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Halo Sport ergonomic effects on older adults' cognitive, balance, and motor performance

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HALO SPORT ERGONOMIC EFFECTS ON OLDER ADULTS' COGNITIVE, BALANCE, AND MOTOR PERFORMANCE

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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ABSTRACT

Purpose: To determine if acute application of transcranial direct current simulation (tDCS), administered via the Halo Sport device, influences performance during cognitive, balance, and a motor task in healthy older adults. In addition, the purpose was to determine if tDCS altered PFC activation during any of the three task domains. **Methods**: Twelve healthy older adults (50.4 ± 5.1 years old) volunteered to participate in two separate trials of cognitive, balance, and a motor task following 20 minutes of tDCS via the Halo Sport or a Sham condition. **Results:** There was a significant increase in performance of the non-dominant motor task when individuals received stimulation via the Halo Sport in comparison to the Sham condition. There were no significant differences in performance of the cognitive, balance, or dominant motor task following Halo Sport. There were also no changes in measurements in brain activation during any of the cognitive, balance, or motor tasks. **Conclusion:** These results indicate that the application of acute tDCS via Halo Sport does not induce changes in PFC activation or cognitive and balance performance but may improve performance of non-dominant hand motor tasks in healthy older adults. Future research could utilize the Halo Sport in rehabilitation scenarios to determine its impact on cross limb transfer.

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has been approved as meeting the thesis requirement for the

Degree of Master of Arts

Date	Dr. Terence Moriarty, Chair, Thesis Committee
Date	Dr. Fabio Fontana, Thesis Committee Member
Date	Dr. Sophia Min, Thesis Committee Member
Date	Dr. Jennifer Waldron, Dean, Graduate College

DEDICATION

This Thesis is dedicated to my family and Mitchell. Your support and encouragement throughout this entire process is greatly appreciated.

Thank you, Dr. Terence Moriarty, for all your time and dedication that you gave to this project. Thank you for all of your guidance to help overcome the obstacles presented during this year. In addition, I appreciate all your encouragement and belief in this thesis project which helped lead it to its’ fullest potential. Thank you Dr. Fabio Fontana and Dr. Sophia Min, for all your support and aid throughout this past year. Additionally, thank you to Kelsey Bourbeau and Abi Auten for your support and help throughout the entirety of the project.

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CHAPTER ONE

INTRODUCTION

Introduction

Background Information

Aging. In the adult population, aging is often accompanied by an altered state of cognitive function, memory and recall, muscle activation, and motor function (Herman et al., 2010; Roos et al., 1997; Salthouse, 2009). A decline in these functions can lead to an inability to perform daily activities proficiently (e.g., unassisted walking), leading to a loss of independence for older adults. Many studies have found that cognitive and motor function can begin to digress when individuals reach their mid-twenties, with these functions becoming even more affected with aging (Balogun et al., 1994; Mattay et al., 2002; Salat et al., 2004; Salthouse, 2009). In 2014, the United States tallied a total of twenty-nine million falls by older adults (Bergen et al., 2016), which may have largely been as a result of inefficiencies in central and peripheral neural networks. Taken together, these altered communication systems can possibly lead to losses in muscle strength/power and a reduction in structural and functional brain changes (Mattay et al., 2002; Roos et al., 1997). A better understanding of the underlying structural and chemical changes that occur as one ages can aid in finding acute and/or long-term ways to reduce the negative effects of aging. Some of the proposed mechanisms related to aging that cause such significant negative effects include a decrease in cortical thickness, decrease of axon and dendrites densities, and altered brain activation (Salat et al., 2004). Thus, identifying such specific mechanisms that may attenuate the loss of independence as well as cognitive and motor function among older adults, which is of great clinical importance in order to improve their quality of life. One such technique, which has the ability to alter cortical excitability and thus may influence the aforementioned cognitive and motor performance, is transcranial direct current stimulation (tDCS).

Transcranial direct current stimulation. Transcranial direct current stimulation (tDCS) is a non-invasive method that stimulates the cortical structures of the brain over which it is positioned. tDCS delivers continuous week electrical current through electrodes on the subject's scalp (Yavari, et al., 2018). These effects and proposed changes in performance can last up to 90 minutes following 10-20 minutes of stimulation (Angius, et al., 2017). Upon stimulation, the threshold of the neuron's membrane potential is altered and enhances the excitability of the neuron (Nitsche & Paulus, 2000).

