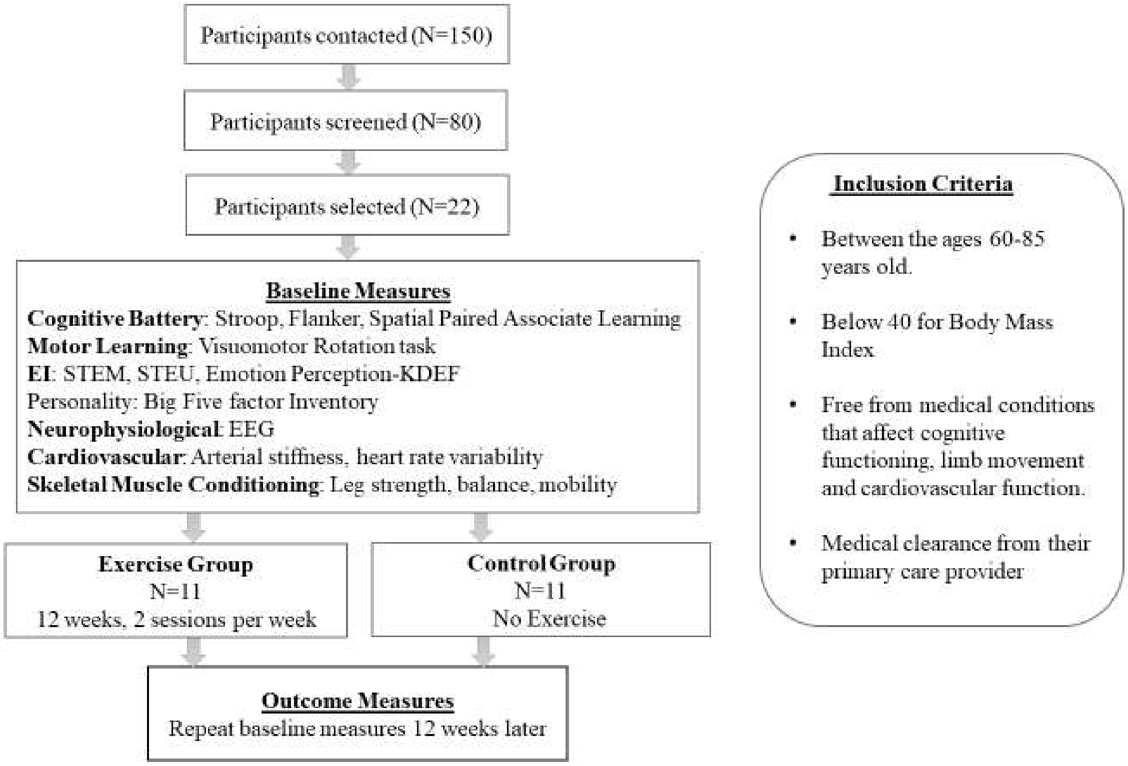


Figure 3.1. The research design for the Exercise Intervention study

3.6.1 Motor Learning Task

The motor learning task was a visuomotor rotation (VMR) task implemented on a robotic device for assessing upper limb movements (KINARM, B-Kin Technologies, Kingston, ON, Canada) (Figures 3.2A and 3.2B). With their dominant hand, participants grasped a handle to move a cursor toward one of four targets displayed on the screen from a start position in the center of the screen. The target location was randomized from trial to trial in sets of four trials across the experiment such that every four-trial set included one movement to each target. The participants were instructed to “make a reaching movement to the target as and when it appeared”. They were also told that the reaction time was not important and so could start moving towards the target as and when they were ready to do so. But once they started their movement, they were to continue moving at a consistent pace. The VMR task consisted of 3 blocks-familiarization stage, adaptation stage and wash-out stage. During an initial familiarization stage, the cursor followed the participant’s hand position to the target. Without warning, a visuomotor rotation was then applied (in the adaptation stage), where the cursor movement was rotated by a 45-degree angle in a clockwise or counterclockwise direction about the start position relative to the position of the participant’s hand. The participant must then adapt by moving their cursor in a straight line at a 45-degree angle in the opposite direction to guide the cursor to the target. During the final (wash-out) stage, the rotation was removed again to assess after-effects. For every trial, after the target was reached the cursor feedback was turned off and participants were instructed to move their hand back towards the midline of their body at the bottom of the screen. Any rotation that was applied was then turned off and the cursor turned back on so that participants could move the cursor back to the start position to begin the next trial. The dependent measure was the angular error in degrees of the initial heading direction of the participant’s hand for each trial. At baseline, equal numbers of participants in each group completed a clockwise and counterclockwise visuomotor rotation.

Figure 3.2A. Kinarm-the robotic equipment used to program and administer the motor learning task.

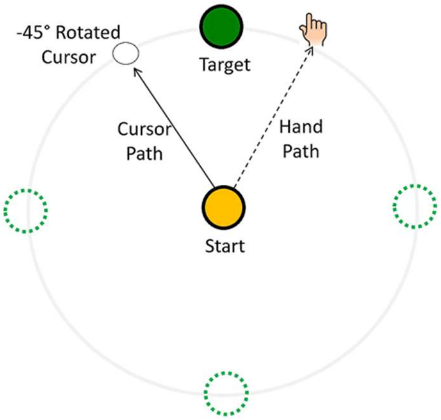


Figure 3.2B. The Visuomotor Rotation (VMR) task where the participant is required to move the cursor from the 'start' position to the 'target'

3.6.2 Cognitive Tasks

The cognitive tasks were included to provide measures of executive functioning. Standard versions of the color-word Stroop and Flanker tasks were administered using the Psychology Experiment Building Language (PEBL) software. A spatial paired-associate learning (PAL) task (Trewartha, 2014) was also administered to provide additional measure of working memory.

3.6.3 Emotional Intelligence (EI) Measures

For measuring emotional intelligence abilities, the Situational Test of Emotion Management, STEM (Austin, 2010; Allen et al., 2015) , Situational Test of Emotional Understanding, STEU (Allen et al., 2014) and emotion perception task designed based on the KDEF database of facial images (Lundqvist et al., 1998) were used. The STEM and STEU consist of multiple-choice questions with items similar to those found in cognitive tests and measure one's abilities to understand and manage emotions. The emotion perception (EP) task was programmed and administered using the PEBL software. For the EP task, participants were instructed to click once on the picture/image as soon as they identified the emotion (happy, sad, angry, afraid, disgust, surprise and neutral). The RT was recorded at this point (RT1). A second RT (RT2) was recorded once the emotion labels had appeared and the participant had to select the relevant label for the picture.

3.6.4 EEG

As part of the baseline and post measures, psychophysiological (electroencephalography) readings were also taken to measure the amplitude of the P3b, the neurophysiological correlate of working memory (WM) updating. The goal was to compare changes in the amplitude and latency of the P3b component elicited during the VMR task. EEG triggers were sent from the Kinarm to the EEG acquisition software through a built in National Instruments card. The EEG acquisition software accepted these stimulus and response triggers and implanted these codes in the EEG data stream for synchronization. A continuous EEG was recorded with an active electrode EEG system, ActiveTwo (BioSemi, Amsterdam, the Netherlands), using a 32-electrode nylon cap, sampled at 512 Hz in a DC to 104 Hz bandwidth. The EEG data were recorded relative to common mode sense and driven right leg (CMS/DRL) electrodes placed on the top of the head, to the left and right of a midline parietal-occipital electrode (POz), respectively.

3.6.5 Exercise intervention

Once the baseline measures were collected, the participants in the control group were informed that they would be contacted after 12 weeks to return for their follow-up testing sessions. The exercise group came in twice a week and to complete exercise sessions at low to moderate intensity based on the exercise protocol elucidated in Table 3.1. An Eccentron exercise machine (BTE Rehab Equipment, Hanover, Maryland, United States) was used to perform an eccentric exercise routine that mimics walking down a flight of stairs. The two pedals of the machine alternately move towards the participant at a constant rate, and the participant attempts to resist the motion. A computer screen mounted in front of the participant provided visual cues regarding force production and timing accuracy, and prompted the participant to transition between warm-up, exercise, and cool-down phases. At the end of 12 weeks, participants completed the same tasks they performed at baseline. The only change was in the motor learning task, where participants performed a rotation opposite to the rotation they experienced at baseline to assess proactive interference.

Table 3.1. Exercise Protocol

Session No	Time (Minutes)	Speed (Reps. Per minute)	RPE (Rate of Perceived Exertion)
1,2	5	15	7
3,4	8	15	9
5,6	10	15	11
7,8	12	17	13
9,10	15	17	13
11,12	15	17	13
13,14	18	19	13
15,16	18	19	13
17,18	20	19	13
19,20	20	21	13
21,22	20	21	13
23,24	20	21	13

3.7 Data Processing

Statistical analyses of these data included t-tests, Regression, Pearson correlation, and ANOVA approaches, as described in the results section. We scrutinized the descriptive measures of central tendency to verify if there was a major difference between the mean and median as that might indicate outlier. We also looked at kurtosis, skewness and carried out the Shapiro–Wilk test of normality. To rule out, or account for preexisting significant or systematic differences, we conducted a one-way ANOVA all the baseline measures between the two groups and found no significant difference between their measures ($p>0.2$). Given our relatively small sample size and the larger number of variables, there was a possibility of overfitting the model in regression. Hence, we performed a dimension reduction operation involving principal component analysis (PCA) trough varimax rotation of the independent variables (IVs).

3.7.1 Motor Learning Task

The VMR task was divided into three blocks - familiarization stage, adaptation stage and wash-out stage. The dependent variable/measure was the angular error (AE) in degrees of the initial heading direction (initial heading angle) of the participant's hand for each trial. The initial heading angle was calculated as the angle between the cursor and the start position when the movement trajectory crossed a distance threshold at the 3 cm radius from the starting position. During the rotation trials, participants corrected for the angular error by adjusting their heading angle in the opposite direction of the rotation. For example, the optimal compensation for the applied rotation was a 45° heading angle if the rotation was -45°. The angular error was then calculated as the difference between the initial heading angle and the optimal heading angle given the rotation that was applied (i.e., either 0°,45°, or -45°). That is, if the participant was moving at a 45° heading angle in a direction opposite to that of the applied rotation (-45°), s/he would have zero angular error. The heading angle and angular errors were all averaged in bins of 4 consecutive trials (i.e., one trial to each target location) for analysis. Proactive interference was calculated as a 'resistance to interference score' that was obtained by subtracting the learning score of the baseline VMR task (calculated as the difference in the angular error between the first and last bin of the adaptation phase) from the learning score of the post intervention VMR task. A higher resistance to interference score implied better motor learning related to an ability to suppress interference from prior learning.

3.7.2 EEG

An exploratory aim of this research project was to investigate the neurophysiological basis of motor learning, specifically in the context of proactive interference. We studied the neurophysiological activity (time and frequency domains) at the Fz, Cz, and Pz sites/channels to test the hypothesis that working memory updating processes, reflected in the P3b ERP component would be associated with learning. Visual inspection of the ERP waveforms revealed a P3b-like waveform and a later slow wave negativity, but there was an apparent preexisting difference between the exercise and control group in these waveforms. For this reason, we performed pre- and post-test, within group comparisons of the mean amplitude of the P3b (component1/C1) and the late negativity slow wave (LNSW) component (component 2/ C2) peaks.

3.8 Results

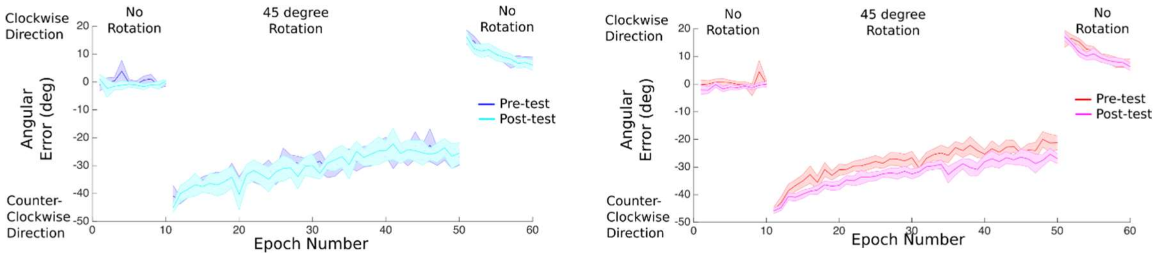
We used an alpha level of .05 for all statistical tests and a Bonferroni correction was applied for all post-hoc comparisons.

3.8.1 Pre-Post Comparisons

3.8.1.1 Visuomotor Task

For the motor learning task, we assessed angular errors across the experiment in an epoch by testing session (pre vs post) ANOVA for each group. Figures 3.3A and 3.3B illustrate the VMR performance of both groups across all epochs. There was a main effect of epoch (or bins) in both, the exercise ($F(59, 590) = 103.421$, $p < 0.001$, $\eta p^2 = 0.912$) and control ($F(59, 590) = 316.408$, $p < 0.001$ 0.0, $\eta p^2 = 0.969$) groups, which was expected as the epochs represent the different blocks (no rotation and rotation applied) and hence are inherently different from each other. We did not find a main effect of testing session in either group, though in the control group. However, a significant epoch by testing session interaction ($F(59, 590) = 1.453$, $p = 0.019$, $\eta p^2 = 0.127$) revealed that the control group experienced interference from pre to post-test in the motor learning task, whereas there was no significant difference between the pre and post measures across epochs for the exercise group ($p > 0.6$).

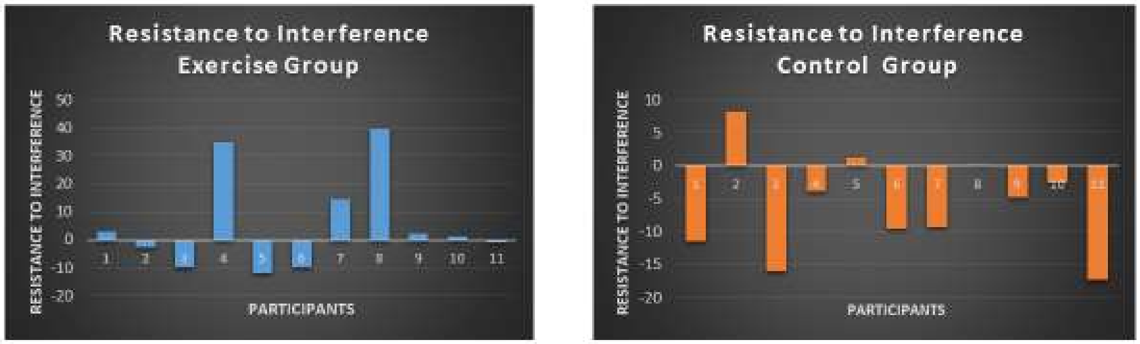
Resistance to proactive interference was calculated as a 'resistance to interference score' that was obtained by subtracting the learning score of the baseline VMR task (calculated as the difference in the angular error between the first and last bin of the adaptation phase) from the learning score of the post intervention VMR task. A higher resistance to interference score implied better motor learning related to an ability to suppress interference from prior learning. The exercise group displayed a superior resistance to interference than the control group (Figures 3.4A and 3.4B).



3.3A **Exercise Group**

3.3B **Control Group**

Figure 3.3A and 3.3B. Graphical representation of the performance on the VMR task by the exercise group (3.3A) and the control group (3.3B). In 3.3A, there is a complete overlap of the pre and post-test measures in the adaptation trials (epochs 10-50). In 3.3B, there is a visible difference between the pre and post-test measures in the adaptation trials (epochs 10-50) of the control group.


3.4A

3.4B

Figures 3.4A and 3.4B. Graphical representation of the resistance to interference experienced by each participant in the exercise group (3.4A) and the control group (3.4B).

3.8.1.2 Treatment Effect on Cognitive and EI Variables

The effectiveness of the intervention on the cognitive and EI variables were evaluated using Hedges' *d*, one of the measures best suited for pretest-posttest-control (PPC) designs such as ours. The Hedges' *g* was calculated first by subtracting the mean change (post-pre) in the control group from the mean change in the exercise group and dividing this difference by the pooled pre-test standard deviation. Hedges' *d* ('*d*') was obtained by adjusting Hedges' *g* for small sample size bias (Morris, 2008).

For the cognitive variables, the treatment effect sizes were highest for Stroop conflict cost accuracy (d_{ppc2}=0.47) and Stroop conflict cost RT (*d*=0.48). All the other variables too (except for Flanker conflict cost), indicated a positive treatment effect. For the EI variables, the effect sizes were largest for emotion perception (EP) accuracy (*d*=0.60), EP RT (*d*=0.67), and STEM-F (*d*=0.62). STEM-A, STEM-S and STEM-Total also exhibited a positive effect of treatment. The pre-test, post-test and pre-post difference means and SDs of the cognitive and EI measures are presented in tables 3.2 and 3.3, respectively. The treatment effect sizes related to these measures are presented in Table 3.4.

Table 3.2. Means and SDs of Cognitive Measures

Exercise Group (N=11)			
Measure	**Pre-test Mean (SD)**	**Post-test Mean (SD)**	**Pre-post Diff. Mean (SD)**
Flanker Mean Accuracy	0.975 (0.016)	0.985 (0.014)	0.01 (0.016)
Flanker Incongruent RT	558.273 (44.675)	569.02 (48.437)	10.748 (27.165)
Flanker Conflict Cost	55.709 (19.14)	65.355 (27.613)	9.645 (26.027)
Stroop Conflict Cost Accuracy	0.021 (0.035)	0.019 (0.038)	-0.002 (0.051)
Stroop Conflict Cost RT	292.490 (156.656)	273.276 (104.804)	-19.215 (89.731)
PAL Avg. Repetition	1.213 (1.00)	1.047 (0.461)	-0.166 (0.898)
Control Group (N=11)			
Flanker Mean Accuracy	0.97 (0.02)	0.977 (0.015)	0.007 (0.024)
Flanker Incongruent RT	562.07 (48.19)	582.53 (35.061)	20.459 (32.681)
Flanker Conflict Cost	57.173 (16.281	69.416 (18.367)	12.243 (15.596)
Stroop Conflict Cost Accuracy	0.032 (0.034	0.013 (0.014)	-0.019 (0.038)
Stroop Conflict Cost RT	314.767 (144.764	220.084 (135.433)	-94.682 (101.481)
PAL Avg. Repetition	1.254 (0.632	0.928 (0.689)	-0.326 (0.521)

Table 3.3. Means and SDs of Emotional Intelligence (EI) Measures

Exercise Group (N=11)			
Measures	**Pre-test Mean (SD)**	**Post-test Mean (SD)**	**Pre-post Diff. Mean (SD)**
STEM - A	8.765 (1.177)	8.97 (0.888)	0.204 (0.838)
STEM - S	10.128 (1.062)	10.477 (0.762)	0.349 (1.268)
STEM - F	4.659 (1.055)	5.349 (1.021)	0.689 (0.893)
STEM- Total	24.129 (2.473)	25.076 (2.497)	0.947 (2.424)
STEU	28.091 (2.737)	28.273 (3.2891)	0.182 (3.027)
EP Accuracy	52.636 (5.353)	54.00 (5.477)	1.364 (3.139)
EP RT	3960.437 (1255.017)	4206.736 (1996.658)	246.306 (1495.554)
Control Group (N=11)			
STEM - A	9.045 (1.476)	8.871 (1.897)	-0.174 (1.641)
STEM – S	9.25 (1.903)	9.394 (2.015)	0.144 (2.127)
STEM - F	5.197 (1.023)	5.22 (1.071)	0.023 (0.933)
STEM- Total	23.674 (3.624)	23.72 (4.596)	0.046 (4.087)
STEU	26.636 (3.171)	28.636 (2.42)	2.00 (3.795)
EP Accuracy	53.546 (5.261)	52.182 (5.382)	-1.364 (2.898)
EP RT	4637.745 (1142.807)	4054.382 (1100.423)	-583.363 (1145.982)

Table 3.4. Treatment Effect Size of Cognitive and EI Measures

Measure	**Effect Size**
Flanker Mean Accuracy	0.158
Flanker Incongruent RT	0.201
Flanker Conflict Cost	-0.141
Stroop Conflict Cost Accuracy	0.469
Stroop Conflict Cost RT	0.481
PAL Avg. Repetition	0.184
STEM - A	0.273
STEM – S	0.128
STEM - F	0.617
STEM- Total	0.280
STEU	- 0.591
EP Accuracy	0.596
EP RT	0.665

3.8.1.3 EEG

As part of the baseline and post measures, psychophysiological (electroencephalography) readings were taken to measure the amplitude of the P3b (component1/ or C1), the neurophysiological correlate of executive functioning, learning, and working memory (WM) updating. The goal was to compare changes (between pre and post) in the mean amplitude of this component elicited during the VMR task. As mentioned earlier, visual inspection of the ERP waveforms revealed a late negativity slow wave (LNSW) component (component 2/ or C2) in addition to the P3b. Due to an apparent preexisting difference between the exercise and control group in these waveforms, we performed pre and post, within group comparisons of the mean amplitude of the P3b and the LNSW peaks. The waveforms are displayed in Figure 3.6.

Both components-C1 and C2 were differentially manifested in the two groups. A time by channel repeated measures ANOVA was performed on the mean amplitude measures of these components for both groups separately, with 2 levels for time (pre and post), and 3 levels for channel (Fz, Cz, and Pz). In the control group (CG), for the P3b, a significant time by channel interaction ($F(2,20) = 3.63$, $p = 0.045$, $\eta p^2 = 0.27$) was observed. Pairwise comparisons for this interaction revealed a significant difference in the P3b for the Cz channel from pre to post test. The mean amplitude of P3b at Cz was larger at pre-test (during learning) than at post-test (transfer) ($M_{diff} = 9.15E-7$, $p = 0.026$). In the exercise group (EG), there was a main effect of channel ($F(2,18) = 11.88$, $p = 0.001$, $\eta p^2 = 0.57$). Pairwise comparisons of the channels revealed that overall, mean amplitude of P3b at Fz was significantly smaller than Cz ($M_{diff} = -1.34E-6$, $p = 0.008$) and Pz ($M_{diff} = -2.70E-6$, $p = 0.006$).

For C2 (LNSW), in the control group (CG), there was a main effect of channel ($F(2, 20) = 5.06$, $p = 0.017$, $\eta p^2 = 0.34$). Pairwise comparisons indicated that the mean amplitude at Cz was significantly smaller than that at Pz ($M_{diff} = -3.21E-6$, $p = 0.008$). In the exercise group (EG), a main effect of channel was observed as well ($F(2,18) = 3.79$, $p = 0.042$, $\eta p^2 = 0.30$), but examination of pairwise comparisons revealed no significant differences.

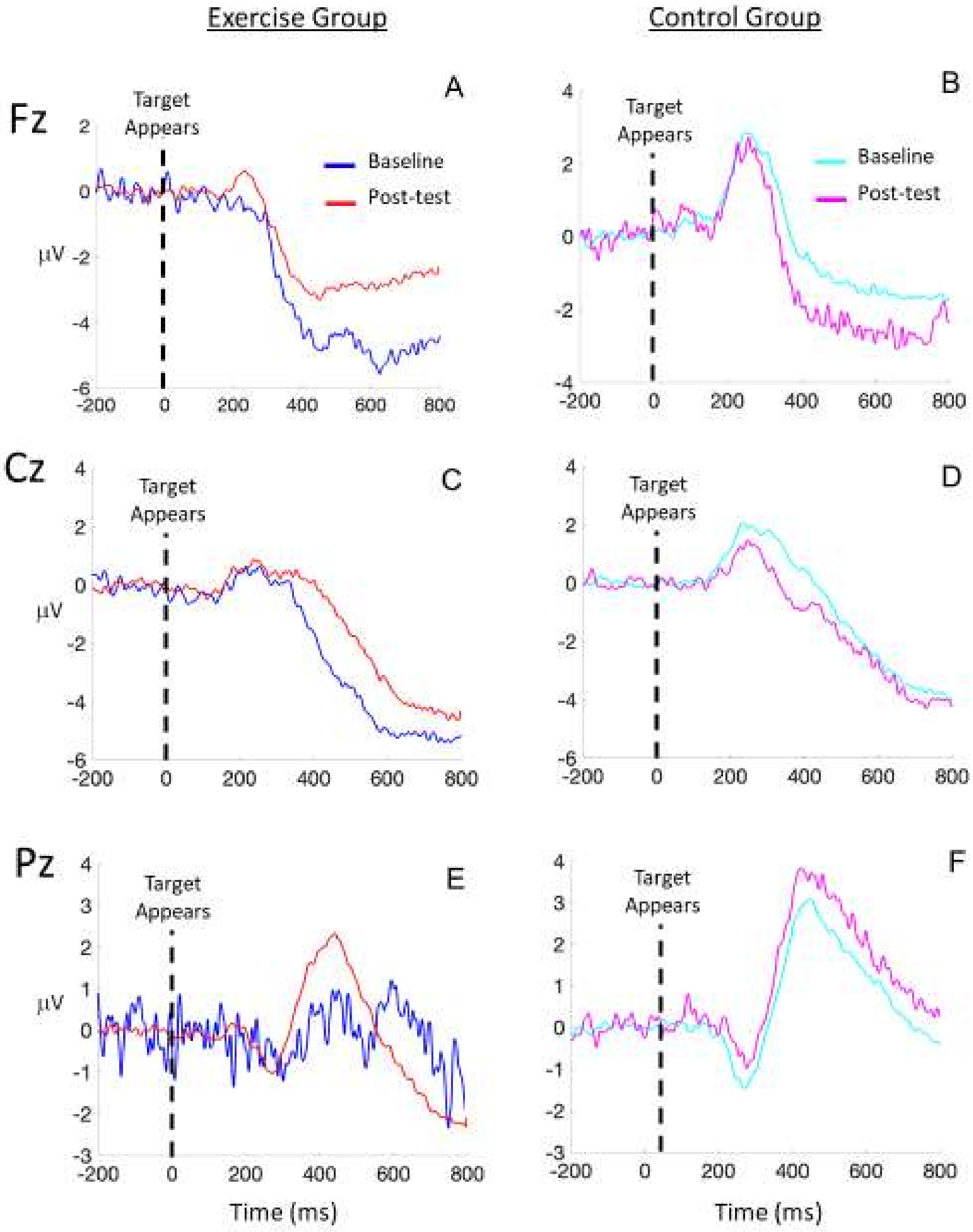


Figure 3.5. ERP waveforms of CG at Fz, Cz and Pz

3.8.1.4 Physical Fitness and Cardiovascular Measures

Among the physical fitness measures, we observed an improvement in the Timed Up and Go (TUG) test for the exercise group ($M = 0.902$, $SD=0.465$), $t(10) = 6.432$, $p = 0.0$). This test was used to assess functional mobility and dynamic balance. There were no significant changes in the cardiovascular/arterial stiffness measures for either group ($p > 0.3$).

3.8.2 Baseline Regression

All regression analyses used a stepwise method and the model was selected based on Akaike information criterion (AIC). Analysis was performed in SPSS and R. Stepwise multiple regressions were performed on the baseline measures for both groups combined.

3.8.2.1 Pre-test Adaptation stage & cognitive measures

The predictors included the following cognitive measures: Flanker task incongruent mean response time (RT), Stroop task incongruent mean accuracy and RT, PAL average number of repetitions. The dependent variable (DV) was the motor learning (ML) measure of averaged angular error (AE) of the adaptation stage. PAL's average number of repetitions was the only cognitive variable that significantly predicted learning in motor skill acquisition during adaptation ($B = -0.61$, $R^2 = 0.37$, $F(1,19) = 11.02$, $p = 0.004$).

3.8.2.2 Pre-test Adaptation stage & ERP measures

The predictors were C1 (P3b) and C2 (LNSW) ERP measures. The dependent variable (DV) was the motor learning (ML) measure of averaged angular error (AE) of the adaptation stage. For both groups combined, the stepwise regression revealed C2 at Pz ($B = 0.56$) and P3b at Cz ($B = -0.44$) to be a significant predictors during Adaptation ($R^2 = 0.46$, $F(1,19) = 7.57$, $p = 0.004$).

3.8.2.3 Pre-test EI variables and cognitive measures

Stroop task performance was a significant predictor of both emotion perception accuracy (predicted by Stroop incongruent mean accuracy) ($B = 0.46$, $R^2 = 0.21$, $F(1,19) = 5.10$, $p = 0.036$) and emotion perception RT (predicted by Stroop incongruent mean RT) ($B = 2.36$, $R^2 = 0.4$, $F(1,20) = 13.56$, $p = 0.001$), consistent with previous observations that EI scores are associated with executive control.

3.8.3 Regression Analysis Post Adapt Angular Error Predicted by Pre-Post Difference Measures

A stepwise multiple regression was performed separately for both the control and exercise groups to examine if pre-post changes in cognitive and EI measures were predictive of motor learning performance during the post adaptation phase.

3.8.3.1 Post-test Adaptation Stage & cognitive change

For the EG, the pre-post change in Flanker incongruent RT predicted ML at post-test (B = -0.92, R^2 = 0.84, $F(1,8)$ = 42.40, p = 0.0). No significant predictors were found for CG.

3.8.3.2 Post-test Adaptation Stage & EI change

The only EI component that predicted ML at post-test was the change in emotion perception accuracy scores (B = - 0.65, R^2 = 0.42, $F(1,8)$ = 5.76, p = 0.043) in the EG. No significant predictors were found for CG.

3.8.3.3 *Post-test Adaptation Stage & ERP change*

For both the CG and the EG, pre-post change in C2 mean amplitude at Pz predicted ML at post-test (B = - 0.74, R^2 = 0.55, $F(1,9)$ = 10.79, p = 0.009 and B = - 0.69, R^2 = 0.47, $F(1,8)$ = 7.16, p = 0.028 respectively) suggesting that the late negativity slow wave may be associated with the ability to overcome proactive interference and learn the new rotation at post-test.

3.8.4 Regression Analysis: Post-test EI and Pre-Post Difference in EI, Predicted by cognitive change

3.8.4.1 Post-test EI & cognitive change

No cognitive variables predicted EI at post-test.

3.8.*4.2 Pre-Post difference in EI and cognitive change*

For the EG, Flanker incongruent RT change was associated with emotion perception accuracy measure (B = 0.76, R^2 = 0.64, $F(1,8)$ = 6.21, p = 0.034). In the CG, the change in Flanker accuracy score was predictive of the change in emotion management (STEM) (B = 0.76, R^2 = 0.58, $F(1,8)$ = 10.84, p = 0.011).

3.9 Discussion

The current study examined the effect of low-moderate intensity eccentric exercise on motor skill acquisition, susceptibility to proactive interference in motor learning, on executive control, and on emotional intelligence abilities. Our results demonstrate that this form of exercise helps improve motor learning and performance by enabling participants to overcome proactive interference. It also improves emotional intelligence capabilities. Based on our regression analyses we argue that these improvements may be mediated by individual differences in exercise-induced improvements in executive control abilities.

3.9.1 Cognitive and Motor Learning Measures

Past literature has documented the positive effect of exercise and physical activity on cognitive abilities (Colcombe & Kramer, 2003; Hillman, Erickson, & Kramer, 2008; Kramer & Erickson, 2007; Sibley & Etnier, 2003). The biggest influence of physical activity was found on EF processes (Colcombe & Kramer, 2003), with higher activation in the frontal and parietal regions for participants with higher level of physical activity (Colcombe et al., 2004; Voelcker-Rehage, 2013). We also saw that dose parameters like program duration, session duration and frequency of the intervention may not affect the magnitude its effect on the said cognitive functions (Sanders et al., 2019).

Though many of these exercise paradigms have utilized metabolic processes like cardiovascular exercises, there have been studies that have used other forms of exercise like resistance training and more motor-demanding forms of exercises, like coordination training, that require a higher level of perceptual skills and cognitive information processing abilities. A motor-demanding training based on coordinative skills /like leg–arm coordination tasks like crossing obstacles, balancing on ropes, etc. has been found to facilitate and enhance brain function. In older adults, a combination of such forms of coordinative exercises and motor fitness (action speed, reaction speed, balance) have shown to enable brain function (predominantly in those areas related to visual–spatial processing) and cognitive performance (Niemann, Godde & Voelcker-Rehage, 2014; Voelcker-Rehage et al., 2010, 2011).

There is a possibility that different kinds of exercises may yield different degrees of improvement in cognitive abilities in separate brain areas. While some studies show that physical fitness was related to higher brain activation in prefrontal and parietal cortex regions, others have demonstrated a lower activation in the prefrontal cortex but a higher activation in the temporal regions. Though cardiovascular training and other types of physical activity enhance older adults' cognitive abilities, the mechanisms underlying this performance change appear to vary, depending on the type of intervention (Voelcker-Rehage, 2013). Behaviorally too, individuals employ different learning strategies and learn at different rates, thus making inferences on brain mechanisms and performance even more complex (Seidler, 2010). In our study, the eccentric exercise intervention displayed enhanced cognitive abilities manifested as reduced susceptibility to proactive interference in the exercise group in a motor learning task. Overall, the intervention demonstrated a positive effect on most of the cognitive variables, the largest effect being on Stroop conflict cost measures (with an average effect size of 47.5). This indicates that the exercise intervention did appear to have a positive effect on the cognitive functions, especially those related to inhibitory control (Stroop conflict cost). The ERP measures also corroborate with the finding that EF performance may predict motor learning (ML) in the context of proactive interference. Some of the effect sizes were relatively small, which could be explained by a couple of factors. One being the small sample size, that potentially resulted in our study being underpowered. Yet another reason could be the characteristics of the sample itself, which consisted of high functioning older adults and might have resulted in a ceiling effect. Since it has been observed that those with the poorest level of EFs gain the most from programs that improve these abilities (Diamond, 2016), there was not much scope for large improvements in our sample. The third explanation could be our exercise intervention, which was reasonably relaxed (low-moderate intensity) and shorter in duration. It therefore did not result in large cardiovascular or metabolic changes which have traditionally been associated with improved cognitive abilities.

The regression analysis on the pre-test adaptation stage of the VMR task revealed the involvement of memory (more specifically spatial and associative memory) throughout this stage. What is interesting about this finding is that spatial and associative memory may not only contribute towards early learning in a sensorimotor adaptation ask, contrary to previous suggestions (e.g., Anguera et al., 2010; Christou et al., 2016; Rajeshkumar & Trewartha, 2019), but in fact continue to be involved throughout the adaptation process. In the context of our study, this might imply that the participants were continuously engaging their spatial and associative memory resources to manipulate the direction of their arm movements with respect to the randomly appearing targets. Thus, in addition to the autonomous processes that comes into play during the later stages of learning, these memory mechanisms continue to be engaged as well. This aligns with previous findings on VMR based studies where both implicit and explicit memory processes have demonstrated to be engaged throughout the motor learning process (Trewartha, 2014; Taylor et al., 2014).

As our goal was to examine if any exercise induced cognitive/EF change predicted ML, we performed a regression on the AE of the adaptation stage at transfer/post-test for both groups (EG and CG). Of all the cognitive variables, change in the RT of Flanker's incongruent trials significantly predicted ML in the EG. This indicated that while spatial associative memory is engaged during a sensorimotor/ VMR adaptation, when it comes to handling proactive interference, a different or additional cognitive mechanism (inhibitory EF) is harnessed to facilitate resisting the interference and improving performance. In line with what we know about inhibitory control (IC) and working memory (WM), IC appeared to have worked better, thus freeing up resources for WM to continuously update information on the changed rotation. We do not know if there has been any structural change or neuronal proliferation, but based on the EEG findings it appears that the EG demonstrated enhanced functionality of the EC processes. The enhancement in inhibitory functioning is in line with findings by Yang et al. (2020) where older adults after a Tai Chi Chuan intervention exhibited a significant improvement in their reaction times in the incongruent flanker trials. It appears that motor learning at pre-test and motor learning at transfer during post-test engaged different cognitive functions. Since this was only observed in the EG and not the CG, might imply that the intervention had enhanced EF ability in some participants that enabled them to engage their EF faculties to resist the interference relatively better than other participants in the EG, and that these individual differences were not evident in the CG. Another aspect which might have facilitated the superior resistance to interference by the EG could be attributed to exercise induced improvement in memory consolidation (Thomas et al., 2016) which would lead the EG to be less prone to interference. However, the current data do not provide a way to assess the impact of consolidation on post-test performance.

To examine longitudinal changes in the neurophysiological processes associated with motor learning in the context of proactive interference we assessed changes in the P3b and LNSW from pre-test to post-test. Based on our review of previous studies we had hypothesized that the P3b amplitude will be larger at post-test compared to pre-test as the proactive interference will call for additional allocation of EF resources to help overcome the interference.

The neurophysiological/ERP findings in fact reflected the behavioral outcome data. While the control group demonstrated a decline in the P3b at the frontocentral electrode sites, there was no significant change observed in the P3b of the exercise group. On visual inspection of the ERP waveforms (Figures 2.5 B and D), we notice that while the mean amplitude of the P3b became smaller/or less positive at Fz and Cz, and the LNSW component became more negative for the CG. And for the EG, the mean amplitude of the P3b becoming larger / or more positive at post-test, and that of the LNSW became less negative (Figures 2.5 A and C). This group was able to counter the interference from the previously learned rotation without letting it negatively affect their motor performance at post-test.

The baseline regression analysis demonstrated a negative association between P3b and AE at Cz and a positive association between LNSW and AE at Pz. This indicated that, more sensory error related cognitive resources (depicted by larger P3b) were associated with larger AEs or deviations, and less conflict processing cognitive processes (depicted by smaller LNSW) were required in conditions with lower AEs.

It has been suggested that the while the cerebellum is engaged during visuomotor adaptation, after exposure to adaptation paradigms, the primary motor cortex is involved in the retention of the newly learnt VMR (Galea et al., 2011). And interestingly, proactive interference in motor learning has been detected to occur due to persisting neural representations of previously learned skills in the primary motor cortex (Cothros et al., 2006). In our study, the exercise intervention might have enhanced or supported learning of the opposite rotation in the EG, by reducing the interference by disrupting these neural signatures.

The posterior P3b has been observed to be evoked by feedback (in a VMR task), with its amplitude increased by sensory error that has been induced by perturbed visual feedback. It has also been correlated with learning rate (Palidis et al., 2018). On visually examining the waveforms, we find that the CG exhibited a more positive P3b at Pz at post-test (Figure 2.5F), indicating that they might be requiring more effort to complete the task at post-test.

Studies had previously shown that fitness and exercise are related to improvement in cognitive function (Colcombe & Kramer, 2003; Hillman et al., 2008; Kramer & Erickson, 2007), executive function (Colcombe & Kramer, 2003; Chang et al., 2012), particularly inhibitory control processes at the perceptual, cognitive, and motor level (Chang et al., 2012; Ludyga et al., 2016; Hsieh et al., 2018). The underlying neural mechanisms of these fitness-induced changes have been depicted through changes in the amplitude and latency measures of neuroelectric components such as the P3b (Pontifex et al., 2009), which has been associated with enhanced inhibition following exercise. It has been found to be maximal over the centroparietal region (Polich, 2007; Shu-Shih Hsieh et al., 2018). The ERP analysis revealed another interesting component - C2 or the Late Negativity Slow Wave (LNSW), that was evoked between 400-800ms. This component appears to resemble the N450, also known as “medial frontal negativity”, a stimulus-locked slow wave and occurs at about at 400–600 ms after target presentation (Larson, et al., 2014). It is most pronounced in the frontocentral region, but may also have a form of broadly dispersed negativity (Van Hooff et al., 2008).

The N450 has been related to conflict processing and has been associated with the activation of the Anterior Cingulate Cortex (ACC). A larger N450 amplitude suggests the use of more neural resources and longer processing time during task-induced conflict detection and ensuing behavioral changes (Shu-Shih Hsieh, et al., 2018), and is typically seen for incongruent trials. In our study, this component displayed a rising trend in both groups, and more so in the exercise group, indicating the possibility that the EG was recruiting the network reflected by this component to manage the interference, thereby not being impeded by the proactive interference to learn the opposite rotation. This suggests that the cognitive mechanisms reflected by these components are engaged in processing the magnitude of the errors made during the VMR task. The regression analysis supplemented these findings. It displayed that a higher change in the mean amplitude of C2 was associated with larger angular errors (AEs) indicating that, more conflict processing cognitive resources were required for trials with larger angular errors. This was true for both groups. The finding for the LNSW is consistent with previous research (Rösler et al., 1997) demonstrating that the amplitude of late slow negative waves is related to task difficulty, and as the task becomes more difficult from the subject's perspective, they have to invest more effort to complete it.

3.9.2 EI Measures

There has been literature documenting the positive effect of exercise on emotion. Endurance exercise akin to 90 minutes moderate intensity running has shown to increase positive emotion promote emotion regulation (Giles et al., 2018). There has also been documentation of the positive effects of acute exercise on cognition, mood and stress. Acute exercise has shown to improve mood states (Reed et al., 2006; Basso & Suzuki, 2016) and decrease stress (Ebbesen et al., 1992; Basso & Suzuki, 2017). Exercise induced reduction in anxiety and stress has also been observed among middle aged and older adults (50-65 years) (King et al., 1993). It has been found to reduce depressive symptoms among older adults (Huang et al., 2015). Even low to moderate volume of exercise has been associated with a significant reduction in depression (Annesi & Vaughn, 2011). Tai Chi has been found effective in reducing fear of falling among older adults (Sattin et al., 2005). In general, different types of exercise programs have been documented to have an enhancing effect on mood and emotion regulation. They have been successfully shown to reduce negative affects including stress, anxiety and depression. This may be attributed to physiological changes brought about by exercise like lowering of the Sympathetic Nervous System (SNS) and Hypothalamic Pituitary Adrenal (HPA) Axis reactivity, increase in BDNF, neurogenesis (Anderson & Shivakumar, 2013) or activating the Dopaminergic (DA) system (which is sensitive to exercise and has been implicated in fear extinction) (Mika et al., 2015). It could also be due to psychological mechanisms like improved self-efficacy developed through positive feedback of increased endurance and duration capabilities, etc. (Anderson & Shivakumar, 2013). In our study, the effect of the exercise intervention was largest for the domains of emotion perception (EP) accuracy (0.60), EP RT (0.67), and STEM-F (0.62). STEM-A, STEM-S and STEM-Total also exhibited a positive effect. As stated in the previous studies, this could be attribute to neurogenesis, activating the Dopaminergic (DA) system and/or activation of different brain regions like the prefrontal cortex. While the above studies emphasize the positive effect of different forms of exercise on emotion and mood, there is not much literature pertaining to investigating the effect of eccentric exercise on the various components of emotional intelligence: perception, understanding and management of emotions in older adults.

When it comes to interdependencies between EI and EF, our findings corroborated previous work in this area. Baseline regression revealed the Stroop task (incongruent mean accuracy and RT) to be predictive of emotion perception accuracy and RT respectively. Furthermore, regression of pre-post differences also demonstrated the link between EF and EI. In the EG, a change in the incongruent RT of the Flanker task predicted the change in emotion perception accuracy, while in the CG, the change on the accuracy score of the Flanker task was predictive of the change in emotion management (STEM). We have seen earlier, that EI comprises of strategic areas that depend on cognitive abilities like attention and executive control to understand emotions accurately and regulate them appropriately (Etkin et al., 2011; Hurtado, et al., 2016; Mayer and Salovey, 1997; Hurtado, et al., 2016). In our study, we found that emotion perception accuracy (categorized under the experiential area) was associated with EF measures. This is not surprising, as the ability to decode and accurately perceive emotions is tied to working memory (Channon et.al., 2008), frontal lobe brain structures and functions. EF and emotion perception appear to share the same frontal, limbic and temporal brain regions (Langenecker et al., 2005). In fact, this one area that has been found to deteriorate with age where older adults have been found to be less accurate in identifying some emotions like sadness, anger, and sadness (Circelli et.al., 2013). Given the positive effect of exercise on brain functionality, especially the prefrontal cortex and EF abilities, one may hypothesize that emotion perception abilities could also be improved through these interventions.

In addition to the above, we also found that, for the EG alone, a change in EI (emotion perception accuracy) was predictive of ML at post-test There have been myriad of studies linking emotion and emotion regulation to enhanced motor learning, control, performance (Beatty et. al., 2014; Masterson, 2015; Coombes et. al., 2005) and even muscle afferent firing (Ackerly et.al., 2017). An ever-increasing database points in this field points influence of emotion on the way people move or make movements by directly influencing reaction speeds, movement rate, accuracy of movements and/ or extent of force production (Beatty et. al., 2014). Examples of where this might come into play in our task, could be the point where the participant starts reaching towards the target as soon as it appears, or when they overcome the rotation to move towards the target. There appear to be common brain regions (like the dorsomedial prefrontal cortex and left ventral premotor cortex) and neurological mechanisms underlying both emotional processes, movement planning and execution of action (Masterson, 2015; Beatty et. al., 2013; Mogenson et al., 1980; Coombes et al., 2012). There is a possibility that our intervention could have enhanced the neurological pathways and brain functions common to both motor learning and emotional intelligence, both of which are also tied to EF capabilities.

Our study paves way for future enquiry into this domain, to better understand the intricate relation between forms of exercise, brain region activation and emotional intelligence. The positive effect of exercise on brain functionality is indisputable. But does this positive effect translate to improvement in skills that are dependent on the involved brain mechanisms? Our research provided us with some answers in this regard, while also raising a few other questions in the process. Overall, we found that the eccentric exercise intervention did result an observable improvement in the ability to handle proactive interference in motor learning, a higher STEM-F score implying an improved ability to manage fear-based emotions and a positive change in the ability to accurately identify emotions in a timely manner. But there were also areas, like emotional understanding or EF abilities, where these improvements did not show a significant enhancement, even though they had displayed a trend in the desired direction. Further exploration in this direction could fill the gaps. One idea would be to utilize brain imaging techniques to study post exercise activation of specific brain regions and emotional intelligence tasks, or study underlying brain mechanisms related to proactive interference in motor learning and development of a relevant measures. Investigating the relation between emotion management of fear, proactive inference and associated brain mechanisms is also another potential area for research.

CHAPTER 4

OPTIMIZING MOTOR LEARNING IN AGING: INTRINSIC MOTIVATION, AUTONOMY SUPPORT & EXTERNAL FOCUS OF ATTENTION

4.1 Introduction

Multiple cognitive mechanisms are involved in motor skill acquisition and include explicit and implicit working memory resources (Trewartha, 2014; Taylor et al., 2014), decision-making, performance monitoring, and associative memory processes (Anguera et al., 2009; Taylor and Ivry 2011; Trewartha et al. 2014; Rajeshkumar & Trewartha, 2019). Aging has been associated with a decline in most of these cognitive abilities. It is also associated with a reduced ability to acquire new motor skills (Seidler 2007), with factors like the explicit memory system and sensory attenuation contributing to this age-related decline in motor adaptation (Wolpe et al., 2018). Effective motor performance is vital for surviving and successful living, with skilled movement being critical in many activities (Wulf & Lewthwaite, 2016). Given the ever-growing population of older adults, it has become imperative to develop interventions that will assist them to live independent lives for as long as possible. Study 1 provided preliminary evidence that exercise interventions may improve motor learning and skill acquisition in older adults, by improving their executive function abilities. It is important to emphasize that this is true even for very high functioning older adults. The emphasis of study 2 is to examine a relatively short-term intervention adopted from the sport psychology field that involves manipulating motivational factors and attentional focus to improve motor performance. This intervention has been shown to improve motor learning among younger adults but has not yet been tested in older populations and not in tasks such as visuomotor rotation. We will also investigate if this intervention can help reduce susceptibility to proactive interference.

Different approaches have been employed to improve motor learning and the process of skill acquisition, with much focus around practice conditions and their effect on learning and performance. But these have not significantly addressed motivational and attentional factors that can improve learning, like conditions that enhance expectancies for future performance, variables that influence learners' autonomy, and an external focus of attention on the intended movement goal. In the motor learning literature, social-cognitive-affective processes like the above have been used to produce improvements in motor learning and performance, but the efficacy of these interventions in older adults has not been tested. In our second study, we cover this ground and will be examining the role of these social-cognitive-affective processes in enhancing motor learning and performance among older adults. There is abundance of literature on the influential role of social-cognitive-affective processes in enhancing learning and performance (Stevens, Anderson, O'Dwyer, & Williams, 2012; Wulf, Chiviacowsy, & Cardozo, 2014; Pascua, Wulf, & Lewthwaite, 2015; Wulf & Lewthwaite, 2016). Enhanced expectancies developed through successful practice sessions increases the participant's self-efficacy and self-confidence (Wulf & Lewthwaite, 2016). There is evidence that self-efficacy that stems from experiencing success during practice sessions is indicative of performance in subsequent motor learning tasks (Stevens, Anderson, O'Dwyer, & Williams, 2012; Wulf, Chiviacowsy, & Cardozo, 2014; Pascua, Wulf, & Lewthwaite, 2015; Wulf &

Lewthwaite, 2016). There has also been support for the need for autonomy/sense of control and performance. It has been demonstrated that learning is enhanced when learners are given control of some aspect of the task. It could be having control over the use of a physical assistance device on balance tasks, or as simple as having a choice in the selection of the stimulus (Wulf & Lewthwaite, 2016; Chiviacowsky et al., 2012; Wulf & Toole, 1999). In all these studies, when learners experienced control, however small, over any aspect of the learning experience, they displayed superior performance. This can be attributed to multiple factors including a deeper processing of pertinent information related to the task at hand, that may be due to a higher involvement by the learner in the learning process (Wulf & Lewthwaite, 2016). It may also be due to higher self-regulations strategies, better error estimation, or a higher level of motivating generated by providing a degree of control /choice to the learner in the practice conditions. External focus of attention, the third aspect of the social-cognitive affective process involves directing he learner's attention to the intended movement goal (external focus) instead of on herself or himself (internal focus), thereby optimizing learning. It essentially speeds up the learning process (Wulf & Lewthwaite, 2016). But the efficacy of these interventions in older adults has not been investigated. In our second study, we examined the efficacy of these social-cognitive-affective instructional techniques for enhancing motor learning and performance among both younger and older adults in a visuomotor rotation task. According to the OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention to Learning) theory of motor learning (Wulf and Lewthwaite, 2016), the aforementioned motivational and attentional factors lead to improved performance and learning by "strengthening the coupling of goals to actions". Any factor that provides the learner with a sense of control and self-efficacy, leads to the synching of motivational, cognitive (attention, perception), physiological and neuromuscular factors to form effective neural connections, ('*goal-action coupling*') leading to effective learning and performance. The theory proposes that three factors: enhanced expectancies (EE) for positive experience or outcomes, autonomy support (AS) and external focus (EF) of attention are key to the facilitation of motor learning and performance.

Figure 4.1. (Wulf & Lewthwaite, 2016) helps elucidate this point. Motivational and Attentional techniques lead to goal directed behavior by increasing focus on task and reducing the focus on self, thereby creating a virtuous cycle of motor learning and performance (Wulf & Lewthwaite, 2016). The authors argue that enhanced expectancy and learner autonomy may activate the dopaminergic system in response to the anticipation of a positive and successful experience, while external focus of attention may contribute towards more efficient functioning of brain networks, thus leading to improved performance. The theory takes into account the interconnected effect of motor, cognitive, affective, and sociocultural factors on learning and performance. The notion that one's mindset can influence performance is not new and has been studied in different contexts, including choking under pressure (Beilock, 2010), and performance when in a state of *flow*, which leads to a positive experience and superior output (Csikszentmihalyi, 1990).

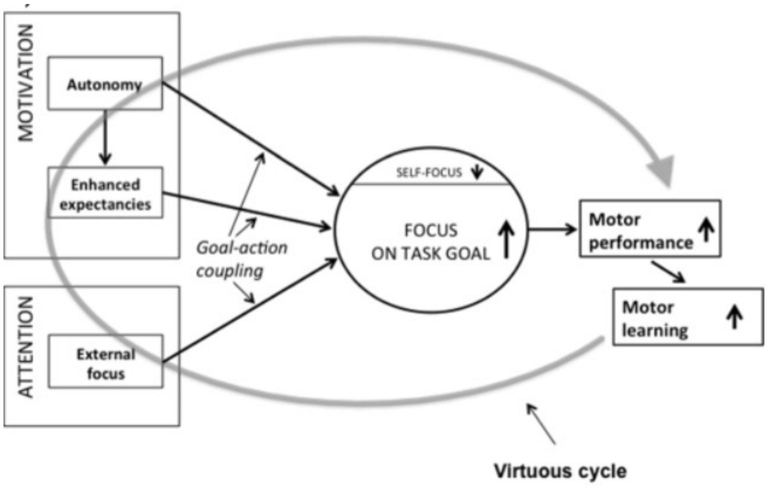


Figure 4.1. OPTIMAL theory - Conditions enhance learners' expectancies, provide autonomy support, and promote an external focus of attention result in a virtuous cycle of enhanced motor learning

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4.2 Enhanced Expectancies (EE)

Enhancing one's expectancies about their forthcoming performance in a skill acquisition task, either by generating positive experiences, expectations and/or outcomes, has shown to improve their performance. Past accomplishments and positive expectations about outcomes, contribute towards generating a sense of self-efficacy (Bandura, 1977) and confidence, which in turn has shown to predict motor performance (Feltz et al., 2008; Rosenqvist & Skans, 2015; Lewthwaite & Wulf, 2017) and learning (Pascua et al., 2015; Steven et al., 2012). There are different ways to influence a performer's perception about their performance, and thereby their confidence. Some of these include providing a superior performance feedback to the participant (Hutchinson et al., 2008; Lewthwaite & Wulf, 2010), providing evidence of their superior performance (Clark & Ste-Marie,2007) making the task look easy (Trempe et al., 2012; Chiviacowsky et al., 2012), altering mindset or priming (Wulf et al., 2012), visual illusions (Witt et al., 2012; Chauvel et.al., 2015), and positive effect.

4.3 Autonomy Support (AS)

Autonomy when learning is an important factor that contributes to enhanced skill learning (Lemos et al., 2017; Wulf & Lewthwaite, 2016,). The element of choice when built in training, has shown to improve learning by improving the motivation to learn. According to Deci and Ryan (2008) this would be termed as "*Autonomous motivation*" where the individual experiences volition ("self-endorsement of their action") and sees value in performing the given activity. Watkins (1984) found that factors such as providing opportunities for independent thinking and giving a choice to students in deciding their learning methodology, encouraged deeper information processing and positively influencing a student's learning. Other studies have also shown that supporting learner's autonomy improves skill acquisition. Chen and Singer (1992) found that both, self-regulation and cognitive strategies are essential for learning and performance. The effect of providing autonomy in learning seems to be robust, irrespective of which factor the learner is given control (choice) over. Various explanations have been given for this effect. One, as we have seen, is that of deeper information processing (Watson, 1984; McCombs, 1989; Chen and Singer, 1992) which results from achieving a sense of "self-control" and thus getting more involved with the task. The other effect is from using autonomy-supportive language that benefits learning (Chiviacowsky and Wulf, 2005; Wulf & Lewthwaite, 2016).

4.4 External Focus of Attention (EF)

According to the action-effect principle (Prinz, 1997; Lawrence et al., 2011), if actions are planned and controlled in relation to/with a focus on, the outcome, then focus on movement effects enhances performance by improving motor programming (Wulf et al., 1998). Based on the action-effect principle and research on attentional focus, Wulf (2001) proposed the constrained action hypothesis, according to which if a performer focuses on their movements, it disrupts the organization of motor programming and impedes their learning and performance. On the other hand, an external focus of attention enhances the efficiency of motor programming (Lawrence et al., 2011). In her review of studies conducted over the past 15 years, Wulf (2012) demonstrates that attentional focus has been proven to improve movement effectiveness as well as efficiency and benefit motor learning. Adopting an external focus on the intended movement effect (e.g., on the goal of the given movement) relative to an internal focus on body movements promotes learning. It has shown to enhance movement effectiveness in balance (Wulf et al., 1998) and accuracy (Wulf et al., 2007, Bell and Hardy, 2009) related tasks and improve movement efficiency in terms of muscular activity (Vance, 2004; Merchant et al., 2008), maximum force production (Wulf et al., 2010) and speed and endurance (Fasoli et al., 2002; Chen et al., 2003). Aside from more efficient and effective muscle coordination, attentional focus induced through instruction has also shown to improve motor movements on a large scale by allowing for more freedom of movements. External Focus resulted in ‘freeing’ of the body’s degree of freedom as opposed to ‘freezing’ of the body’s degrees of freedom that seemed to be brought about by internal focus of attention. Other studies (Poolton et. al, 2006; Maxwell and Masters, 2002; McNevin et al., 2003) have also exhibited the efficacy of external focus in motor skill acquisition with Emanuel et al. (2008) demonstrating its effectives under conditions of secondary task loading, Laufer et al. (2006) in rehabilitation training and Abdollahipour et al. (2019) elucidating its advantage among individuals with major visual impairment, where the participants trained with external focus performed better in both, the discrete as well as the locomotion-based continuous motor tasks given to them in spite of being visually impaired.

4.5 Mechanisms

All three motivational and attentional factors appear to optimize skill acquisition by influencing learning, memory, and brain’s functional connectivity. One theory is that these motivational effects generate a dopaminergic response which in turn strengthens memory and learning (Wise, 2004; Gruber et al., 2016; Lewthwaite & Wulf, 2017), and as we have seen in study 1, and as demonstrated in other studies, memory plays an important role in motor learning (Anguera et al., 2009; Taylor and Ivry 2011; Trewartha et al. 2014; Rajeshkumar & Trewartha, 2019). Rewards and expectancies can enhance attention to task-relevant cues, while also aiding in inhibiting irrelevant ones (Themanson and Rosen, 2015; Shomstein and Johnson, 2013). Autonomy-supportive conditions generated by using autonomy-supportive language (Hooyman et al., 2014) and/ or providing a choice has been found to create a sense of agency / control that facilitates superior learning and performance through improved processing of task related errors and higher self-regulatory responses. Legault and Inzlicht (2013) attribute the higher level of self-regulation to enhanced neuroaffective responses to self-regulatory failure which results in improving performance. Overall, an AS condition promotes perceived self-efficacy and intrinsic motivation, which in turn leads to performance enhancement. External focus of attention, as we have seen has been observed to improve movement effectiveness and efficiency by helping direct attention to the task goal instead of focusing on oneself and one’s body movements, which disrupt effective learning and performance. In neurophysiological terms, external focus modulates the activity of inhibitory circuits within the primary motor cortex (M1), and this increased inhibition is associated with improved motor function (Kuhn et al., 2017). Additionally, the positive affect generated due to the EF mediated improved performance results in the secondary benefit of enhanced expectancies about performance which again, is a contributor of better skill acquisition.

Studies have demonstrated that various combinations of any 2 of these aforementioned variables result in an even better learning as compared to the presence of only 1 variable, or none. (Wulf & Lewthwaite, 2016). Wulf and colleagues have taken this a step further and displayed that when all 3 factors are combined, it results in a more enhanced learning and leads to immediate performance benefits in a novel motor task. They also showed that implementing these consecutively leads to incremental performance growth (Chua et al., 2018).

The applications of the OPTIMAL theory of learning range from improving motor skills in children and novice performers to athletes and even in the context of clinical rehabilitation. But, to date, this has been tested only in healthy younger adults and it is unknown whether these effects are generalizable to other age groups or clinical populations. To address this gap in the literature, we conducted an examination into the effectiveness of these motivational and attentional factors as facilitators of learning and performance among older adults, a group that is known to exhibit impairments in motor learning and declines in acquiring new motor skills (Howard & Howard, 1997; Seidler, 2006). Given that the exercise intervention employed in Study 1 reduced susceptibility to proactive interference in motor learning, we aimed to investigate if the motivational and attentional techniques in Study 2 would have similar benefits. As part of this exploration, we examined various cognitive domains that have been found to be involved with motor learning - implicit and explicit memory processes, executive functions including inhibition, cognitive flexibility and working memory updating to ascertain their contribution and/or association with the ability to reduce proactive interference. We also investigated if achievement motivation and emotional intelligence (EI) abilities (emotion regulation, emotion management and emotional understanding), played a role in enhancing skill acquisition and reduced susceptibility to proactive interference.

We predicted that when used in combination, EE, AS and EF as instructional motivational techniques would lead to improved learning and performance in both the age groups (young and old). We also hypothesized that, irrespective of age, the experimental group participants would learn a visuomotor rotation task (VMR) better than their control group counterparts and that the comparative level of improvement displayed by the older adults in the experimental group will be equivalent to that of the younger adult experimental group. It was also anticipated that the experimental groups would also be less susceptible to proactive interference.

4.6 Method

4.6.1 Participants

In this study we recruited a total of 69 participants with 30 older adults (60-80 years of age) and 39 young adults (18-25 years of age). The older adults were recruited from the greater Houghton area by contacting individuals from our existing database via email and phone calls, and if required, through posters/flyers. Participants in the young adult group were recruited from the undergraduate student population at Michigan Tech through the Department of Cognitive and Learning Sciences SONA psychology subject pool system. All participants were only included if they were right-handed and did not have any medical condition that affects their movement and cognitive functioning. Participation in this research was strictly voluntary. All of them read and signed an informed consent form and were informed that they were free to withdraw from the study at any time without penalty. As part of the screening process, we also administered the health questionnaire to all participants wherein we asked them to provide all health-related information.

4.6.2 Motor Learning Task

The motor learning task was a visuomotor rotation (VMR) task implemented on a robotic device for assessing upper limb movements (KINARM, B-Kin Technologies, Kingston, ON, Canada) (Figures 2.2 A and B). With their dominant hand, participants grasped a handle to move a cursor toward one of four targets displayed on the screen from a start position in the center of the screen. The target location was randomized from trial to trial in sets of four trials across the experiment such that every four-trial set included one movement to each target. The participants were instructed to "make a reaching movement to the target as and when it appeared". They were also told that the reaction time was not important and so could start moving towards the target as and when they were ready to do so. But once they started their movement, they were to continue moving at a consistent pace. The VMR task for this study comprised of 3 blocks (Figure 4.2): Block 1 was the familiarization stage (consisting of 24 trials), where the cursor followed the participant's hand position to the target. This was followed by Block 2, the *learning phase*, comprising of the adaptation stage (100 trials) and the wash-out or aftereffects stage (24 trials). In the adaptation stage of this phase, a visuomotor rotation was applied without warning, where the cursor movement was rotated by a 45-degree angle in a clockwise or counterclockwise direction about the start position relative to the position of the participant's hand. The participant must then adapt by moving their cursor in a straight line at a 45-degree angle in the opposite direction to guide the cursor to the target. In the wash-out or aftereffects stage, the rotation was removed again to assess after-effects. Block 3, the transfer phase consisted of the adaptation and aftereffects stage like the previous block, with the only difference being, that in the adaptation stage of this block, the participants experienced an opposite rotation to what they had experienced in Block 2 and had to adapt accordingly. For every trial, after the target was reached the cursor feedback was turned off and participants were instructed to move their hand back towards the midline of their body at the bottom of the screen. Any rotation that was applied was then turned off and the cursor turned back on so that participants could move the cursor back to the start position to begin the next trial. The dependent measure was the angular error in degrees of the initial heading direction of the participant's hand for each trial.

The dependent variable/measure was the angular error (AE) in degrees of the initial heading direction (initial heading angle) of the participant's hand for each trial. The initial heading angle was calculated as the angle between the cursor and the start position when the movement trajectory crossed a distance threshold at the 3 cm radius from the starting position. During the rotation trials, participants corrected for the angular error by adjusting their heading angle in the opposite direction of the rotation. For example, the optimal compensation for the applied rotation was a 45° heading angle if the rotation was -45°. The angular error was then calculated as the difference between the initial heading angle and the optimal heading angle given the rotation that was applied (i.e., either 0°,45°, or -45°). That is, if the participant was moving at a 45° heading angle in a direction opposite to that of the applied rotation (-45°), s/he would have zero angular error. The heading angle and angular errors were all averaged in bins of 4 consecutive trials (i.e., one trial to each target location) for analysis. Proactive interference was calculated as a 'resistance to interference score' that was obtained by subtracting the learning score of the baseline VMR task (calculated as the difference in the angular error between the first and last bin of the adaptation phase) from the learning score of the post intervention VMR task. A higher resistance to interference score implied better motor learning related to an ability to suppress interference from prior learning.

4.6.3 Cognitive, Motivation, & Emotional Intelligence (EI) Measures

The goal of the cognitive tasks is to measure individual differences in executive function, implicit learning, and explicit memory to examine the cognitive mechanisms potentially underlying the ability to learn the visuomotor rotation and to handle proactive interference. These tasks were implemented using the Psychology Experiment Building Language (PEBL: Mueller and Piper, 2014). To understand the relation of the 'ability to handle proactive interference' with the underlying cognitive mechanism/s, we measured various facets of memory and executive function: explicit memory using Corsi block span tasks, implicit learning through pursuit rotor task, executive function through Flanker (to measure inhibitory ability) and Berg's card sorting test (for measuring cognitive flexibility). Emotional intelligence (EI), specifically emotion management, and motivation variables will be measured using relevant standardized psychometric instruments to ascertain their role in skill acquisition and performance in response to motivational instructions. These include the Emotion regulation technique (ERQ: John et al., 2008), emotion management ability (STEM-B: Allen et al., 2015), achievement motivation (Cassidy and Lynn, 1989) and perceived stress (PSS-10; Roberti et al., 2011) questionnaires.

4.6.4 Procedure

The experiment was designed as a mixed factorial study with two between-participants factors (age group - old vs. young, and group – control vs. experimental) and a within-subject factors (phase – learning vs. transfer). The two groups of 30 older and 39 younger adults were randomly subdivided into experimental and control groups with 15 participants in each group in the OA group and 20 and 19 in the young adult's EG and CG respectively. The participants first answered the motivation and emotional intelligence questionnaires, followed by Block 1: familiarization stage of the visuomotor rotation (VMR) task. They were then administered the cognitive tests, post which they proceeded to Block 2, the learning phase (adaptation stage + aftereffects stage), of the VMR task. At this stage, participants in the experimental groups received instructions that were a combination of the motivational and attentional paradigms (EE-AS-EF) before starting the adaptation stage, while the control group received standard instructions (Figure 4.3). After completing the adaptation and aftereffects stages of this block (Block 2), participants completed the demographic health questionnaire before proceeding to the final block: Block 3, the transfer phase (Figure 4.2). Being an explorative study, at the end of the task, participants were asked questions on their experience to elicit their thoughts and feelings about the various steps involved in the intervention (appendix).

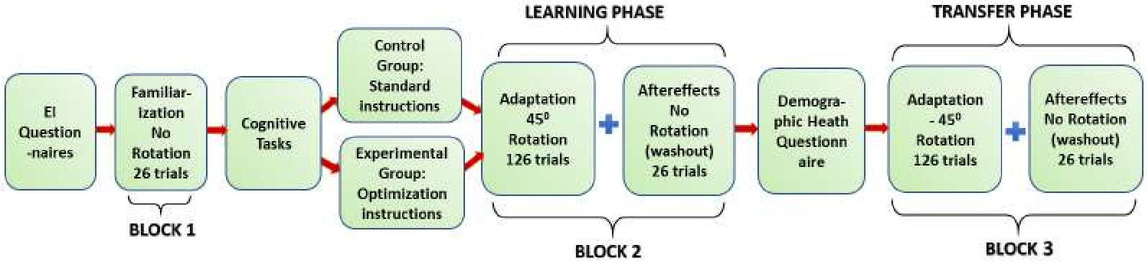

Figure 4.2. Experiment Procedure

Figure 4.3. Instructions given to the experimental and control group participants.

4.7 Data Processing

Statistical analyses of these data included ANOVA approaches and Pearson Correlation, as described in the results section. We scrutinized the descriptive measures of central tendency to verify if there was a major difference between the mean and median as that might indicate outlier. We also looked at kurtosis, skewness and carried out the Shapiro–Wilk test of normality. To rule out, or account for preexisting significant or systematic differences, we conducted a One-Way ANOVA of all the cognitive and EI measures between the two groups.

Motor learning data: The motor learning data were processed in the same way as study 1, as described in section 3.5.2.

4.8 Results

4.8.1 Cognitive and EI Between Group Differences

We conducted two One-Way ANOVA analyses of the cognitive, EI and personality measures to examine if any of the subgroups were significantly different from each other on any of the CV, EI or personality measures. The first ANOVA compared the means of all the said variables for all four groups (YA-EG, YA-CG, OA-EG, and OA-CG), while the second ANOVA compared the means between the two age groups (OA and YA). For the larger ANOVA, Tukey HSD post hoc tests were performed. Those variables for which the assumption of homogeneity of variance was not met, the Games-Howell post hoc values (for the ANOVA with 4 groups) and the Welch results (for the ANOVA with 2 groups) were taken into consideration. The means and standard deviations of all the measures for the various groups are displayed in tables 4.1 and 4.2. The YAs displayed higher scores in some of the cognitive measures like CORSI ($F(1,66.64) = 18.38, p = 0$)), Flanker incongruent reaction time ($F(1,67) = 61.46, p = 0$)), the EI measure of ERQ-S (emotion regulation by suppression) ($F(1, 67) = 5.99, p = 0.017$)) and the personality dimension of Neuroticism ($F(1,67) = 8.6, p = 0.005$)). The older adults had higher scores in the personality variables of Agreeableness ($F(1, 67) = 18.94, p = 0$)), Conscientiousness ($F(1, 67) = 6.73, p = 0.012$)), and Openness ($F(1, 67) = 8.78, p = 0.004$)) . These group differences did not influence the impact of the intervention on motor learning.

Table 4.1. Means & Standard Deviations: Cognitive and EI Measures of YA-EG, YA-CG, OA-EG, and OA-CG

Measures	**Mean (SD)**			
Cognition	**YA-EG (n=20)**	**YA-CG (n=19)**	**OA-EG (n=15)**	**OA-CG (n=15)**
BCST perseverative errors	11.34 (7.15)	12.25 (5.13)	14.58 (13.54)	12.53 (11.61)
CORSI Memory Span	5.80 (0.71)	5.47 (1.07)	4.90 (0.74)	4.67 (0.77)
Flanker Mean Accuracy	0.94 (0.11)	0.91 (0.23)	0.92 (0.15)	0.97 (0.04)
Flanker Incongruent Reaction Time	452.66 (44.78)	473.76 (99.27)	598.15 (70.90)	597.36 (57.19)
Flanker Conflict Cost	46.60 (22.62)	47.80(18.32)	61.63 (38.06)	52.89 (31.50)
Pursuit Rotor Learning Score	294.25 (859.22)	1033.61 (1128.15)	820.47 (1257.65)	1397.60 (872.64)
Emotional Intelligence				
Achievement Motivation	36.40 (4.72)	33.68 (4.95)	34.00 (4.24)	35.53 (3.83)
Emotion Regulation by Reappraisal	30.05 (7.59)	29.79 (5.67	31.73 (5.96)	30.13 (7.96)
Emotion Regulation by Suppression	15.15 (4.76)	17.16 (5.84)	13.07 (4.88)	13.07 (5.08)
Perceived Stress	18.50 (2.95)	20.21 (3.34)	18.47 (3.54)	18.60 (2.85)
Emotion Management (STEM)	10.84 (1.95)	11.50 (1.87)	11.54 (1.88)	11.91 (1.89)
Emotional Understanding (STEU)	12.25 (2.17)	12.74 (1.97)	11.87 (1.51)	12.53 (1.85)

Personality				
Extraversion (E)	3.33 (0.64)	3.38 (0.97)	3.53 (0.67)	3.66 (0.84)
Agreeableness (A)	3.72 (0.60)	3.90 (0.60)	4.34 (0.41)	4.39 (0.43)
Conscientiousness (C)	3.73 (0.62)	3.54 (0.62)	3.95 (0.47)	4.06 (0.61)
Neuroticism (N)	2.90 (0.67)	2.94 (0.86)	2.54 (0.48)	2.27 (0.80)
Openness (O)	3.59 (0.59)	3.60 (0.53)	3.88 (0.49)	4.11 (0.63)

Table 4.2. Means & Standard Deviations: Cognitive and EI Measures of YA & OA

Measures	**Mean (SD)**	
Cognition	**YA (n=39)**	**OA (n=30)**
BCST perseverative errors	11.79 (6.19)	13.56 (12.44)
CORSI Memory Span	5.64 (0.91)	4.78 (0.75)
Flanker Mean Accuracy	0.92 (0.18)	0.94 (0.11)
Flanker Incongruent Reaction Time	462.94 (76.06)	597.75 (63.29)
Flanker Conflict Cost (IC-C)	47.18 (20.38)	57.26 (34.61)
Pursuit Rotor Learning Score	654.45 (1054.59)	1109.03 (1103.33)
Emotional Intelligence		
Achievement Motivation	35.08 (4.96)	34.77 (4.05)
Emotion Regulation by Reappraisal	29.92(6.64)	30.93 (6.96)
Emotion Regulation by Suppression	16.13(5.34)	13.07 (4.89)
Perceived Stress	19.33 (3.22)	18.53 (3.16)
Emotion Management (STEM)	11.16 (1.92)	11.72 (1.86)
Emotional Understanding (STEU)	12.49 (2.06)	12.20 (1.69)
Personality		
Extraversion (E)	3.36 (0.81)	3.59 (0.75)
Agreeableness (A)	3.81 (0.60)	4.37 (0.41)
Conscientiousness (C)	3.63 (0.62)	4.00 (0.54)
Neuroticism (N)	2.92 (0.76)	2.41 (0.66)
Openness (O)	3.59 (0.55)	3.99 (0.57)

4.8.2 Impact of OPTIMAL intervention on ML

Adaptation: We performed a phase (learning vs. transfer) by bins (25) repeated measures ANOVA with group and age as between groups factors to assess the impact of the OPTIMAL intervention on ML. The ANOVA exhibited a main effect of phase ($F(1,60) = 51.87$, $p = 0$, n=0.46) and bins ($F(30,1800) = 320.55$, p = 0, $\eta p^2 = 0.84$) and a phase by group by age interaction ($F(1,60) = 5.39$, $p = 0.024$ $\eta p^2 = 0.08$). For the interaction, Bonferroni adjusted pairwise comparisons showed that in the younger adults, the participants in the experimental group (EG) performed worse in the learning phase, with a significantly higher angular error (AE) than those in the control group (CG) (M_{diff}= 6.08, $p = 0.005$). In the older adult group, there was no difference in AE between the CG and EG groups in the learning phase ($p > 0.5$). There was also no significant difference in AE between the EG and CG during the transfer test for either younger or older adults ($p > 0.5$). Additionally, when comparing learning to the transfer test, the AE was significantly larger during transfer (indicating interference) in the younger adult CG ($p < 0.0005$), in the older adult CG ($p < 0.01$), and the older adult EG ($p < 0.0005$), but in the younger adult EG this comparison is only marginally significant ($p = 0.058$) (Figure 4.4). Thus, the interference effect in the older adults was largest for the EG but in the younger adults the interference was largest in the CG. Interestingly, a marginally significant difference was also observed in the learning phase between the older and younger adults' in the EG, with older adults exhibiting a smaller AE compared to the younger adults (M_{diff} = 4.06, $p = 0.06$). This suggests that older adults performed better during initial learning than younger adults with the experimental manipulation.

After-Effects: A phase (learning and transfer) by bins (6) repeated measures ANOVA with group and age as between groups factors exhibited a main effect of phase (F (1,60) = 23.82, $p = 0.00$, $\eta p^2 = 0.28$) and bins ($F(5,300) = 17.34$, $p = 0.00$, $\eta p^2 = 0.22$) and a phase by group by age interaction ($F(1,60) = 4.17$, $p = 0.045$ $\eta p^2 = 0.07$). For the interaction, Bonferroni adjusted pairwise comparisons showed that the after-effects were larger during learning phase in the older adult EG group compared to the that of the younger adult EG group ($p = 0.008$), indicating that they had a better memory of their initial learning, leading to larger after-effects, compared to their younger counterparts. Within older adults, there was a significant difference in the aftereffects between learning and transfer in the EG ($p = 0.001$), but not in the CG ($p > 0.18$). While in the younger adult group, there was a significant difference in the aftereffects between learning and transfer in the CG ($p = 0.002$) and not in the EG ($p > 0.13$)

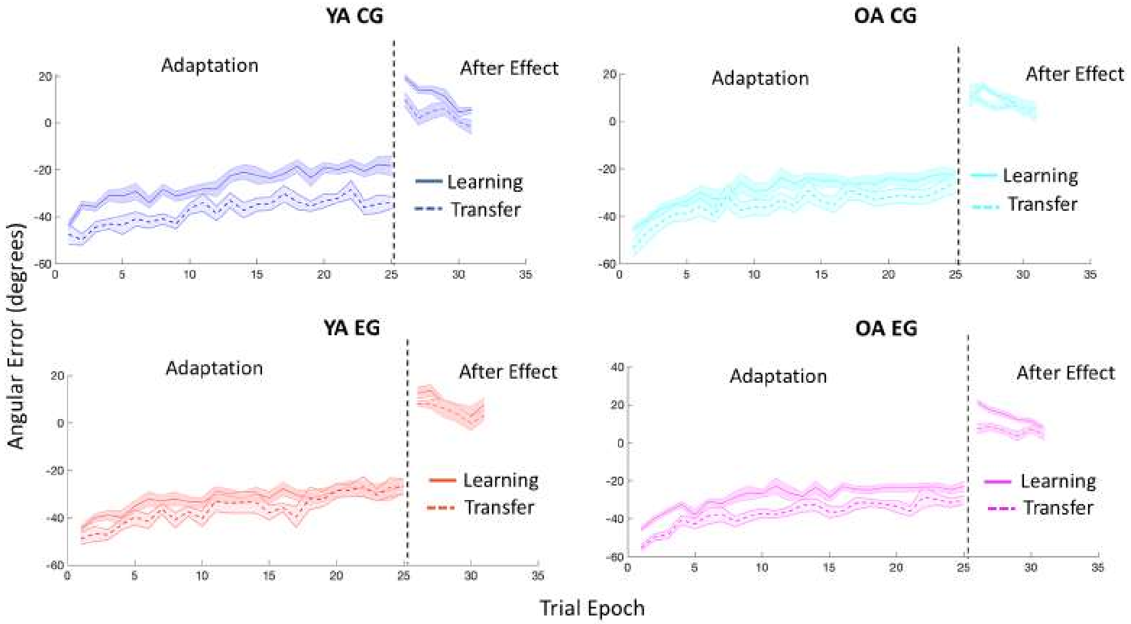

Figure 4.4. Learning & Transfer Phases of All Groups

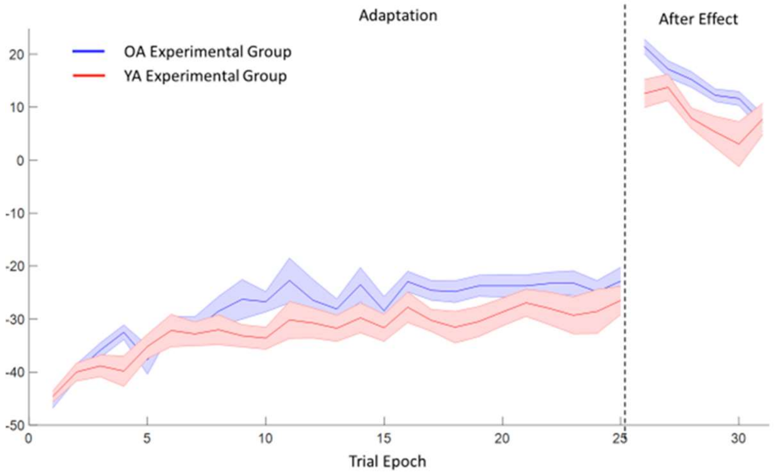

Figure 4.5. Learning Phase - OA and YA Experimental Groups

4.8.3 Correlation

We conducted a correlation analysis to examine the cognitive, emotional intelligence (EI) and motivational factors associated with learning and the susceptibility to interference. Table 4.3 displays the correlation of Interference and Learn Adapt measures with the cognitive & EI variables. Table 4.4 displays the correlation of Learn After and Trans After with the cognitive & EI variables. The significant correlations are marked with an asterisk.

Table 4.3 Correlation: Interference, Learn Adapt with Cognitive & EI Variables.

		YAEG (N=20)		**YACG (N=19)**		**OAEG (N=15)**		**OACG (N=15)**	
		Interference	Learn Adapt	Interference	Learn Adapt	Interference	Learn Adapt	Interference	Learn Adapt
BCST Perseverative Errors	Pearson Correlation	-0.104	-0.162	0.026	-0.240	-0.473	0.350	0.192	-0.018
	Sig. (2-tailed)	0.662	0.495	0.916	0.322	0.075	0.200	0.494	0.950
CORSI Memory Span	Pearson Correlation	**.475***	0.398	0.062	0.181	0.111	-0.227	0.338	-0.164
	Sig. (2-tailed)	0.034	0.082	0.801	0.458	0.694	0.415	0.218	0.560
Flanker Mean Accuracy	Pearson Correlation	**.449***	-0.285	-0.337	0.243	0.384	-0.256	-0.208	0.100
	Sig. (2-tailed)	0.047	0.223	0.159	0.316	0.158	0.358	0.457	0.722
Flanker Incongruent Response Time (ms)	Pearson Correlation	0.024	0.010	0.436	-0.259	-0.251	0.114	0.193	-0.116
	Sig. (2-tailed)	0.919	0.966	0.062	0.284	0.367	0.687	0.491	0.680
Flanker Conflict Cost (IC-C)	Pearson Correlation	**-0.442**	0.039	0.043	-0.100	-0.159	0.047	0.022	-0.495
	Sig. (2-tailed)	0.051	0.870	0.861	0.682	0.570	0.868	0.939	0.061
Pursuit Rotor Learning Score	Pearson Correlation	-0.191	0.221	0.184	0.139	0.473	-0.353	-0.033	0.049
	Sig. (2-tailed)	0.42	0.349	0.45	0.571	0.075	0.196	0.907	0.862
Achievement Motivation	Pearson Correlation	0.305	-0.235	0.101	-0.112	0.064	-0.429	-0.094	-0.328
	Sig. (2-tailed)	0.191	0.318	0.68	0.648	0.822	0.111	0.740	0.233
ERQ Reappraisal	Pearson Correlation	0.118	0.216	-0.162	0.385	-0.117	0.284	0.196	-0.183

	Sig. (2-tailed)	0.619	0.361	0.508	0.104	0.678	0.304	0.484	0.514
ERQ Suppression	Pearson Correlation	0	0.417	0.01	-0.359	0.185	0.019	-0.088	-0.310
	Sig. (2-tailed)	0.999	0.067	0.968	0.131	0.509	0.946	0.756	0.260
Perceived Stress	Pearson Correlation	0.036	-0.194	0.143	-0.004	0.380	-0.221	0.201	-0.402
	Sig. (2-tailed)	0.879	0.414	0.558	0.988	0.162	0.430	0.472	0.138
Emotion Management (STEM)	Pearson Correlation	-0.271	0.225	0.13	0.221	-0.316	0.140	0.237	0.001
	Sig. (2-tailed)	0.247	0.341	0.596	0.363	0.251	0.619	0.395	0.997
Emotional Understanding (STEU)	Pearson Correlation	-0.375	0.117	-0.152	-0.066	0.311	-0.314	0.014	0.207
	Sig. (2-tailed)	0.104	0.623	0.535	0.787	0.259	0.254	0.961	0.460

Table 4.4 Correlation: Learn After, Trans After with Cognitive & EI Variables.

		YAEG (N=20)		**YACG (N=19)**		**OAEG (N=15)**		**OACG (N=15)**	
		Learn After	Trans After	Learn After	Trans After	Learn After	Trans After	Learn After	Trans After
BCST Perseverative Errors	Pearson Correlation	-0.094	0.407	**.649****	0.216	0.116	-0.290	-0.339	0.079
	Sig. (2-tailed)	0.710	0.075	0.007	0.375	0.680	0.294	0.217	0.779
CORSI Memory Span	Pearson Correlation	0.468	0.125	**-.540***	-0.162	0.198	0.342	-0.370	0.451
	Sig. (2-tailed)	0.050	0.601	0.031	0.508	0.480	0.213	0.174	0.092
Flanker Mean Accuracy	Pearson Correlation	**-.562***	**-.599****	-0.003	**-.521***	**-.517***	0.312	0.013	0.056
	Sig. (2-tailed)	0.015	0.005	0.991	0.022	0.048	0.257	0.964	0.842
Flanker Incongruent Response Time (ms)	Pearson Correlation	0.171	-0.050	0.082	**.666****	0.364	-0.252	-0.470	-0.107
	Sig. (2-tailed)	0.497	0.835	0.764	0.002	0.183	0.365	0.077	0.703
Flanker Conflict Cost (IC-C)	Pearson Correlation	**.541***	0.211	-0.302	-0.363	0.051	-0.163	-0.362	0.243
	Sig. (2-tailed)	0.020	0.372	0.256	0.127	0.856	0.562	0.185	0.382

Pursuit Rotor Learning Score	Pearson Correlation	0.285	0.129	-0.035	**.466***	-0.225	-0.003	-0.028	-0.440
	Sig. (2-tailed)	0.252	0.589	0.899	0.045	0.421	0.991	0.921	0.101
Achievement Motivation	Pearson Correlation	**-.520***	-0.207	-0.024	-0.064	-0.301	-0.422	-0.318	-0.016
	Sig. (2-tailed)	0.027	0.382	0.931	0.793	0.275	0.117	0.248	0.955
ERQ Reappraisal	Pearson Correlation	0.013	0.217	-0.012	0.191	0.025	0.233	-0.037	**-.582***
	Sig. (2-tailed)	0.960	0.359	0.966	0.433	0.931	0.404	0.896	0.023
ERQ Suppression	Pearson Correlation	-0.120	0.049	-0.056	-0.377	-0.131	0.413	-0.187	0.036
	Sig. (2-tailed)	0.636	0.836	0.837	0.112	0.641	0.126	0.505	0.898
Perceived Stress	Pearson Correlation	-0.103	0.026	0.184	0.131	-0.162	0.357	-0.344	0.156
	Sig. (2-tailed)	0.684	0.912	0.494	0.593	0.564	0.192	0.209	0.578
Emotion Management (STEM)	Pearson Correlation	0.141	0.197	0.283	-0.122	0.125	**-.623***	0.202	0.005
	Sig. (2-tailed)	0.576	0.406	0.289	0.618	0.656	0.013	0.469	0.986
Emotional Understanding (STEU)	Pearson Correlation	0.040	0.020	-0.158	-0.340	-0.171	0.227	0.389	0.138
	Sig. (2-tailed)	0.875	0.933	0.560	0.154	0.543	0.416	0.152	0.625

4.9 Discussion

We hypothesized that when used in combination, EE, AS and EF will lead to improved learning and performance in both age groups (young and old). Irrespective of age, the experimental group (EG) participants would learn the visuomotor rotation task (VMR) better than their control group (CG) counterparts, that the comparative level of improvement displayed by older adults in the EG would be equivalent to the younger adult EG, and overall, the experimental groups would also be less susceptible to proactive interference. Thus, we expected to find a higher level of skill acquisition in both groups that received the optimization (motivational instructions). But, contrary to our expectations, we found that the experimental groups did not perform better than their control group counterparts in the adaptation stage. In fact, among the younger adults, the control group performed better than the experimental group in the learning phase. In the transfer phase, we found no significant difference in angular error (AE) between the EG and CG for either the younger or older adults. The AE was larger at transfer than at initial learning for all four groups indicating that each group experienced proactive interference, although this was only marginal in the case for the YA-EG.

Although the adaptation stage did not differ between groups for the YAs or OAs, there was some evidence that the OAs in the EG developed a stronger memory for the rotation during adaptation in the learning phase as their after-effects were somewhat larger than the OAs in the CG. The OAs in the EG also experienced more proactive interference during transfer than the OAs in the CG, again providing evidence that their memory for the perturbation during initial learning was stronger. Likewise, the aftereffects were smaller during transfer for the OA-EG group, confirming that they were able to learn less during transfer, likely due to proactive interference. This pattern of observations was generally opposite in the younger adult groups. YAs in the CG performed better at initial learning than the EG, suggesting that the intervention was not effective for YAs. The YA-CG learned more during initial learning than the YA-EG as evidenced by larger proactive interference at transfer, and larger after-effects during the learning phase compared to the transfer phase (again opposite to the OA pattern). Overall, the performance of YA-CG was similar to that of OA-EG. When comparing the OAs and YAs in the exercise groups, the OA-EG performed marginally better than the YA-EG in the learning phase. They also displayed a larger aftereffect than their younger EG counterparts. These key findings provide evidence that the intervention was somewhat successful at improving learning, or at least memory of what was learned, in the older adults, but not in the younger adults. In fact, the intervention may have interfered with learning in the YAs.

Multiple studies have demonstrated the positive influence of the OPTIMAL theory of motor learning on skill acquisition, more so among younger adults. The three facets (Enhanced Expectancies-EE, Autonomy Support-AS, and External Focus of attention-EF) either individually, or in combination have led to improvement in learning. So why did we not see an effect here? One of our suppositions is that the choices given to the YAs as part of the AS portion of the optimization instructions might have some of made them more anxious (negative affect) instead of happy (positive affect) (which we deduced based on the participants' responses in the post task qualitative interview). The anxiety in turn contributed to lower self-efficacy and intrinsic motivation. It might have also facilitated internal focus of attention, where instead of focusing on the target, the participant turns her/his attention to her/his bodily movements, which, as we have learned, leads to lower movement efficiency and effectiveness (Wulf, 2001).

There have been studies with a similar finding as ours, where the researchers did not find a difference in the learning and execution of a skill by using one of the OPTIMAL techniques in younger adults (Lawrence et al., 2011; Ong & Hodges, 2018). Lawrence et al. (2011) examined if the external focus of attention as mentioned in the OPTIMAL theory would improve learning in a form sport (novel gymnastics routine) among novice performers and they failed to find any support for this in their study. In a more recent study, Ong and colleagues evaluated the impact of success-related feedback on learning of a balance task. They found that though positive feedback influenced competency and arousal, it failed to impact balance outcomes. Other studies too in the past, have failed to replicate Wulf's findings, especially in research related to investigating novice and expert performers (Beilock et al., 2002; Perkins et al., 2003; Ford et al., 2005). But these studies used different conditions to manipulate attentional focus. Unlike Wulf, who used direct verbal instructions, they indirectly manipulated attentional focus by using a distracting task, which might have resulted in different results. These findings indicate that the efficacy of the OPTIMAL theory might apply to only certain types of physical movements and skills.

The relation between executive function (EF), memory, emotional intelligence (EI) and motor learning is once again established in this study. We observed that certain executive control, implicit learning, and emotion management variables predicted motor performance in the various participant groups. These relationships were more prevalent in the aftereffects stage than the adaptation stage. The only variables that were correlated with the motor learning (ML) interference measures were the CORSI memory span, Flanker accuracy, and Flanker conflict cost (to a marginal extent), and that too only in the YA-EG. While higher CORSI and Flanker conflict costs scores were associated with more interference, higher Flanker accuracy scores were correlated with lower interference. In the aftereffects stage of the learning phase, in the YA-EG, higher Flanker accuracy and achievement motivation were correlated with lower aftereffect, and higher Flanker conflict cost was associated with higher aftereffects. In the YA-CG, higher BCST perseverative errors score was associated with larger aftereffects, while CORSI memory span exhibited a negative correlation. In the OA-EG, Flanker accuracy was negatively correlated with the aftereffects measure. No correlation was observed in the OA-CG. In the aftereffects stage of the transfer phase, cognitive variables continued to be associated with degree of aftereffects in the younger adults (Flanker accuracy in YA-EG, Flanker accuracy, Flanker incongruent response time, and Pursuit Rotor score in YA-CG). For both groups, higher Flanker accuracy scores were associated with lower aftereffects. For the YA-CG, a higher response time in Flanker incongruent trials was associated with larger aftereffects and the pursuit rotor score was positively associated with aftereffects (higher implicit learning was correlated with larger aftereffects). For the older adults, the EI variables (emotion management-STEM and emotion regulation by reappraisal-ERR) and not the cognitive measures, were significantly associated with their degree of aftereffects. Higher STEM and ERR scores were associated with lower aftereffects in OA-EG and OA-CG, respectively.

Contrary to most previous findings where adaptation to VMRs has shown to decline with age (Etnier and Landers 1998; McNay and Willingham 1998; Fernandez-Ruiz et al. 2000; Teulings et al. 2002; Wang et al. 2011; Bruin et al. 2016), the older adults in our study performed as well as, if not better, than the younger adults (Figure 4.5). Irrespective of age and manipulation, everybody experienced similar level of interference at transfer.

Among all groups, the CG of the younger adults experienced the maximum interference, and the least interference was experienced by the CG of the older adults. The interference of the EG and CG of the older adults were quite similar, with OA-EG experiencing slightly more interference than the OA-CG. There have been a few studies that, like ours, have found no age-related adaptive deficits in older adults (Canavan et al. 1990; Roller et al. 2002; Buch et al. 2003). It is hypothesized that various factors like the type of instructions, cognitive status of the participants, differences in experimental paradigms can influence skill acquisition/motor learning and performance in older adults. More recent studies have shown that the time course of kinematic distortions also influence the level of adaptation and aftereffects (for example, Buch et al. (2003) found that, when exposed to gradual as opposed to sudden VMR, older adults did not significantly differ in their performance than the younger participants).

In our study, we found that the older adult experimental group (OA-EG) had larger aftereffects than their peers in the CG and their younger counterparts in the experimental group, demonstrating a stronger memory of the adapted movement. This is a novel finding and entails further examination of the intervention's differential impact on the two age groups. Thus, though we did not see an immediate effect of the intervention during the learning phase, older adults in the experimental group did display an enhanced after effect at transfer. This indicates that the older adults might have responded differently to the instructions than the younger adults indicating a difference in the way the two age groups respond to motivation such as used in our study. A similar difference was also observed by Huang and colleagues (2018) in their study examining the effects of motivational feedback on age-related decline in reaching adaptation and found that older adults benefitted from motivational feedback during learning as well as retention and suggest that motivational feedback can be used as a potential compensatory mechanism to help attenuate age-related differences and foster learning. A similar finding was made by Wulf and Chiviacowsky (2012) in their study on how altering mindset can enhance ML in older adults. In their research, participants who were given fabricated positive feedback indicating that their performance was better than average, or informing them that participants such as themselves, typically do well in the given task, displayed more effective learning than those who received veridical feedback only. The researchers attribute this enhanced learning and performing of the experimental group to their higher level of self-efficacy, as evidenced by their self-efficacy ratings. Studies such as this provide evidence that psychological factors do play more than a minor role in attenuating deficits associated with aging. Similar to Wulf and Chiviacowsky's observations, and in line with our preceding study, here too, we observed a relation between EI variables and motor learning, in the OA groups. Emotion management and emotion regulation predicted AE in the OA-EG and OA-CG respectively during the aftereffects stage of the VMR task at transfer. Somehow, these variables mediated their memory of the perturbation, as reflected in the size of the aftereffects. An additional contributing and differentiating factor could also be that the older adults in our study were in general more positive about the whole experience including the intervention and did not feel anxious with any of the instructions or feel boredom, like some of their younger counterparts. OAs looked forward to the task and enjoyed it. Further studies in this area could shed more light on the underlying neurobehavioral mechanisms of this phenomenon.

The fact that the OA-EG and YA-CG groups demonstrated a significantly larger after-effects at learning is a strong indicator that the manipulation (rotation) has been learned (Krakauer, 2009). Overall, motor learning/skill acquisition is more holistic than it appears with various cognitive and EI variables being involved in the learning and performance of a motor task. In addition, the nature/type of the skill/activity to be learned, whether the individual in question is a novice or expert, may also mediate the effect of the training intervention. These aspects need to be examined further. That it is not just the CV, ML or EI variables, but the combination of EF, memory, EI abilities, motor abilities, skill level that affect skill acquisition.

Though we did see some evidence of the ‘desired’ effect, or positive impact of the intervention in the OA group, one reason why we might not have seen a similar effect in the younger adults may be because of the way the instructions were framed/wordings of the instructions. In our study, while some of the younger adults experienced anxiety in response to the instructions, in the OA group, it did not appear to make much of a difference, at least not initially. But it did appear to have a positive effect on their performance during the latter half of the transfer phase, where OAs in the EG were able to retain their learning of the opposite rotation for a much longer duration as compared to the other groups. Future studies could include differently worded directives for better effect and/or various kinds of instructions language for comparison: *controlling language* in addition to the *autonomy support language* and *neutral language* (Hooyman et al., 2014). Additionally, measures like self-efficacy, positive and negative affect, and perception of choice (as a manipulation check) could be included in addition to, or instead of, the retrospective qualitative interview that we did, to further understand the effect of the instructions on the individual and their performance. We could also give the optimization instructions at transfer instead of leaning and examine if this facilitates reduced susceptibility to inference. There is also the possibility that this task is not be right kind of for this type of intervention. Overall, there does appear to be an inherent difference in the way the two age groups responded to the optimization and this phenomenon could be explored further in future studies.

We anticipate that this study will help us to improve our understanding of how motivational and attentional instructions can improve motor learning and overcome proactive interference. It will inform towards implementation of these interventions/techniques in various applied settings to enhance learning, performance, therapy, and treatment (Laufer et al., 2007) by providing data on the age-related differences and related psycho-neuro-physiological implications. We hope that the findings from this study will provide reference for development of social-cognitive-affective based interventions for various age groups and will have implications for instructional support in different settings for older adults. Knowing that motivational techniques work better with older adults can open new pathways to augment and/or supplement more expensive treatment and training methods to improve motor learning and performance.

4.10 Assessment of the OPTIMAL Theory

This study brings to light the fact that the effectiveness of the OPTIMAL theory might be mediated by various cognitive, emotional, biological, demographical factors and the type of motor task involved. The theory might apply to only certain types of physical movements and skills. While some tasks/activities may be more responsive to OPTIMAL theory-based intervention, others may need a different approach. For example, it has been observed that in tasks involving less proceduralized movements, like using a less-favored limb to dribble a ball, having an internal focus rather an external focus of attention seems to improve performance. It appears that sometimes, when a task is new, or complex, or not yet automatized, an internal focus of attention, or focusing one's attention on one's movements (like hand or foot placements) may help in learning the task better (Lawrence et al., 2011, Ford et al., 2005). Thus, we may not be able to generalize the application of the OPTIMAL theory to all types of tasks, movements and/or audience. Also, a movement effect has to be clearly specified for the principle of external focus of attention to work. In tasks where this the movement effect is not clear, application of the OPTIMAL theory may not have an impact (Lawrence et al., 2011). Once the movements become automatic, adopting an external focus of attention might be beneficial. There is also a possibility that positive feedback and perceptions of success, though benefit self-efficacy and confidence, may not always contribute to learning (Carter et al., 2016; Ong & Hodges, 2018). The level of task difficulty may also mediate the effect of perceived success and positive feedback. Participants might find improving on a difficult task more rewarding than an easy one (Ong & Hodges, 2018). More work is required in this area to determine the types of motor learning tasks that the OPTIMAL theory will be best suited for. This knowledge could then inform design of training strategies for different types of skills and different audiences. The role of language and its degree of effectiveness needs to be explored further by designing experiments and training paradigms for various types of tasks using different instructional language modalities (autonomy support, neutral or controlling). One other aspect is the potential effect of the element of 'choice' in the autonomy support paradigm. In our study, this appeared to have differential effects on the two age groups. Thus, the perception of choice by the participants might also be a factor to be considered when planning task commands/directives. As there are diverse elements implicated in the learning of a motor skill, understanding, and acknowledging their role in the context of learning, will improve the effectiveness of such interventions.

CHAPTER 5

GENERAL DISCUSSION

5.1 General Discussion

Our research was a pilot project to examine the effectiveness of two very distinct forms of interventions in enhancing motor learning/skill acquisition, specifically in older adults. The first intervention comprised of a form of eccentric exercise that was performed over a period of 12 weeks, while the other was a more immediate, short term intervention involving a motivation based instructional manipulation.

The positive effect of exercise on brain functionality is indisputable. It has shown to improve cognitive abilities like spatial working memory (Ruitenberg et al., 2018; Chen et al., 2019), executive functions (Hillman et al., 2008; Diamond, 2013; Diamond 2016) emotional and cognitive control (Dietrich, 2006; Giles et al., 2018), by positively influencing brain regions like the prefrontal lobe, anterior cingulate cortex/supplementary motor area (ACC/SMA), hippocampus (Chen et al., 2019), premotor, parietal and occipital cortex (Langan and Seidler, 2011). But does this positive effect translate to improvement in skills that are dependent on the involved brain mechanisms? Our research provided us with some answers in this regard, while also raising a few other questions in the process. Overall, we found that the eccentric exercise intervention did result an observable improvement in the ability to handle proactive interference in motor learning. It also demonstrated to have a positive effect on cognitive and emotion management abilities. But there were also areas like emotional understanding, where these improvements did not show a significant enhancement. We also found a high level of individual differences in the scale of improvements. This resonates to some extent with Pontifex, Hillman and Polich (2009)'s findings on the differential and selective effect of fitness on attentional systems in older adults. They found that the effect is modulated by task difficulty. While physical activity can lead to improved cognitive abilities, it may not be able to prevent age-related cognitive decline due to depletion of neural structures like white or grey matter for example. On the other hand, there have been other studies providing a link between exercise and neuronal propagation (Cotman et al., 2002) and increases in monoamines (norepinephrine and dopamine) (Brown et al., 1979; MacRae, Spirduso et al., 1987) and human studies indicating that exercise can lead to age-related decreases in neuronal tissue loss in the frontal, parietal, and temporal cortices (Colcombe et al., 2004). The answer may lie in the link between cognitive engagement and exercise; the more cognitively demanding an exercise/physical activity, the more effect it would likely have on enhancing brain activation and linked cognitive abilities (Bherer et al., 2013; Voelcker-Rehage & Niemann, 2013). Another method to accentuate the positive effect of exercise is to design interventions that are a combination of physical and cognitive training, which have shown promising results (Bamidis et al., 2015).

In the optimization study, we found that our intervention had a differential effect on the younger and older adults. While it was somewhat successful at improving learning in the older adults, in the younger adults, it may even have interfered with their learning. Similar to the previous study, here too, we found executive control and emotion management variables associated with motor learning and performance. Whereas in the younger adult groups, the EF variables were associated with their motor performance, in the older adults, it was EF and EI variables (emotion management and emotion regulation by reappraisal) that were correlated with motor performance. Another observation that echoed previous finding in this area was that mindset does play a role in mediating skill acquisition. The older adults in our study exuded a positive attitude towards the whole process. They were curious to understand and learn the task and enjoyed the experience. The younger adults (some of them at least) on the other hand, were more skeptical and even anxious. Thus, while the older adults' positive attitude appears to have aided them in the process of learning a novel motor skill, for the younger adults, their negative affect appeared to impede their learning ability. Further follow up studies will have to be carried out to examine this in more detail.

The act of motor learning itself generates substantial brain activity in various cortical and subcortical regions including and not limited to the basal ganglia, anterior cingulate cortex, inferior frontal gyrus, medial cerebellum, and visual and parietal cortical areas (Seidler, 2010). Different aspects of motor learning (initial learning, later stages of learning, acquisition, transfer, retention, recall) have been associated with changes in brain activation in different brain regions (Bedard & Sanes, 2014; Floyer-Lea & Matthews, 2003). In terms of behavioral mechanisms, motor learning has shown to improve abilities like spatial working memory, associate, explicit and implicit memory processes (Anguera et al., 2009; Taylor & Ivry 2011; Trewartha et al. 2014; Rajeshkumar & Trewartha, 2019), executive control processes such as those involved in making intentional strategic corrections that facilitate perceptual motor integration (Willingham,1998; Heuer & Hegele, 2008), etc. Given its positive effect on the brain, motor learning itself may be utilized as an intervention to improve cognitive functioning. By including individualized training methods (e.g. customized instructions) in this process, one could enhance the benefits derived from the it.

5.2 Limitations

We did have our share of limitations. In the exercise intervention study, we did not have an active control group, and building this in would have made the evidence for our intervention-based findings stronger. We also had very stringent selection criteria and limited our participant pool to highly functional older adults. Future iterations should look at a broader range of health conditions/status. The exercise itself was a low-moderate intensity exercise program and may not have been robust enough to bring about significant neuro-physiological changes. The sample size was also quite modest, which also limits the type of analyses that can be performed. In the Optimization study, though we did see some evidence of the desired effect, or positive impact of the intervention in the OA group, we did not see a robust effect overall, and none in the younger adult group. One explanation could be the wordings of the instructions. They might have to be framed differently to have a significant impact on learning and skill improvement. We could also time the instructions differently, giving it before transfer instead of the learning phase to observe it had a more direct effect in reducing proactive interference.

There were individual differences in how participants responded to the interventions, with each of them displaying different levels of improvement. Obtaining a better understanding of this variation (and identifying its physiological/behavioral biomarkers if possible), can enable designing more effective individualized raining interventions with better results.

5.3 Applications & Human Factor Implications

These are preliminary works with implications for designing innovative, simple, and effective interventions to improve about exercise induced improvements in skill acquisition and motor learning, in addition to preventing and managing age related cognitive decline. The findings from these studies have applications across domains of mental health, rehabilitation (physiotherapy, occupational therapy, etc.), education, and training. For example, prescribed exercise could be switched for, or compliment pharmacological treatments to bring about improvements in cognitive, motor, and emotional functioning. This may be enhanced by adding a cognitive training component to it. For such interventions to be truly effective, the choice of exercise and training model would have to be tailored to the client/patient, based on their physiological and psychological requirements/characteristics. Findings from studies such ours can help inform these decisions and contribute towards devising training interventions for various populations depending on the type of tasks and the characteristics of the trainee (older adult vs younger adult, novice vs. experts, etc.). In the rehabilitation domain, it could be something as simple as tailoring certain technical nuances of the instructional method, or planning the training based on user-based cognitive and emotional abilities/strengths, and these might look different for younger and older adults. Brain imaging and non-invasive brain stimulation could help obtain real time information on the regional and functional brain activation/s associated with such interventions and add to this body of knowledge. Future research involving identification and segregation of neurocoritcal or neurophysiological markers related to skill acquisition in different contexts will contribute substantially towards understanding these interlinkages in a more comprehensive manner and designing result-based intervention and treatment programs.

5.4 Conclusion

Such studies would improve our knowledge regarding neurophysiological and behavioral basis of conditions like proactive interference and shed more light on the individual difference in motor learning. This would inform towards training methodologies and interventions to make learning more effective and efficient. For example, it has been found that just by changing the design (gradual increase in rotation versus sudden increase) it increased learning. This points to the fact that the way a study is designed, including the instructional methodology can influence learning, and the way it does, can be different for different people. Training strategies have to take into consideration individual differences to make it more effective.

Overall, motor learning/skill acquisition is more holistic than it appears with various cognitive and emotional intelligence variables being involved in the learning and performance of a motor task. In addition, the nature/type of the skill/activity to be learned, whether the individual in question is a novice or expert, may also mediate the effect of the training intervention. We hope that our findings will encourage future enquiry into this domain, to better understand the intricate relation between forms of exercise, brain region activation and emotional intelligence, leading to novel and innovative interventions that will make motor skills acquisition an enriching and effective experience.

References

Abdollahipour, R., Land, W. M., Cereser, A., & Chiviacowsky, S. (2019). External relative to internal attentional focus enhances motor performance and learning in visually impaired individuals. *Disability and rehabilitation*, 1-10.

Ackerley, R., Aimonetti, J. M., & Ribot-Ciscar, E. (2017). Emotions alter muscle proprioceptive coding of movements in humans. *Scientific Reports*, *7*(1), 1-9.

Albinet, C. T., Abou-Dest, A., André, N., & Audiffren, M. (2016). Executive functions improvement following a 5-month aquaerobics program in older adults: role of cardiac vagal control in inhibition performance. *Biological psychology*, *115*, 69-77.

Albinet, C. T., Abou-Dest, A., André, N., & Audiffren, M. (2016). Executive functions improvement following a 5-month aquaerobics program in older adults: role of cardiac vagal control in inhibition performance. *Biological psychology*, *115*, 69-77.

Allen, V. D., Weissman, A., Hellwig, S., MacCann, C., & Roberts, R. D. (2014). Development of the situational test of emotional understanding–brief (STEU-B) using item response theory. *Personality and Individual Differences*, *65*, 3-7.

Allen, V., Rahman, N., Weissman, A., MacCann, C., Lewis, C., & Roberts, R. D. (2015). The Situational Test of Emotional Management–Brief (STEM-B): Development and validation using item response theory and latent class analysis. Personality and Individual Differences, 81, 195-200.

Amin, H. U., Malik, A. S., Kamel, N., Chooi, W. T., & Hussain, M. (2015). P300 correlates with learning & memory abilities and fluid intelligence. *Journal of neuroengineering and rehabilitation*, *12*(1), 87.

Amoruso, L., Gelormini, C., Aboitiz, F. A., González, A., Manes, F., Cardona, J., & Ibanez, A. (2013). N400 ERPs for actions: building meaning in context. *Frontiers in human neuroscience*, *7*, 57.

Amoruso, L., Gelormini, C., Aboitiz, F., Alvarez González, M., Manes, F., Cardona, J. F., & Ibanez, A. (2013). N400 ERPs for actions: building meaning in context. *Frontiers in human neuroscience*, *7*, 57. https://doi.org/10.3389/fnhum.2013.00057

Anderson, E. H., & Shivakumar, G. (2013). Effects of exercise and physical activity on anxiety. *Frontiers in psychiatry*, *4*, 27.

Anderson, N. D., & Craik, F. I. (2000). Memory in the aging brain. *The Oxford handbook of memory*, 411-425.

Anguera J.A., Bo J., Seidler R.D. (2012) Aging Effects on Motor Learning. In: Seel N.M. (eds) Encyclopedia of the Sciences of Learning. Springer, Boston, MA

Anguera, J. A., Reuter-Lorenz, P. A., Willingham, D. T., & Seidler, R. D. (2010). Contributions of spatial working memory to visuomotor learning. *Journal of cognitive neuroscience*, *22*(9), 1917-1930.

Anguera, J. A., Russell, C. A., Noll, D. C., & Seidler, R. D. (2007). Neural correlates associated with intermanual transfer of sensorimotor adaptation. *Brain research*, *1185*, 136-151.

Anguera, J. A., Seidler, R. D., Gehring, W. J. (2009). Changes in performance monitoring during sensorimotor adaptation. Journal of Neurophysiology, 102, 1868–1879

Anguera, J., Reuter-Lorenz, P., Willingham, D., Seidler, R. (2011). Failure to engage spatial working memory contributes to age-related declines in visuomotor learning. *Journal of Cognitive Neuroscience, 23,* 11–25.

Annesi, J. J., & Vaughn, L. L. (2011). Relationship of exercise volume with change in depression and its association with self-efficacy to control emotional eating in severely obese women. Advances in preventive medicine, 2011.
asymmetry of the cerebral cortex: replicability of regional differences in volume. *Neurobiol. Aging* (in the press).

Attentional focus and motor learning: a review of 15 yearsGabriele Wulf* nternational Review of Sport and Exercise Psychology, 2013Vol. 6, No. 1, 77104, http://dx.doi.org/10.1080/1750984X.2012.723728

Austin, E. J. (2010). Measurement of ability emotional intelligence: Results for two new tests. *British Journal of Psychology*, *101*(3), 563-578.

Austin, E. J. (2010). Measurement of ability emotional intelligence: Results for two new tests. *British Journal of Psychology*, *101*(3), 563-578.

Baddeley AD, Hitch GJ. 1994. Developments in the concept of working memory. *Neuropsychology* 8:485–93

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology*, *8*(4), 485.

Badre, D., & Wagner, A. D. (2006). Computational and neurobiological mechanisms underlying cognitive flexibility. *Proceedings of the National Academy of Sciences*, *103*(18), 7186-7191.

Bailey, C. E. (2007). Cognitive accuracy and intelligent executive function in the brain and in business. *Annals of the New York Academy of Sciences*, *1118*(1), 122-141.

Baltes, P. B., Staudinger, U. M., & Lindenberger, U. (1999). Lifespan psychology: Theory and application to intellectual functioning. *Annual review of psychology*, *50*(1), 471-507.

Bamidis, P. D., Fissler, P., Papageorgiou, S. G., Zilidou, V., Konstantinidis, E. I., Billis, A. S., ... & Tsilikopoulou, G. (2015). Gains in cognition through combined cognitive and physical training: the role of training dosage and severity of neurocognitive disorder. *Frontiers in Aging Neuroscience*, *7*, 152.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review*, *84*(2), 191.

Basso, J. C., & Suzuki, W. A. (2017). The effects of acute exercise on mood, cognition, neurophysiology, and neurochemical pathways: a review. *Brain Plasticity*, *2*(2), 127-152.

Basso, J. C., Shang, A., Elman, M., Karmouta, R., & Suzuki, W. A. (2015). Acute exercise improves prefrontal cortex but not hippocampal function in healthy adults. *Journal of the International Neuropsychological Society*, *21*(10), 791-801.

Beatty, G. F., Fawver, B., Hancock, G. M., & Janelle, C. M. (2014). Regulating emotions uniquely modifies reaction time, rate of force production, and accuracy of a goal-directed motor action. *Human movement science*, *33*, 1-13.

Bédard, P., & Sanes, J. N. (2014). Brain representations for acquiring and recalling visual–motor adaptations. *Neuroimage*, *101*, 225-235.

Beilock, S. (2010). *Choke: What the secrets of the brain reveal about getting it right when you have to*. Simon and Schuster.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied*, *8*(1), 6.

Bell, J. J., & Hardy, J. (2009). Effects of attentional focus on skilled performance in golf. *Journal of Applied Sport Psychology*, *21*(2), 163-177.

Berchtold, N. C., Chinn, G., Chou, M., Kesslak, J. P., & Cotman, C. W. (2005). Exercise primes a molecular memory for brain-derived neurotrophic factor protein induction in the rat hippocampus. *Neuroscience*, *133*(3), 853-861.

Bherer, L., Erickson, K. I., & Liu-Ambrose, T. (2013). A Review of the Effects of Physical Activity and Exercise on Cognitive and Brain Functions in Older Adults. *Journal of Aging Research,* 2013.

Bledowski, C., Prvulovic, D., Hoechstetter, K., Scherg, M., Wibral, M., Goebel, R., & Linden, D. E. (2004). Localizing P300 generators in visual target and distractor processing: a combined event-related potential and functional magnetic resonance imaging study. *Journal of Neuroscience*, *24*(42), 9353-9360.

Blumenthal, J. A., Babyak, M. A., Doraiswamy, P. M., Watkins, L., Hoffman, B. M., Barbour, K. A., ... & Hinderliter, A. (2007). Exercise and pharmacotherapy in the treatment of major depressive disorder. *Psychosomatic medicine*, *69*(7), 587.

Bock, O., & Girgenrath, M. (2006). Relationship between sensorimotor adaptation and cognitive functions in younger and older subjects. *Experimental Brain Research*, *169*(3), 400-406.

Bock, O., Schneider, S., & Bloomberg, J. (2001). Conditions for interference versus facilitation during sequential sensorimotor adaptation. *Experimental Brain Research*, *138*(3), 359-365.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in cognitive sciences*, *8*(12), 539-546.

Brashers-Krug, T., Shadmehr, R., & Bizzi, E. (1996). Consolidation in human motor memory. *Nature*, *382*(6588), 252-255.

Brennan, M., Welsh, M. C., & Fisher, C. B. (1997). Aging and executive function skills: An examination of a community-dwelling older adult population. *Perceptual and motor skills*, *84*(3_suppl), 1187-1197.

Brown, B. S., Payne, T., Kim, C., Moore, G., Krebs, P., & Martin, W. (1979). Chronic response of rat brain norepinephrine and serotonin levels to endurance training. Journal of Applied Physiology, 46, 19–23.

Browne, R. A. V., Costa, E. C., Sales, M. M., Fonteles, A. I., Moraes, J. F. V. N. D., & Barros, J. D. F. (2016). Acute effect of vigorous aerobic exercise on the inhibitory control in adolescents. *Revista Paulista de Pediatria*, *34*(2), 154-161.

Brunia, C. H. M., & Damen, E. J. P. (1988). Distribution of slow brain potentials related to motor preparation and stimulus anticipation in a time estimation task. *Electroencephalography and clinical neurophysiology*, *69*(3), 234-243.

Buch, E. R., Young, S., & Contreras-Vidal, J. L. (2003). Visuomotor adaptation in normal aging. *Learning & memory*, *10*(1), 55-63.

Buckner, R. L. (2004). Memory and executive function in aging and AD: multiple factors that cause decline and reserve factors that compensate. *Neuron*, *44*(1), 195-208.

Bunge, S. A., Dudukovic, N. M., Thomason, M. E., Vaidya, C. J., & Gabrieli, J. D. (2002). Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. *Neuron*, *33*(2), 301-311.

Cabello, R., Navarro, B., Latorre, J. M., & Fernández-Berrocal, P. (2014). Ability of university-level education to prevent age-related decline in emotional intelligence. *Frontiers in Aging Neuroscience*, *6*, 37.

Canavan, A. G. M., Passingham, R. E., Marsden, C. D., Quinn, N., Wyke, M., & Polkey, C. E. (1990). Prism adaptation and other tasks involving spatial abilities in patients with Parkinson's disease, patients with frontal lobe lesions and patients with unilateral temporal lobectomies. *Neuropsychologia*, *28*(9), 969-984.

Canavan, A.G., Passingham, R.E., Marsden, C.D., Quinn, N., Wyke, M., and

Carr, L. A., Nigg, J. T., & Henderson, J. M. (2006). Attentional versus motor inhibition in adults with attention-deficit/hyperactivity disorder. *Neuropsychology*, *20*(4), 430.

Carron, A. V., & Morford, W. R. (1968). Anxiety, stress and motor learning. *Perceptual and motor skills*, *27*(2), 507-511.

Carter, M. J., Smith, V., & Ste-Marie, D. M. (2016). Judgments of learning are significantly higher following feedback on relatively good versus relatively poor trials despite no actual learning differences. *Human movement science*, *45*, 63-70.

Cassidy, T., & Lynn, R. (1989). A multifactorial approach to achievement motivation: The development of a comprehensive measure. *Journal of Occupational Psychology.*

Celnik, P. (2015). Understanding and modulating motor learning with cerebellar stimulation. *The Cerebellum*, *14*(2), 171-174.

Center on Developing Child. (2019). retrieved from http://developingchild.harvard.edu/science/key-concepts/executive-function/

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain research*, *1453*, 87-101.

Chapman, B. P., Hayslip, B. (2006) Emotional intelligence in young and middle adulthood: Cross-sectional analysis of latent structure and means. Psychology and Aging 21(2): 411. doi:10.1037/0882-7974.21.2.411.

Chauvel, G., Wulf, G., & Maquestiaux, F. (2015). Visual illusions can facilitate sport skill learning. *Psychonomic bulletin & review*, *22*(3), 717-721.

Chen, D., & Singer, R. N. (1992). Self-regulation and cognitive strategies in sport participation. *International Journal of Sport Psychology*.

Chen, F. T., Chen, Y. P., Schneider, S., Kao, S. C., Huang, C. M., & Chang, Y. K. (2019). Effects of exercise modes on neural processing of working memory in late middle-aged adults: An fMRI study. *Frontiers in aging neuroscience*, *11*, 224.

Chen, H. H., Liu, Y. T., Mayer-Kress, G., & Newell, K. M. (2005). Learning the pedalo locomotion task. *Journal of Motor Behavior*, *37*(3), 247-256.

Chen, Y., Peng, Y., & Fang, P. (2016). Emotional intelligence mediates the relationship between age and subjective well-being. *The International Journal of Aging and Human Development*, *83*(2), 91-107.

Chiviacowsky, S., & Wulf, G. (2005). Self-controlled feedback is effective if it is based on the learner's performance. *Research quarterly for exercise and sport*, *76*(1), 42-48.

Chiviacowsky, S., Wulf, G., & Lewthwaite, R. (2012). Self-controlled learning: the importance of protecting perceptions of competence. *Frontiers in psychology*, *3*, 458.

Chiviacowsky, S., Wulf, G., & Lewthwaite, R. (2012). Self-controlled learning: the importance of protecting perceptions of competence. *Frontiers in psychology*, *3*, 458.

Chiviacowsky, S., Wulf, G., Lewthwaite, R., & Campos, T. (2012). Motor learning benefits of self-controlled practice in persons with Parkinson's disease. *Gait & Posture, 35,* 601–605.

Christensen, H., Henderson, A. S., Griffiths, K., & Levings, C. (1997). Does ageing inevitably lead to declines in cognitive performance? A longitudinal study of elite academics. *Personality and Individual Differences*, *23*(1), 67-78.

Christensen, H., Mackinnon, A. J., Korten, A. E., Jorm, A. F., Henderson, A. S., Jacomb, P., & Rodgers, B. (1999). An analysis of diversity in the cognitive performance of elderly community dwellers: Individual differences in change scores as a function of age. *Psychology and Aging, 14*(3), 365–379. https://doi.org/10.1037/0882-7974.14.3.365

Christou, A. I., Miall, R. C., McNab, F., & Galea, J. M. (2016). Individual differences in explicit and implicit visuomotor learning and working memory capacity. *Scientific reports*, *6*, 36633.

Chua, L. K., Wulf, G. & Lewthwaite, R. (2018). Onward and upward: Optimizing motor performance. *Human Movement Science*, *60*, 107–114. https://doi.org/10.1016/j.humov.2018.05.006

Circelli, K. S., Clark, U. S., & Cronin-Golomb, A. (2013). Visual scanning patterns and executive function in relation to facial emotion recognition in aging. *Aging, Neuropsychology, and Cognition*, *20*(2), 148-173.

Clark, S. E., & Ste-Marie, D. M. (2007). The impact of self-as-a-model interventions on children's self-regulation of learning and swimming performance. *Journal of sports sciences*, *25*(5), 577-586.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: a parallel distributed processing account of the Stroop effect. *Psychological review*, *97*(3), 332.

Cohen, J. R., Berkman, E. T., & Lieberman, M. D. (2012). Ventrolateral PFC as a self-control muscle and how to use it without trying. *Principles of Frontal Lobe Functions*.

Colcombe , S. J., Kramer, A. F., Erickson, K. I., Scalf, P., McAuley, E., Cohen, N. J., et al. (2004). Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National Academy of Sciences*, *101*, 3316–3321.

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

Cole, K. R. & Shields, R. K. (2019). Age and Cognitive Stress Influences Motor Skill Acquisition, Consolidation, and Dual-Task Effect in Humans. *Journal of Motor Behavior, 51(6)*, 622-639, DOI: 10.1080/00222895.2018.1547893

Collins, A., & Koechlin, E. (2012). Reasoning, learning, and creativity: frontal lobe function and human decision-making. PLoS biology, 10(3), e1001293.

Coombes, S. A., Corcos, D. M., Pavuluri, M. N., & Vaillancourt, D. E. (2012). Maintaining force control despite changes in emotional context engages dorsomedial prefrontal and premotor cortex. *Cerebral cortex*, *22*(3), 616-627.

Coombes, S. A., Janelle, C. M., & Duley, A. R. (2005). Emotion and motor control: Movement attributes following affective picture processing. *Journal of motor behavior*, *37*(6), 425-436.

Cothros, N., Köhler, S., Dickie, E. W., Mirsattari, S. M., & Gribble, P. L. (2006). Proactive interference as a result of persisting neural representations of previously learned motor skills in primary motor cortex. *Journal of cognitive neuroscience*, *18*(12), 2167-2176.

Cothros, N., Köhler, S., Dickie, E. W., Mirsattari, S. M., & Gribble, P. L. (2006). Proactive interference as a result of persisting neural representations of previously learned motor skills in primary motor cortex. *Journal of cognitive neuroscience*, *18*(12), 2167-2176.

Cotman, C. W., & Engesser-Cesar, C. (2002). Exercise enhances and protects brain function. Exercise and Sport Sciences Reviews, 30, 75–79.

Crawford, J. R., Bryan, J., Luszcz, M. A., Obonsawin, M. C., & Stewart, L. (2000). The executive decline hypothesis of cognitive aging: Do executive deficits qualify as differential deficits and do they mediate age-related memory decline?. *Aging, Neuropsychology, and Cognition*, *7*(1), 9-31.

Csikszentmihalyi, M. (1990). Flow. The Psychology of Optimal Experience. New York (HarperPerennial) 1990.

Dai, C. T., Chang, Y. K., satts, C. J., & Hung, T. M. (2013). Exercise mode and executive function in older adults: an ERP study of task-switching. *Brain and cognition*, *83*(2), 153-162.

Daigneault, S., & Braun, C. M. (1993). Working memory and the self-ordered pointing task: Further evidence of early prefrontal decline in normal aging. *Journal of clinical and Experimental Neuropsychology*, *15*(6), 881-895.

Dajani, D. R., & Uddin, L. Q. (2015). Demystifying cognitive flexibility: Implications for clinical and developmental neuroscience. *Trends in neurosciences*, *38*(9), 571-578.

Dal Maso, F., Desormeau, B., Boudrias, M. H., & Roig, M. (2018). Acute cardiovascular exercise promotes functional changes in cortico-motor networks during the early stages of motor memory consolidation. *NeuroImage*, *174*, 380-392.

Day, A. L., and Carroll, S. A. (2004). Using an ability-based measure of emotional intelligence to predict individual performance, group performance, and group citizenship behaviours. *Pers. Indiv. Differ*. 36, 1443–1458. doi: 10.1016/S0191-8869(03)00240-X

de Bruin, N., Bryant, D. C., MacLean, J. N., & Gonzalez, C. L. (2016). Assessing visuospatial abilities in healthy aging: a novel visuomotor task. *Frontiers in aging neuroscience*, *8*, 7.

De Luca d'Alessandro, E., Bonacci, S., & Giraldi, G. (2011). Aging populations: the health and quality of life of the elderly. *La Clinica Terapeutica*, *162*(1), e13-8.

Deci, E. L., & Ryan, R. M. (2008). Self-determination theory: A macrotheory of human motivation, development, and health. *Canadian psychology/Psychologie canadienne*, *49*(3), 182.

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*, 135-168.

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental cognitive neuroscience*, *18*, 34-48.

Dichter GS, van der Stelt O, Boch JL, Belger A. Relations among intelligence, executive function, and P300 event related potentials in schizophrenia. J Nerv Ment Dis. 2006;194:179–87

Dietrich, A. (2006). Transient hypofrontality as a mechanism for the psychological

Donchin, E., & Coles, M. G. (1988). Is the P300 component a manifestation of context updating?. *Behavioral and brain sciences*, *11*(3), 357-374.

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., ... & Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Medicine and science in sports and exercise*, *48*(6), 1197.

Du, X., Choa, F. S., Summerfelt, A., Rowland, L. M., Chiappelli, J., Kochunov, P., & Hong, L. E. (2017). N100 as a generic cortical electrophysiological marker based on decomposition of TMS-evoked potentials across five anatomic locations.

Experimental brain research, *235*(1), 69–81. https://doi.org/10.1007/s00221-016-4773-7

Duchesne, C., Lungu, O., Nadeau, A., Robillard, M. E., Boré, A., Bobeuf, F., ... & Doyon, J. (2015). Enhancing both motor and cognitive functioning in Parkinson's disease: aerobic exercise as a rehabilitative intervention. *Brain and cognition, 99*, 68-77.

Dulas, M. R., & Duarte, A. (2016). Age-related changes in overcoming proactive interference in associative memory: The role of PFC-mediated executive control processes at retrieval. *NeuroImage, 132,* 116-128.

Ebbesen BL, et al. Effects of acute exercise on cardiovascular reactivity. J Behav Med. 1992;15(5):489-507.

Ebbesen, B. L., Prkachin, K. M., Mills, D. E., & Green, H. J. (1992). Effects of acute exercise on cardiovascular reactivity. *Journal of Behavioral Medicine, 15(5),* 489-507.

effects of exercise. *Psychiatry Res*. *145*, 79–83. doi: 10.1016/j.psychres.2005.

Ehsani, F., Abdollahi, I., Mohseni Bandpei, M. A., Zahiri, N., & Jaberzadeh, S. (2015). Motor Learning and Movement Performance: Older versus Younger Adults. *Basic and clinical neuroscience*, *6*(4), 231–238.

Emanuel, M., Jarus, T., & Bart, O. (2008). Effect of focus of attention and age on motor acquisition, retention, and transfer: a randomized trial. *Physical therapy*, *88*(2), 251-260.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of learning and motivation*, *44*, 145-200.

Erickson, K. I., & Kramer, A. F. (2009). Aerobic exercise effects on cognitive and neural plasticity in older adults. *British journal of sports medicine, 43(1)*, 22-24.

Etkin A., Egner T., Kalisch R. (2011). Emotional processing in anterior cingulate and medial prefrontal cortex. Trends Cogn Sci, 15(2), 85-93.

Etnier, J. L., & Landers, D. M. (1998). Motor performance and motor learning as a function of age and fitness. *Research Quarterly for Exercise and Sport*, *69*(2), 136-146.

Eversheim, U., & Bock, O. (2001). Evidence for processing stages in skill acquisition: a dual-task study. *Learning & Memory*, *8*(4), 183-189.

Farrelly, D., & Austin, E. J. (2007). Ability EI as an intelligence? Associations of the MSCEIT with performance on emotion processing and social tasks and with cognitive ability. *Cognition and Emotion*, *21*(5), 1043-1063.

Fasoli, S. E., Trombly, C. A., Tickle-Degnen, L., & Verfaellie, M. H. (2002). Effect of instructions on functional reach in persons with and without cerebrovascular accident. *American Journal of Occupational Therapy*, *56*(4), 380-390.

Feltz, D. L., Chow, G. M., & Hepler, T. J. (2008). Path analysis of self-efficacy and diving performance revisited. *Journal of Sport and Exercise Psychology*, *30*(3), 401-411.

Fernández-Ruiz, J., Hall, C., Vergara, P., & Dıaz, R. (2000). Prism adaptation in normal aging: slower adaptation rate and larger aftereffect. *Cognitive Brain Research*, *9*(3), 223-226.

Fisk, J. E., & Warr, P. (1996). Age and working memory: The role of perceptual speed, the central executive, and the phonological loop. *Psychology and aging*, *11*(2), 316.

Floyer-Lea, A., & Matthews, P. M. (2005). Distinguishable brain activation networks for short-and long-term motor skill learning. *Journal of neurophysiology*, *94*(1), 512-518.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*(1), 152-170.

Ford, P., Hodges, N. J., & Williams, A. M. (2005). Online attentional-focus manipulations in a soccer-dribbling task: Implications for the proceduralization of motor skills. *Journal of motor behavior*, *37*(5), 386-394.

Friedman, N. P., & Miyake, A. (2004). The Relations among Inhibition and Interference Control Functions: A Latent-Vari- able Analysis. Journal of Experimental Psychology: General, 133, 101-135. http://dx.doi.org/10.1037/0096-3445.133.1.101

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General, 137*(2), 201-225. doi:http://services.lib.mtu.edu:2080/10.1037/0096-3445.137.2.201

Fujiyama, H., Garry, M. I., Levin, O., Swinnen, S. P., & Summers, J. J. (2009). Age-related differences in inhibitory processes during interlimb coordination. *Brain research*, *1262*, 38-47.

Galdona N, Martínez-Taboada C, Etxeberria I, et al. Positive aging: the relationship between emotional intelligence and psychological, social and physical wellbeing. *MOJ Gerontol Ger.* 2018;3(1):9–11. DOI: 10.15406/mojgg.2018.03.00073

Galea, J. M., Vazquez, A., Pasricha, N., Orban de Xivry, J. J., & Celnik, P. (2011). Dissociating the roles of the cerebellum and motor cortex during adaptive learning: the motor cortex retains what the cerebellum learns. *Cerebral cortex*, *21*(8), 1761-1770.

Gamboz N, Russo R, Fox E. 2002. Age differences and the identity negative priming effect: an updated meta-analysis. Psychol. Aging 17:525–31

Gao, F., Edden, R. A., Li, M., Puts, N. A., Wang, G., Liu, C., ... & Wang, X. (2013). Edited magnetic resonance spectroscopy detects an age-related decline in brain GABA levels. *Neuroimage*, *78*, 75-82.

Gardner KJ, Qualter P. Factor structure, measurement invariance and structural invariance of the MSCEIT V2.0. *Pers Indiv Diff.* 2011;51(4):492–496.

Giles, G. E., Eddy, M. E., Brunyé, T. T., Urry, H. L., Graber, H. L., Barbour, R. L., ... & Kanarek, R. B. (2018). Endurance exercise enhances emotional valence and emotion regulation. *Frontiers in human neuroscience, 12,* 398.

Goble, D. J., Coxon, J. P., Van Impe, A., De Vos, J., Wenderoth, N., & Swinnen, S. P. (2010). The neural control of bimanual movements in the elderly: Brain regions exhibiting age-related increases in activity, frequency-induced neural modulation, and task-specific compensatory recruitment. *Human brain mapping*, *31*(8), 1281-1295.

Goedert, K. & Willingham D. B. (2002). Patterns of Interference in Sequence Learning and Prism Adaptation Inconsistent With the Consolidation Hypothesis. *Learning & Memory, 9*, 279-292.

Goldberg, S., Smith, G. S., Barnes, A., Ma, Y., Kramer, E., Robeson, K., ... & Eidelberg, D. (2004). Serotonin modulation of cerebral glucose metabolism in normal aging. *Neurobiology of aging*, *25*(2), 167-174.

Gomez-Pinilla, F., & Hillman, C. (2013). The influence of exercise on cognitive abilities. *Comprehensive Physiology*, *3*(1), 403-428.

Good, C. D., Johnsrude, I. S., Ashburner, J., Henson, R. N., Friston, K. J., & Frackowiak, R. S. (2001). A voxel-based morphometric study of ageing in 465 normal adult human brains. *Neuroimage*, *14*(1), 21-36.

Graydon, F. X., Friston, K. J., Thomas, C. G., Brooks, V. B., & Menon, R. S. (2005). Learning-related fMRI activation associated with a rotational visuo-motor transformation. *Cognitive brain research*, *22*(3), 373-383.

Greenwood, B. N., Spence, K. G., Crevling, D. M., Clark, P. J., Craig, W. C., & Fleshner, M. (2013). Exercise-induced stress resistance is independent of exercise controllability and the medial prefrontal cortex. *European Journal of Neuroscience*, *37*(3), 469-478.

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. *Journal of personality and social psychology*, *85*(2), 348.

Gruber, M. J., Ritchey, M., Wang, S. F., Doss, M. K., & Ranganath, C. (2016). Post-learning hippocampal dynamics promote preferential retention of rewarding events. *Neuron*, *89*(5), 1110-1120.

Gunning-Dixon, F. M., & Raz, N. (2000). The cognitive correlates of white matter abnormalities in normal aging: a quantitative review. *Neuropsychology*, *14*(2), 224.

Hansen, J. C., & Hillyard, S. A. (1983). Selective attention to multidimensional auditory stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *9*(1), 1.

Hansen, J. C., & Hillyard, S. A. (1988). Temporal dynamics of human auditory selective attention. *Psychophysiology*, *25*(3), 316-329.

Hanslmayr, S., Pastötter, B., Bäuml, K. H., Gruber, S., Wimber, M., & Klimesch, W. (2008). The electrophysiological dynamics of interference during the Stroop task. *Journal of cognitive neuroscience*, *20*(2), 215-225.

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In *Interference and inhibition in cognition* (pp. 175-204). Academic Press.

Harter, M. R., Miller, S. L., Price, N. J., LaLonde, M. E., & Keyes, A. L. (1989). Neural processes involved in directing attention. *Journal of Cognitive Neuroscience*, *1*(3), 223-237.

Haseltine W. A. (2018, April 2). *Aging Populations Will Challenge Healthcare Systems All Over the World*. Retrieved from https://www.forbes.com/sites/williamhaseltine/2018/04/02/aging-populations-will-challenge-healthcare-systems-all-over-the-world/#56b1b7ca2cc3

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of experimental psychology: Learning, memory, and cognition*, *17*(1), 163.

Hatta, A., Nishihira, Y., Kim, S. R., Kaneda, T., Kida, T., Kamijo, K., ... & Haga, S. (2005). Effects of habitual moderate exercise on response processing and cognitive processing in older adults. *The Japanese journal of physiology*, *55*(1), 29-36.

Hedden, T., & Gabrieli, J. D. (2004). Insights into the ageing mind: a view from cognitive neuroscience. *Nature reviews neuroscience*, *5*(2), 87-96.

Heise, K. F., Zimerman, M., Hoppe, J., Gerloff, C., Wegscheider, K., & Hummel, F. C. (2013). The aging motor system as a model for plastic changes of GABA-mediated intracortical inhibition and their behavioral relevance. *Journal of Neuroscience*, *33*(21), 9039-9049.

Herring, M. P., O'Connor, P. J., & Dishman, R. K. (2010). The effect of exercise training on anxiety symptoms among patients: a systematic review. *Archives of internal medicine*, *170*(4), 321-331.

Herring, M. P., O'Connor, P. J., & Dishman, R. K. (2010). The effect of exercise training on anxiety symptoms among patients: a systematic review. *Archives of internal medicine*, *170*(4), 321-331.

Heuer, H., & Hegele, M. (2008). Adaptation to visuomotor rotations in younger and older adults. *Psychology and Aging, 23*(1), 190–202. https://doi.org/10.1037/0882-7974.23.1.190

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. *Journal of neuroscience*, *28*(1), 91-99.

Hillman, C. H., Belopolsky, A. V., Snook, E. M., Kramer, A. F., & McAuley, E. (2004). Physical activity and executive control: implications for increased cognitive health during older adulthood. *Research quarterly for exercise and sport*, *75*(2), 176-185.

Hillman, C.H., Erickson, K.I., & Kramer, A.F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews. Neuroscience, 9,* 58–65, http://dx.doi.org/10.1038/nrn2298.

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*(3), 781-787.

Hogan, M. (2005). Physical and cognitive activity and exercise for older adults: a review. *International Journal of Aging & Human Development, 60*, 95–126.

Hooyman, A., Wulf, G., & Lewthwaite, R. (2014). Impacts of autonomy-supportive versus controlling instructional language on motor learning. *Human Movement Science*, *36*, 190-198.

Howard Jr, J. H., & Howard, D. V. (1997). Age differences in implicit learning of higher order dependencies in serial patterns. *Psychology and aging*, *12*(4), 634.

Howard, S. J., Johnson, J., & Pascual-Leone, J. (2014). Clarifying inhibitory control: Diversity and development of attentional inhibition. *Cognitive Development*, *31*, 1-21.

Hsieh, S. S., Huang, C. J., Wu, C. T., Chang, Y. K., & Hung, T. M. (2018). Acute Exercise Facilitates the N450 Inhibition Marker and P3 Attention Marker during Stroop Test in Young and Older Adults. *Journal of clinical medicine*, *7*(11), 391. https://doi.org/10.3390/jcm7110391

Huang, J., Hegele, M., & Billino, J. (2018). Motivational modulation of age-related effects on reaching adaptation. *Frontiers in Psychology*, *9*, 2285.

Huang, T. T., Liu, C. B., Tsai, Y. H., Chin, Y. F., & Wong, C. H. (2015). Physical fitness exercise versus cognitive behavior therapy on reducing the depressive symptoms among community-dwelling elderly adults: A randomized controlled trial. *International journal of nursing studies*, *52*(10), 1542-1552.

Huang, V. S., Haith, A., Mazzoni, P., & Krakauer, J. W. (2011). Rethinking motor learning and savings in adaptation paradigms: model-free memory for successful actions combines with internal models. *Neuron*, *70*(4), 787-801.

Hübner, L., Godde, B., & Voelcker-Rehage, C. (2018). Acute exercise as an intervention to trigger motor performance and EEG beta activity in older adults. *Neural Plasticity*, *2018*.

Hurtado, M. M., Triviño, M., Arnedo, M., Roldán. G. (2016). Are executive functions related to emotional intelligence? A correlational study in schizophrenia and borderline personality disorder. *Psychiatry Research, 246*, 84-88

Hutchinson, J. C., Sherman, T., Martinovic, N., & Tenenbaum, G. (2008). The effect of manipulated self-efficacy on perceived and sustained effort. *Journal of Applied Sport Psychology*, *20*(4), 457-472.

Im-Bolter, N., Johnson, J., Ling, D., & Pascual-Leone, J. (2015). Inhibition: Mental control process or mental resource?. *Journal of Cognition and Development*, *16*(4), 666-681.

Imamizu, H., Miyauchi, S., Tamada, T., Sasaki, Y., Takino, R., PuÈtz, B., ... & Kawato, M. (2000). Human cerebellar activity reflecting an acquired internal model of a new tool. *Nature*, *403*(6766), 192-195.

Imbir, K. K., Spustek, T., Duda, J., Bernatowicz, G., & Żygierewicz, J. (2017). N450 and LPC Event-Related Potential Correlates of an Emotional Stroop Task with Words Differing in Valence and Emotional Origin. *Frontiers in psychology*, *8*, 880. https://doi.org/10.3389/fpsyg.2017.00880

Inoue, K., Kawashima, R., Satoh, K., Kinomura, S., Sugiura, M., Goto, R., ... & Fukuda, H. (2000). A PET study of visuomotor learning under optical rotation. *Neuroimage*, *11*(5), 505-516.

Inoue, K., Kawashima, R., Satoh, K., Kinomura, S., Sugiura, M., Goto, R., ... & Fukuda, H. (2000). A PET study of visuomotor learning under optical rotation. *Neuroimage*, *11*(5), 505-516.

James, C., Bore, M., & Zito, S. (2012). Emotional intelligence and personality as predictors of psychological well-being. *Journal of Psychoeducational Assessment*, *30*(4), 425-438.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy. *Handbook of personality: Theory and research*, *3*(2), 114-158.

Johnson R. (1993). On the neural generators of the P300 component of the event-related potential. *Psychophysiology, 30*, 90–97

K.Rabe, O. Livne, E. R. Gizewski et al., "Adaptation to visuomotor rotation and force field perturbation is correlated to different brain areas in patients with cerebellar degeneration," Journal of Neurophysiology, vol. 101, no. 4, pp. 1961–1971, 2009.

Kaliman P, Párrizas M, Lalanza JF, Camins A, Escorihuela RM, Pallàs M. Neurophysiological and epigenetic effects of physical exercise on the aging process. Ageing Res Rev. 2011;10:475–86.

Keisler, A., & Shadmehr, R. (2010). A shared resource between declarative memory and motor memory. *Journal of Neuroscience*, *30*(44), 14817-14823.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of exercise on the cognitive functioning of healthy older adults: a systematic review and meta-analysis. *Ageing research reviews, 16,* 12-31.

Kimura, K., Obuchi, S., Arai, T., Nagasawa, H., Shiba, Y., Watanabe, S., et al. (2010). The influence of short-term strength training on health-related quality of life and executive cognitive function. *J. Physiol. Anthropol. 29*, 95–101. doi:10.2114/jpa2.29.95

King, A. C., Taylor, C. B., & Haskell, W. L. (1993). Effects of differing intensities and formats of 12 months of exercise training on psychological outcomes in older adults. *Health Psychology, 12*(4), 292-300. http://dx.doi.org/10.1037/0278-6133.12.4.292

King, B. R., Hoedlmoser, K., Hirschauer, F., Dolfen, N., & Albouy, G. (2017). Sleeping on the motor engram: the multifaceted nature of sleep-related motor memory consolidation. *Neuroscience & Biobehavioral Reviews*, *80*, 1-22.

Kirk-Sanchez, N. J., & McGough, E. L. (2013). Physical exercise and cognitive performance in the elderly: current perspectives. *Clinical Interventions in Aging*, *9*, 51–62.

Kirschbaum, C., Pirke, K., & Hellhammer, D. H. (1993). The "Trier Social Stress Test"—A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology, 28,* 76–81.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, *38*(3), 557-577.

Kornhuber, H. H., & Deecke, L. (1965). Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. [Changes in the Brain Potential in Voluntary Movements and Passive Movements in Man: Readiness Potential and Reafferent Potentials]. *Pflüger's Archiv für die gesamte Physiologie des Menschen und der Tiere*, *284*(1), 1-17.

Koydemir, S., & Schütz, A. (2012). Emotional intelligence predicts components of subjective well-being beyond personality: A two-country study using self-and informant reports. *The Journal of Positive Psychology*, *7*(2), 107-118.

Krakauer, J. W. & Shadmehr R. (2006). Consolidation of motor memory. *Trends in Neurosciences, 29,* 58-64.

Krakauer, J. W. (2009). Motor learning and consolidation: the case of visuomotor rotation. In *Progress in motor control* (pp. 405-421). Springer, Boston, MA.

Krakauer, J. W., Ghilardi, M. F., Mentis, M., Barnes, A., Veytsman, M., Eidelberg, D., & Ghez, C. (2004). Differential cortical and subcortical activations in learning rotations and gains for reaching: a PET study. *Journal of neurophysiology*, *91*(2), 924-933.

Kramer, A. F., & Erickson, K. I. (2007). Effects of physical activity on cognition, well-being, and brain: human interventions. *Alzheimer's & Dementia*, *3*(2), S45-S51.

Krigolson, O. E., Cheng, D., & Binsted, G. (2015). The role of visual processing in motor learning and control: Insights from electroencephalography. *Vision Research*, *110*, 277-285.

Kroll, W., & Clarkson, P. M. (1978). Age, isometric knee extension strength, and fractionated resisted response time. *Experimental Aging Research, 4*(5), 389-409.

Kuhn, Y. A., Keller, M., Ruffieux, J., & Taube, W. (2017). Adopting an external focus of attention alters intracortical inhibition within the primary motor cortex. *Acta Physiologica*, *220*(2), 289-299.

Lamar, M., Cutter, W. J., Rubia, K., Brammer, M., Daly, E. M., Craig, M. C., ... & Murphy, D. G. (2009). 5-HT, prefrontal function and aging: fMRI of inhibition and acute tryptophan depletion. *Neurobiology of Aging*, *30*(7), 1135-1146.

Lang, M., Lang, W., Uhl, F., Kornhuber, A., Deecke, L., & Kornhuber, H. H. (1987). Slow negative potential shifts indicating verbal cognitive learning in a concept formation task. *Human Neurobiology*.

Lang, W., Lang, M., Uhl, F., Koska, C., Kornhuber, A., & Deecke, L. (1988). Negative cortical DC shifts preceding and accompanying simultaneous and sequential finger movements. *Experimental Brain Research*, *71*(3), 579-587.

Langan, J., & Seidler, R. D. (2011). Age differences in spatial working memory contributions to visuomotor adaptation and transfer. *Behavioural brain research*, *225*(1), 160-168.

Langenecker, S. A., Bieliauskas, L. A., Rapport, L. J., Zubieta, J. K., Wilde, E. A., & Berent, S. (2005). Face emotion perception and executive functioning deficits in depression. *Journal of clinical and experimental neuropsychology*, *27*(3), 320-333.

Larson, M. J., Clayson, P. E., & Clawson, A. (2014). Making sense of all the conflict: a theoretical review and critique of conflict-related ERPs. *International Journal of Psychophysiology*, *93*(3), 283-297.

Laufer, Y., Rotem-Lehrer, N., Ronen, Z., Khayutin, G., & Rozenberg, I. (2007). Effect of attention focus on acquisition and retention of postural control following ankle sprain. *Archives of physical medicine and rehabilitation*, *88*(1), 105-108.

Lawrence, G. P., Gottwald, V. M., Hardy, J., & Khan, M. A. (2011). Internal and external focus of attention in a novice form sport. *Research quarterly for exercise and sport*, *82*(3), 431-441.

Legault, L., & Inzlicht, M. (2013). Self-determination, self-regulation, and the brain: Autonomy improves performance by enhancing neuroaffective responsiveness to self-regulation failure. *Journal of personality and social psychology*, *105*(1), 123.

Lemos, A., Wulf, G., Lewthwaite, R., & Chiviacowsky, S. (2017). Autonomy support enhances performance expectancies, positive affect, and motor learning. *Psychology of Sport and Exercise*, *31*, 28-34.

Leow, L. A., De Rugy, A., Loftus, A. M., & Hammond, G. (2013). Different mechanisms contributing to savings and anterograde interference are impaired in Parkinson's disease. *Frontiers in human neuroscience*, *7*, 55.

Levin O, Fujiyama H, Boisgontier MP, Swinnen SP, Summers JJ. Aging and motor inhibition: a converging perspective provided by brain stimulation and imaging approaches. Neurosci Biobehav Rev. 2014;43:100–17.

Levin, O., & Netz, Y. (2015). Aerobic training as a means to enhance inhibition: what’s yet to be studied?. *European Review of Aging and Physical Activity*, *12*(1), 14.

Lewthwaite, R., & Wulf, G. (2010). Social-comparative feedback affects motor skill learning. *Quarterly journal of experimental psychology*, *63*(4), 738-749.

Lewthwaite, R., & Wulf, G. (2017). Optimizing motivation and attention for motor performance and learning. *Current Opinion in Psychology, 16*, 38–42. http://dx.doi.org/10.1016/j.copsyc.2017.04.005.

Liotti, M., Woldorff, M. G., Perez III, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*(5), 701-711.

Liston, C., McEwen, B. S., & Casey, B. J. (2009). Psychosocial stress reversibly disrupts prefrontal processing and attentional control. *Proceedings of the National Academy of Sciences*, *106*(3), 912-917.

Lloyd, B. A., Hake, H. S., Ishiwata, T., Farmer, C. E., Loetz, E. C., Fleshner, M., ... & Greenwood, B. N. (2017). Exercise increases mTOR signaling in brain regions involved in cognition and emotional behavior. *Behavioural brain research*, *323*, 56-67.

Logie, R. H., Cocchini, G., Delia Sala, S., & Baddeley, A. D. (2004). Is there a specific executive capacity for dual task coordination? Evidence from Alzheimer's disease. *Neuropsychology*, *18*(3), 504.

Luck, S. J. (2005). An introduction to event related potentials and their neural origins. *An introduction to the event related potential technique*, *11*.

Luck, S. J., Heinze, H. J., Mangun, G. R., & Hillyard, S. A. (1990). Visual event-related potentials index focused attention within bilateral stimulus arrays. II. Functional dissociation of P1 and N1 components. *Electroencephalography and clinical neurophysiology*, *75*(6), 528-542.

Ludyga, S., Gerber, M., Brand, S., Holsboer-Trachsler, E., & Pühse, U. (2016). Acute effects of moderate aerobic exercise on specific aspects of executive function in different age and fitness groups: A meta-analysis. *Psychophysiology*, *53*(11), 1611-1626.

Lundqvist, D., Flykt, A., & Ohman, A. (1998). Karolinska directed emotional faces [database of standardized facial images]. Psychology Section, Department of Clinical Neuroscience, Karolinska Hospital, S-171, 76.

Lunt, L., Bramham, J., Morris, R. G., Bullock, P. R., Selway, R. P., Xenitidis, K., & David, A. S. (2012). Prefrontal cortex dysfunction and 'jumping to conclusions': bias or deficit?. *Journal of Neuropsychology*, *6*(1), 65-78.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, *288*(5472), 1835-1838.

MacPherson, S. E., Phillips, L. H., & Della Sala, S. (2002). Age, executive function and social decision making: a dorsolateral prefrontal theory of cognitive aging. *Psychology and aging*, *17*(4), 598.

MacRae, P. G., Spirduso, W. W., Cartee, G. D., Farrar, R. P.,&Wilcox, R. E. (1987). Endurance training effects on striatal D2 dopamine receptor binding and striatal dopamine metabolite levels. Neuroscience Letters, 79, 138–144.

Mandolesi, L., Polverino, A., Montuori, S., Foti, F., Ferraioli, G., Sorrentino, P., & Sorrentino, G. (2018). Effects of physical exercise on cognitive functioning and wellbeing: biological and psychological benefits. *Frontiers in psychology*, *9*.

Mang, C. S., Brown, K. E., Neva, J. L., Snow, N. J., Campbell, K. L., & Boyd, L. A. (2016). Promoting motor cortical plasticity with acute aerobic exercise: a role for cerebellar circuits. *Neural plasticity*, *2016*.

Mang, C. S., Snow, N. J., Campbell, K. L., Ross, C. J., & Boyd, L. A. (2014). A single bout of high-intensity aerobic exercise facilitates response to paired associative stimulation and promotes sequence-specific implicit motor learning. *Journal of applied physiology*, *117*(11), 1325-1336.

Marchant, D., Greig, M., & Scott, C. (2008). Attentional focusing strategies influence muscle activity during isokinetic biceps curls. *Athletic Insight: The Online Journal of Sport Psychology*.

Markela-Lerenc, J., Ille, N., Kaiser, S., Fiedler, P., Mundt, C., & Weisbrod, M. (2004). Prefrontal-cingulate activation during executive control: which comes first?. *Cognitive Brain Research*, *18*(3), 278-287.

Maroulakis E, Zervas Y. Effects of aerobic exercise on mood of adult women. Percept Mot Skills. 1993;76(3 Pt 1):795-801.

Masaki, H., & Sommer, W. (2012). Cognitive neuroscience of motor learning and motor control. *The Journal of Physical Fitness and Sports Medicine*, *1*(3), 369-380.

Masters, R. S. W., & Maxwell, J. P. (2004). Implicit motor learning, reinvestment and movement disruption: What you don't know won't hurt you. In A. M. Williams & N. J. Hodges (Eds.), *Skill Acquisition in Sport* (pp. 207–228). New York: Routledge.

Masters, R. S. W., Poolton, J. M., Maxwell, J. P., & Raab, M. (2008). Implicit motor learning and complex decision making in time-constrained environments. *Journal of Motor Behavior, 40(1)*, 71-79.

Masterson, J. (2015). The role of emotion, vision, and touch in movement learning neuroplasticity and the mirror neuron system. *International Journal of Complementary & Alternative Medicine*, *1*(2), 00008.

Maxwell, J. P. and Masters, R. S. W. 2002. External versus internal focus instructions: Is the learner paying attention?. *International Journal of Applied Sports Sciences*, 14: 70–88.

Maxwell, J. P., Masters, R. S., & Eves, F. F. (2000). From novice to no know-how: A longitudinal study of implicit motor learning. *Journal of sports sciences*, *18*(2), 111-120.

Mayer JD, Caruso DR, Salovey P. Selecting a measure of emotional intelligence: The case for ability scales. In: Bar-On, R Parker, editors. *The handbook of emotional intelligence: Theory, development, assessment, and application at home, school, and in the workplace*. CA: Jossey-Bass, USA; 2000. p. 320–342.

Mayer, J. D., Caruso, D. R., & Salovey, P. (1999). Emotional intelligence meets traditional standards for an intelligence. *Intelligence, 27,* 267–298.

Mayer, J. D., Caruso, D. R., Salovey, P. (2000) Selecting a measure of emotional intelligence: The case for ability scales. In: Bar-On, R., Parker, J. D. A. (eds) The handbook of emotional intelligence: Theory, development, assessment, and application at home, school, and in the workplace, San Francisco, CA: Jossey-Bass, pp. 320–342.

Mayer, J. D., Salovey, P. (1997). What is emotional intelligence?. In: Salovey, P., Sluyter, D. (Eds.), *Emotional Development and Emotional Intelligence: Implications for Educators*. Basic Books, Nueva York.

Mayer, J. D., Salovey, P., & Caruso, D. R. (2002). *MSCEIT user's manual*. Toronto: Multi-Health Systems.

McAlister, C., & Schmitter-Edgecombe, M. (2016). Executive function subcomponents and their relations to everyday functioning in healthy older adults. *Journal of clinical and experimental neuropsychology*, *38*(8), 925-940.

McCombs, B. L. (1989). Self-regulated learning and academic achievement: A phenomenological view. In *Self-regulated learning and academic achievement* (pp. 51-82). Springer, New York, NY.

McDougle, S. D., Bond, K. M., Taylor, J. A. (2015). Explicit and implicit processes constitute the fast and slow processes of sensorimotor learning. *Journal of Neuroscience, 35*, 9568–9579

McDougle, S. D., Ivry, R. B., Taylor, J. A. (2016). Taking aim at the cognitive side of learning in sensorimotor adaptation tasks. *Trends in Cognitive Science, 20,* 535–544

McNay, E. C., & Willingham, D. B. (1998). Deficit in learning of a motor skill requiring strategy, but not of perceptuomotor recalibration, with aging. *Learning & Memory*, *4*(5), 411-420.

McNevin, N. H., Shea, C. H. and Wulf, G. 2003. Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, 67: 22–29.

Mika, A., Bouchet, C. A., Bunker, P., Hellwinkel, J. E., Spence, K. G., Day, H. E., ... & Greenwood, B. N. (2015). Voluntary exercise during extinction of auditory fear conditioning reduces the relapse of fear associated with potentiated activity of striatal direct pathway neurons. *Neurobiology of learning and memory*, *125*, 224-235.

Miller, S. M., & Taylor-Piliae, R. E. (2014). Effects of Tai Chi on cognitive function in community-dwelling older adults: a review. Geriatric Nursing, 35(1), 9-19.

Mogenson, G. J., Jones, D. L., & Yim, C. Y. (1980). From motivation to action: functional interface between the limbic system and the motor system. *Progress in neurobiology*, *14*(2-3), 69-97.

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational research methods*, *11*(2), 364-386.

Morton, J. B., & Munakata, Y. (2002). Active versus latent representations: a model of perseveration, knowledge-action dissociation, and décalage. *Developmental Psychobiology*, *40*, 255-265.

Mueller, S. T. and Piper, B. J. (2014) The Psychology Experiment Building Language (PEBL) and PEBL Test Battery. *Journal of Neuroscience Methods, 222*, 250-259. Neurosci. Biobehav Rev., 80 (2017), pp. 1-22

Nguyen, M. H., & Kruse, A. (2012). A randomized controlled trial of Tai chi for balance, sleep quality and cognitive performance in elderly Vietnamese. *Clinical interventions in aging*, *7*, 185.

Niemann, C., Godde, B., & Voelcker-Rehage, C. (2014). Not only cardiovascular, but also coordinative exercise increases hippocampal volume in older adults. Frontiers in aging neuroscience, 6, 170. https://doi.org/10.3389/fnagi.2014.00170

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological bulletin*, *126*(2), 220.

Nigg, J. T., Butler, K. M., Huang-Pollock, C. L., & Henderson, J. M. (2002). Inhibitory processes in adults with persistent childhood onset ADHD. *Journal of consulting and clinical psychology*, *70*(1), 153.

O'Brien, J., Edwards, J., Maxfield, N., Karidas, S., Williams, V., & Lister, J. (2011). Effects of cognitive training on attention allocation and speed of processing in older adults: An ERP study. *Journal of Vision*, *11*(11), 203-203.

Ong, N. T., & Hodges, N. J. (2018). Balancing our perceptions of the efficacy of success-based feedback manipulations on motor learning. *Journal of motor behavior*, *50*(6), 614-630.

Ostadan, F., Centeno, C., Daloze, J. F., Frenn, M., Lundbye-Jensen, J., & Roig, M. (2016). Changes in corticospinal excitability during consolidation predict acute exercise-induced off-line gains in procedural memory. *Neurobiology of learning and memory*, *136*, 196-203.

Palidis, D. J., Cashaback, J., & Gribble, P. L. (2019). Neural signatures of reward and sensory error feedback processing in motor learning. *Journal of neurophysiology*, *121*(4), 1561–1574. https://doi.org/10.1152/jn.00792.2018

Palmer, B. R., Gignac, G., Manocha, R., and Stough, C. (2005). A psychometric evaluation of the Mayer–Salovey–Caruso Emotional intelligence test version 2.0. *Intelligence* 33, 285–305. doi: 10.1016/j.intell.2004.11.003

Parasuraman, R. (Ed.). (2000). *The attentive brain*. Mit Press.

Parsons, M. W., Harrington, D. L., & Rao, S. M. (2005). Distinct neural systems underlie learning visuomotor and spatial representations of motor skills. *Human brain mapping*, *24*(3), 229-247.

Parsons, M. W., Harrington, D. L., & Rao, S. M. (2005). Distinct neural systems underlie learning visuomotor and spatial representations of motor skills. *Human brain mapping*, *24*(3), 229-247.

Pascua, L. A. M., Wulf, G., & Lewthwaite, R. (2015). Additive benefits of external focus and enhanced performance expectancy for motor learning. *Journal of Sports Sciences, 33,* 58–66.

Pascua, L. A., Wulf, G., & Lewthwaite, R. (2015). Additive benefits of external focus and enhanced performance expectancy for motor learning. *Journal of sports sciences*, *33*(1), 58-66.

Patel, S. H., & Azzam, P. N. (2005). Characterization of N200 and P300: selected studies of the event-related potential. *International journal of medical sciences*, *2*(4), 147.

Perkins-Ceccato, N., Passmore, S. R., & Lee, T. D. (2003). Effects of focus of attention depend on golfers' skill. *Journal of sports sciences*, *21*(8), 593-600.

Phillips, L. H., Channon, S., Tunstall, M., Hedenstrom, A., & Lyons, K. (2008). The role of working memory in decoding emotions. *Emotion*, *8*(2), 184.
physical activity on cognition and brain function. *Trends in Cognitive Sciences, 11*(8),342–348.

Ploughman, M. (2008). Exercise is brain food: the effects of physical activity on cognitive function. *Developmental neurorehabilitation*, *11*(3), 236-240.

Polich J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Polich J. Updating P300: An integrative theory of P3a and P3b. Clin Neurophysiol. 2007;118:2128–48

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology*, *118*(10), 2128-2148.

Polkey, C.E. 1990. Prism adaptation and other tasks involving spatial abilities in patients with Parkinson's disease, patients with frontal lobe lesions and patients with unilateral temporal lobectomies. *Neuropsychologia* **28:** 969–984.

Pontifex, M. B., Hillman, C. H., & Polich, J. (2009). Age, physical fitness, and attention: P3a and P3b. *Psychophysiology*, *46*(2), 379-387.

Poolton, J. M., Maxwell, J. P., Masters, R. S. W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing?. *Journal of sports sciences*, *24*(1), 89-99.

Poolton, J. M., Maxwell, J. P., Masters, R. S. W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing?. *Journal of sports sciences*, *24*(1), 89-99.

Posner, M. I., & DiGirolamo, G. J. (1998). 1 8 Executive Attention: Conflict, Target Detection, and Cognitive Control.

Posner, M. I., & Raichle, M. E. (1994). Networks of attention. *Images of mind*, 153-179.

Postle, B. R., Brush, L. N., & Nick, A. M. (2004). Prefrontal cortex and the mediation of proactive interference in working memory. *Cognitive, Affective, & Behavioral Neuroscience*, *4*(4), 600-608.

Powers MB, Medina JL, Burns S, Kauffman BY, Monfils M, Asmundson GJ, Diamond A, McIntyre C, Smits JA. Exercise Augmentation of Exposure Therapy for PTSD: Rationale and Pilot Efficacy Data. Cogn Behav Ther. 2015:1–14.

Powers, M. B., Medina, J. L., Burns, S., Kauffman, B. Y., Monfils, M., Asmundson, G. J., ... & Smits, J. A. (2015). Exercise augmentation of exposure therapy for PTSD: rationale and pilot efficacy data. *Cognitive behaviour therapy*, *44*(4), 314-327.

Prinz, W. (1997). Perception and action planning. *European journal of cognitive psychology*, *9*(2), 129-154.

Rajeshkumar, L., & Trewartha, K. M. (2019). Advanced spatial knowledge of target location eliminates age-related differences in early sensorimotor learning. *Experimental brain Research*, 1-11.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings.

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

Raz, N., Lindenberger, U., Rodrigue, K. M., et al. (2005). Regional brain changes in aging healthy adults: General trends, individual differences, and modifiers. *Cerebral Cortex, 15*, 1676–1689.

Raz, N., Rodrigue, K. M., Head, D., Kennedy, K. M., & Acker, J. D. (2004). Differential aging of the medial temporal lobe: a study of a five-year change. *Neurology*, *62*(3), 433-438.

Rebai, M., Bernard, C., & Lannou, J. (1997). The Stroop's test evokes a negative brain potential, the N400. *International Journal of Neuroscience*, *91*(1-2), 85-94.

Reed J, Ones DS. The effect of acute aerobic exercise on positive activated affect: A meta-analysis. Psychology of Sport and Exercise. 2006;7(5):477-514.

Reed, J. & Ones, D. S. (2006). The effect of acute aerobic exercise on positive activated affect: A meta-analysis. *Psychology of Sport and Exercise, 7(5)*, 477-514

Rendeiro, C., & Rhodes, J. S. (2018). A new perspective of the hippocampus in the origin of exercise-brain interactions. *Brain Structure & Function*, *223(6)*, 2527–2545. https://doi.org/10.1007/s00429-018-1665-6

Reza Abdollahipour, William M. Land, Ana Cereser & Suzete Chiviacowsky (2019) External relative to internal attentional focus enhances motor performance and learning in visually impaired individuals, Disability and Rehabilitation, DOI: 10.1080/09638288.2019.1566408

Riggs, N. R., Blair, C. B., & Greenberg, M. T. (2004). Concurrent and 2-year longitudinal relations between executive function and the behavior of 1st and 2nd grade children. *Child Neuropsychology*, *9*(4), 267-276.

Riggs, N. R., Jahromi, L. B., Razza, R. P., Dillworth-Bart, J. E., & Mueller, U. (2006). Executive function and the promotion of social–emotional competence. *Journal of Applied Developmental Psychology*, *27*(4), 300-309.

Rigoli, D., Piek, J. P., Kane, R., & Oosterlaan, J. (2012). An examination of the relationship between motor coordination and executive functions in adolescents. *Developmental Medicine Child Neurology 54,* 1025-1031

Roberti, J. W., Harrington, L. N., & Storch, E. A. (2006). Further psychometric support for the 10-item version of the perceived stress scale. *Journal of College Counseling, 9(2)*, 135-147.

Roig M, Nordbrandt S, Geertsen SS, Nielsen JB. The effects of cardiovascular exercise on human memory: a review with meta-analysis. Neurosci Biobehav Rev. Elsevier Ltd; 2013;37: 1645–66.

Roig, M., Ritterband-Rosenbaum, A., Lundbye-Jensen, J., & Nielsen, J. B. (2014). Aging increases the susceptibility to motor memory interference and reduces off-line gains in motor skill learning. *Neurobiology of Aging*, *35*(8), 1892-1900.

Roig, M., Skriver, K., Lundbye-Jensen, J., Kiens, B., & Nielsen, J. B. (2012). A single bout of exercise improves motor memory. *PloS one*, *7*(9), e44594.

Roig, M., Thomas, R., Mang, C. S., Snow, N. J., Ostadan, F., Boyd, L. A., & Lundbye-Jensen, J. (2016). Time-dependent effects of cardiovascular exercise on memory. *Exercise and sport sciences reviews*, *44*(2), 81-88.Rösler, F., Heil, M., & Röder, B. (1997). Slow negative brain potentials as reflections of specific modular resources of cognition. *Biological psychology*, *45*(1-3), 109-141.

Roller, C. A., Cohen, H. S., Kimball, K. T., & Bloomberg, J. J. (2002). Effects of normal aging on visuo-motor plasticity. *Neurobiology of aging*, *23*(1), 117-123.

Rosenqvist, O., & Skans, O. N. (2015). Confidence enhanced performance?–The causal effects of success on future performance in professional golf tournaments. *Journal of Economic Behavior & Organization*, *117*, 281-295.

Rösler, F., Heil, M., & Röder, B. (1997). Slow negative brain potentials as reflections of specific modular resources of cognition. *Biological psychology*, *45*(1-3), 109-141.

Ruffman,T.,Henry,J.D.,Livingstone,V.,andPhillips,L.H.(2008).A meta- analytic review of emotion recognition and aging: implications for neuropsychological models of aging. *Neurosci.Biobehav.Rev.* 32, 863–881.doi: 10.1016/j.neubiorev.2008.01.001

Ruitenberg, M. F. L., Koppelmans, V., De Dios, Y. E., Gadd, N. E., Wood, S. J., Reuter-Lorenz, P. A., ... & Seidler, R. D. (2018). Neural correlates of multi-day learning and savings in sensorimotor adaptation. *Scientific reports*, *8*(1), 1-14.

Ryan, E. D. (1962). Effects of stress on motor performance and learning. Research Quarterly. American Association for Health, Physical Education and Recreation, 33(1), 111-119.

Saklofske, D. H., Austin, E. J., Galloway, J., & Davidson,K. (2007). Individual difference correlates of health-related behaviours: Preliminary evidence for linksbetween emotional intelligence and coping. Personalityand Individual Differences 42, 491–502.

Saklofske, D. H., Austin, E. J., Rohr, B. A., & Andrews, J. J. (2007). Personality, emotional intelligence and exercise. *Journal of health psychology*, *12*(6), 937-948.

Salthouse, T. A. (2017). Contributions of the individual differences approach to cognitive aging. *The Journals of Gerontology: Series B*, *72*(1), 7-15.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental psychology*, *27*(5), 763.

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

Sanders, L. M., Hortobágyi, T., la Bastide-van Gemert, S., van der Zee, E. A., & van Heuvelen, M. J. (2019). Dose-response relationship between exercise and cognitive function in older adults with and without cognitive impairment: a systematic review and meta-analysis. *PloS one*, *14*(1), e0210036.

Sattin, R. W., Easley, K. A., Wolf, S. L., Chen, Y., & Kutner, M. H. (2005). Reduction in fear of falling through intense tai chi exercise training in older, transitionally frail adults. *Journal of the American Geriatrics Society*, *53*(7), 1168-1178.

Sawaki, L., Yaseen, Z., Kopylev, L., & Cohen, L. G. (2003). Age-dependent changes in the ability to encode a novel elementary motor memory. *Annals of Neurology: Official Journal of the American Neurological Association and the Child Neurology Society*, *53*(4), 521-524.

Schmidt, R. A. (1988). Motor Control and Learning: A Behavioral Emphasis. Vol. 2. Champaign, IL: Human Kinetics.

Seidler, R. D. (2007). Aging affects motor learning but not savings at transfer of learning. *Learning & memory, 14*(1-2), 17-21.

Seidler, R. D. (2010). Neural correlates of motor learning, transfer of learning, and learning to learn. *Exercise and sport sciences reviews, 38*(1), 3.

Seidler, R. D., Bernard, J. A., Burutolu, T. B., Fling, B. W., Gordon, M. T., Gwin, J. T., ... & Lipps, D. B. (2010). Motor control and aging: links to age-related brain structural, functional, and biochemical effects. *Neuroscience & Biobehavioral Reviews*, *34*(5), 721-733.

Seidler, R. D., Bo, J., & Anguera, J. A. (2012). Neurocognitive contributions to motor skill learning: the role of working memory. *Journal of motor behavior*, *44*(6), 445-453.

Seidler, R. D., Noll, D. C., & Chintalapati, P. (2006). Bilateral basal ganglia activation associated with sensorimotor adaptation. *Experimental brain research*, *175*(3), 544-555.

Shadmehr R, Brashers-Krug T (1997) Functional stages in the formation of human long-term motor memory. J Neurosci 17: 409–419

Shadmehr R, Holcomb HH (1999) Inhibitory control of competing motor memories. Exp Brain Res 126:235–251

Shadmehr, R., & Mussa-Ivaldi, F. A. (1994). Adaptive representation of dynamics during learning of a motor task. *Journal of neuroscience*, *14*(5), 3208-3224.

Shomstein, S., & Johnson, J. (2013). Shaping attention with reward: Effects of reward on space-and object-based selection. *Psychological science*, *24*(12), 2369-2378.

Sibille, E., Su, J., Leman, S., Le Guisquet, A. M., Ibarguen-Vargas, Y., Joeyen-Waldorf, J., ... & Belzung, C. (2007). Lack of serotonin 1B receptor expression leads to age-related motor dysfunction, early onset of brain molecular aging and reduced longevity. *Molecular psychiatry*, *12*(11), 1042-1056.

Sibley, B.A., & Etnier, J.L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science, 15*(3), 243–256.

Sitnikova T., Kuperberg G., Holcomb P. J. (2003). Semantic integration in videos of real-world events: an electrophysiological investigation. Psychophysiology 40, 160–164 10.1111/1469-8986.00016

Sitnikova, T., Kuperberg, G., & Holcomb, P. J. (2003). Semantic integration in videos of real–world events: An electrophysiological investigation. *Psychophysiology*, *40*(1), 160-164.

Sliter, M., Chen, Y., Withrow, S., & Sliter, K. (2013). Older and (emotionally) smarter? Emotional intelligence as a mediator in the relationship between age and emotional labor strategies in service employees. *Experimental Aging Research*, *39*(4), 466-479.

Sliter, M., Chen, Y., Withrow, S., & Sliter, K. (2013). Older and (emotionally) smarter? Emotional intelligence as a mediator in the relationship between age and emotional labor strategies in service employees. *Experimental Aging Research*, *39*(4), 466-479.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science*, *283*(5408), 1657-1661.

Smith, M. A., Ghazizadeh, A., & Shadmehr, R. (2006). Interacting adaptive processes with different timescales underlie short-term motor learning. *PLoS Biol*, *4*(6), e179.

Spirduso, W. W. (1980). Physical fitness, aging, and psychomotor speed. *Journal of Gerontology, 35*, 850-865.

Spirduso, W. W. (1983). Exercise and the aging brain. *Research Quarterly for Exercise and Sport, 54*(2), 208-218.

Spirduso, W. W., MacCrae H. H., & Osborne, L. (1988). Exercise effects on aged motor function. *Annals of the New York Academy of Sciences, 515*, 363-375.

Spirduso, W.W. (1975). Reaction and movement time as a function of age and physical activity level. *Journal of Gerontology, 30,* 435–440.

Squires, N. K., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalography and clinical neurophysiology*, *38*(4), 387-401.

Stadler, M. A., & Frensch, P. A. (1998). *Handbook of implicit learning*. Sage Publications, Inc.

Statton, M. A., Encarnacion, M., Celnik, P., & Bastian, A. J. (2015). A single bout of moderate aerobic exercise improves motor skill acquisition. *PloS one*, *10*(10), e0141393.

Steib, S., Wanner, P., Adler, W., Winkler, J., Klucken, J., & Pfeifer, K. (2018). A single bout of aerobic exercise improves motor skill consolidation in Parkinson's disease. *Frontiers in aging neuroscience*, *10*, 328.

Stevens, D., Anderson, D. I., O'Dwyer, N. J., & Williams, A. M. (2012). Does self-efficacy mediate transfer effects in the learning of easy and difficult motor skills? Consciousness and Cognition, 21, 1122–1128.

Susceptibility to Memory Interference Effects following Frontal Lobe Damage: Findings from Tests of Paired-Associate Learning Arthur P. Shimamura, Paul J. Jurica, Jennifer A. Mangels, Felick B. Gershberg and Robert T. Knight

Tarasuik, J. C., Ciorciari, J., & Stough, C. (2009). Understanding the neurobiology of emotional intelligence: A review. In *Assessing Emotional Intelligence* (pp. 307-320). Springer, Boston, MA.

Taylor, J. A., & Thoroughman, K. A. (2007). Divided attention impairs human motor adaptation but not feedback control. *Journal of neurophysiology*, *98*(1), 317-326.

Taylor, J. A., & Thoroughman, K. A. (2008). Motor adaptation scaled by the difficulty of a secondary cognitive task. *PLoS One*, *3*(6), e2485.

Taylor, J. A., Ivry, R.B. (2011). Flexible cognitive strategies during motor learning. PLoS Comput Biol, 7, e1001096

Taylor, J. A., Krakauer, J. W., & Ivry, R. B. (2014). Explicit and implicit contributions to learning in a sensorimotor adaptation task. *Journal of Neuroscience*, *34*(8), 3023-3032.

Teulings, H. L., Contreras-Vidal, J. L., Stelmach, G. E., & Adler, C. H. (2002). Adaptation of handwriting size under distorted visual feedback in patients with Parkinson's disease and elderly and young controls. *Journal of Neurology, Neurosurgery & Psychiatry*, *72*(3), 315-324.

Themanson, J. R., & Rosen, P. J. (2015). Examining the relationships between self-efficacy, task-relevant attentional control, and task performance: Evidence from event-related brain potentials. *British Journal of Psychology*, *106*(2), 253-271.

Thomas, R., Beck, M. M., Lind, R. R., Korsgaard Johnsen, L., Geertsen, S. S., Christiansen, L., ... & Lundbye-Jensen, J. (2016). Acute exercise and motor memory consolidation: the role of exercise timing. *Neural plasticity*, *2016*.

Thomas, R., Johnsen, L. K., Geertsen, S. S., Christiansen, L., Ritz, C., Roig, M., & Lundbye-Jensen, J. (2016). Acute exercise and motor memory consolidation: the role of exercise intensity. *PloS one*, *11*(7), e0159589.

Toni, I., & Passingham, R. E. (1999). Prefrontal-basal ganglia pathways are involved in the learning of arbitrary visuomotor associations: a PET study. *Experimental Brain Research*, *127*(1), 19-32.

Trempe, M., Sabourin, M., & Proteau, L. (2012). Success modulates consolidation of a visuomotor adaptation task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(1), 52.

Trewartha, K. M., Garcia, A., Wolpert, D. M., Flanagan, J. R. (2014). Fast but fleeting: adaptive motor learning processes associated with aging and cognitive decline. *Journal of Neuroscience, 34,* 13411–13421

Troyer, A. K., Graves, R. E., & Cullum, C. M. (1994). Executive functioning as a mediator of the relationship between age and episodic memory in healthy aging. *Aging and Cogntion*, *1*(1), 45-53.

Tsaousis, I., & Kazi, S. (2013). Factorial invariance and latent mean differences of scores on trait emotional intelligence across gender and age. *Personality and Individual Differences*, *54*(2), 169-173.

Tsaousis, I., & Nikolaou, I. (2005). Exploring the rela-tionship of emotional intelligence with physical andpsychological health functioning. Stress and Health,21, 77–86.

Tseng, Y. W., Diedrichsen, J., Krakauer, J. W., Shadmehr, R., & Bastian, A. J. (2007). Sensory prediction errors drive cerebellum-dependent adaptation of reaching. *Journal of neurophysiology*, *98*(1), 54-62.

Tucker-Drob, E. M., & Salthouse, T. A. (2011). in Cognitive Aging. *The Wiley-Blackwell handbook of individual differences*, 242.

US Census Bureau. (2018). Older People Projected to Outnumber Children. *Available online: https://www.census.gov/newsroom/press-releases/2018/cb18-41-population-projections.html*

van Dinteren, R., Arns, M., Jongsma, M. L., & Kessels, R. P. (2014). P300 development across the lifespan: a systematic review and meta-analysis. *PloS one*, *9*(2), e87347. https://doi.org/10.1371/journal.pone.0087347

Van Hooff, J. C., Dietz, K. C., Sharma, D., & Bowman, H. (2008). Neural correlates of intrusion of emotion words in a modified Stroop task. *International journal of psychophysiology*, *67*(1), 23-34.

Van Rooy, D. L., Alonso, A., & Viswesvaran, C. (2005). Group differences in emotional intelligence scores: Theoretical and practical implications. *Personality and Individual differences*, *38*(3), 689-700.

Van Rooy, D. L., Alonso, A., Viswesvaran, C. (2005) Group differences in emotional intelligence scores: Theoretical and practical implications. Personality and Individual Differences 38(3): 689–700. doi:10.1016/j.paid.2004.05.023.

Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of motor behavior*, *36*(4), 450-459.

Voelcker-Rehage C, Niemann C. Structural and functional brain changes related to physical activity in different age groups. Neurosci Biobehav Rev. 2013;37:2268–95.

Voelcker-Rehage, C., & Niemann, C. (2013). Structural and functional brain changes related to different types of physical activity across the life span. *Neuroscience & Biobehavioral Reviews*, *37*(9), 2268-2295.

Voelcker-Rehage, C., Godde, B., & Staudinger, U. M. (2011). Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. *Frontiers in human Neuroscience*, *5*, 26.

Voelcker-Rehage,C.,Godde,B.,and Staudinger, U.M.(2010).Physical and motor fitness are both related to cognition in old age. Eur.J.Neurosci. 31, 167–176.doi:10.1111/j.1460-9568.2009.07014.x

Voelcker-Rehage,C.,Godde,B.,andStaudinger,U.M.(2011).Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. Front.Hum.Neurosci. 5:26. doi: 10.3389/fnhum.2011.00026

Volkow, N. D. *et al*. Measuring age-related changes in dopamine D2 receptors with 11C-raclopride and 18F-*N*methylspiroperidol. *Psychiatry Res.* **67**, 11–16 (1996).

Voss, M. W., Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. (2011). Exercise, brain, and cognition across the life span. *Journal of applied physiology*, *111*(5), 1505-1513.

Wais, P. E., Rubens, M. T., Boccanfuso, J., & Gazzaley, A. (2010). Neural mechanisms underlying the impact of visual distraction on retrieval of long-term memory. *Journal of Neuroscience*, *30*(25), 8541-8550.

Walter Schneider∗, Jason M. Chein. Cognitive Science 27 (2003) 525–559 Controlled & automatic processing: behavior, theory,and biological mechanisms

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: an electric sign of sensori-motor association and expectancy in the human brain. *Nature*, *203*(4943), 380-384.

Wang, J., Przybyla, A., Wuebbenhorst, K. *et al.* Aging reduces asymmetries in interlimb transfer of visuomotor adaptation. *Exp Brain Res* **210,** 283 (2011). https://doi.org/10.1007/s00221-011-2631-1

Watkins, D. (1984). Student perceptions of factors influencing tertiary learning. *Higher Education Research and Development*, *3*(1), 33-50.

Webb, C. A., Schwab, Z. J., Weber, M., DelDonno, S., Kipman, M., Weiner, M. R., & Killgore, W. D. (2013). Convergent and divergent validity of integrative versus mixed model measures of emotional intelligence. *Intelligence*, *41*(3), 149-156.

Welsh, M. C., & Pennington, B. F. (1988). Assessing frontal lobe functioning in children: Views from developmental psychology. *Developmental neuropsychology*, *4*(3), 199-230.

Welsh, M., Cicerello, A., Cuneo, K., & Brennan, M. (1995). Error and temporal patterns in Tower of Hanoi performance: Cognitive mechanisms and individual differences. *The Journal of General Psychology*, *122*(1), 69-81.

Willingham, D. B. (1998). A neuropsychological theory of motor skill learning. *Psychological review*, *105*(3), 558.

Willingham, D. B. (2001). Becoming aware of motor skill. *Trends in cognitive sciences*, *5*(5), 181-182.

Wise, R. A. (2004). Dopamine, learning and motivation. *Nature reviews neuroscience*, *5*(6), 483-494.

Witt, J. K., Linkenauger, S. A., & Proffitt, D. R. (2012). Get me out of this slump! Visual illusions improve sports performance. *Psychological Science*, *23*(4), 397-399.

Wolpe, N., Ingram, J. N., Tsvetanov, K. A., Henson, R. N., Kievit, R. A., Wolpert, D. M., & Rowe, J. B. (2018). Motor learning decline with age is related to differences in the explicit memory system. *BioRxiv*, 353870.

Wulf, G., & Lewthwaite, R. (2010). Effortless motor learning? An external focus of attention enhances movement effectiveness and efficiency. *Effortless attention: A new perspective in attention and action*, 75-101.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9

Wulf, G., & Toole, T. (1999). Physical assistance devices in complex motor skill learning: Benefits of a self-controlled practice schedule. *Research Quarterly for Exercise and Sport, 70*, 265–272.

Wulf, G., Chiviacowsky, S., & Cardozo, P. (2014). Additive benefits of autonomy support and enhanced expectancies for motor learning. *Human Movement Science, 37,* 12–20.

Wulf, G., Chiviacowsky, S., & Lewthwaite, R. (2012). Altering mindset can enhance motor learning in older adults. *Psychology and Aging*, *27*(1), 14.

Wulf, G., Höß, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of motor behavior*, *30*(2), 169-179.

Wulf, G., Lewthwaite, R., Cardozo, P., & Chiviacowsky, S. (2018). Triple play: Additive contributions of enhanced expectancies, autonomy support, and external attentional focus to motor learning. *Quarterly Journal of Experimental Psychology (2006)*, *71*(4), 824–831. https://doi.org/10.1080/17470218.2016.1276204

Wulf, G., Prinz, W. Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review* 8, 648–660 (2001). https://doi.org/10.3758/BF03196201

Yang, Y., Chen, T., Shao, M., Yan, S., Yue, G. H., & Jiang, C. (2019). Effects of Tai Chi Chuan on inhibitory control in elderly women: An fNIRS study. *Frontiers in Human Neuroscience*, *13*.

Zheng, H., Liu, Y., Li, W., Yang, B., Chen, D., Wang, X., ... & Halberg, F. (2006). Beneficial effects of exercise and its molecular mechanisms on depression in rats. *Behavioural brain research*, *168*(1), 47-55.

Ziegler, G., Dahnke, R., Jäncke, L., Yotter, R. A., May, A., & Gaser, C. (2012). Brain structural trajectories over the adult lifespan. Human brain mapping, 33(10), 2377-2389.

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Figure 3.1: “Conditions that fail to enhance learners’ expectancies and support their need for autonomy, and promote an internal focus of attention result in a vicious cycle of non-optimal learning (a), whereas conditions that enhance expectancies, provide autonomy support, and promote an external focus result in a virtuous cycle of enhanced motor learning (b)” Reprinted by permission from Springer Nature: Springer. Psychonomic Bulletin & Review. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning, Gabriele Wulf et al, 2016. https://link.springer.com/article/10.3758/s13423-015-0999-9 Accessed November 2020.