When tDCS has been applied over the motor cortex (M1), studies indicate changes in performance and learning (Hummel et al., 2005; Kaminski et al., 2016; Stagg et al., 2011). Halo Sport is a commercial product that delivers tDCS over the vertex of the individual's head, aiming to stimulate the M1. Specific to the Halo Sport device, Yang et al., (2018) found a chronic increase in dynamic balance performance in elite soccer players when applied after plyometric training for eight weeks. Changes in cognitive performance and learning have also been reported when tDCS is applied to the M1 (Huang et al., 2019), the dorsolateral prefrontal cortex (DLPFC) (Andrews et al., 2011), and the temporal lobes (Ferrucci et al., 2008; Martin et al., 2013). Since both dynamic and static balance are produced as a result of a combination of cognitive and motor processes, tDCS has the potential to alter balance performance in older adults.

Taken together, a multitude of studies have provided interesting insights into the possible positive ergogenic effects of tDCS on cognition, balance, and motor tasks in various populations. Since there are many similarities and differences between these investigations, the exact mechanisms that cause an alteration in performance as a result of application of tDCS are difficult to identify and still largely unknown. It has been suggested in past research that there are alterations in the central and peripheral neural networks following tDCS application due to increasing M1 output (Angius, et al., 2017; Huang et al., 2019; Nitsche & Paulus, 2000). However, this mechanistic approach is in contrast to previous findings that found an increase in the time until muscular failure, and there was no change in the cortical excitability after tDCS application (Abdelmoula et al., 2016).

Prefrontal cortex oxygenation. Another area of the brain which is less studied is the prefrontal cortex (PFC). A previous investigation of PFC activity reported increased oxygenation of this cortical area measured by brain oxygenation via functional near-infrared spectroscopy (fNIRS) during neuromuscular fatigue via electrical muscle stimulation of the elbow flexors (Ferrari et al., 2011). While the effect of tDCS on changes in PFC activation during balance tasks are not well understood, noninvasive fNIRS is a commonly used tool which allows investigation of these changes. The advantages of fNIRS are that it is also portable and provides live feedback regarding physiological changes associated with brain activity (Obrig & Villringer, 2003). This may provide mechanistic insight into how tDCS can alter PFC activation during cognitive and motor tasks in older adults. Mechanistic insight may also shed light on how neuromodulation from tDCS affects performance of cognition, balance, and motor tasks.

Research Question

Past research has contradicting findings on tDCS effects on balance, cognitive, and motor performance in healthy older adults. In addition, there has been very little discussion about the underlying mechanisms of tDCS. tDCS is believed to increase neuromodulation and cortical excitability however there is minimal research involving changes in PFC oxygenation during or after receiving tDCS. A better understanding of PFC oxygenation may lead to knowledge of how PFC is activated after being stimulated by tDCS. This gap in the research has made it difficult to determine if and why tDCS could be a beneficial tool to use with a variety of tasks in healthy older individuals.

Purpose of the Study

The present study seeks to evaluate if tDCS (administered via the Halo Sport device) influences cognition, balance, and motor performance among older adults. We further aim to explore if the change in performance is associated with changes in PFC oxygenation (i.e., PFC activation). Results may provide important insights into the mechanisms of how tDCS influences cognition, balance, and motor-dexterity performance. Further, results may allow clinicians to utilize this technique to improve balance or rehabilitation exercise performance and improve quality of life among the older population.

Significance of the Study

The novelty of this study is the utilization of fNIRS brain imaging technology in observing PFC activation during a cognitive task while receiving tDCS. Additionally, it will measure PFC activation during a balance and motor-dexterity task, following application of tDCS. This study is also unique in that it will only use adults 45 to 60 years old, and it will compare the tDCS stimulation to a sham stimulation. To the author's knowledge, upon completion of data collection, this will be the first known study to evaluate PFC oxygenation through fNIRS while receiving tDCS and investigate the research questions listed below. These findings will extend the understanding of the neurophysiological changes that may accompany the use of tDCS. The findings will also open up new pathways for tDCS research. The results of the proposed research will also expand on how older adult's task performance of various domains could be affected by an acute bout of tDCS.

Research Questions and Hypotheses

1. What is the impact of tDCS application (via the Halo Sport device) over the motor cortex on cognitive performance in healthy older individuals?

Hypothesis 1: tDCS application over the motor cortex will improve cognitive performance in healthy older individuals.

Past research has discovered that individuals that receive tDCS application, while conducting cognitive tasks, perform at a higher level and with greater accuracy in various populations (Ferrucci et al., 2008; Fertonani et al., 2014; Martin et al., 2013).

These findings would be reliable assurance that in healthy older individuals, cognitive performance would be enhanced by tDCS.

2. What is the impact of tDCS application (via the Halo Sport device) over the motor cortex on motor-dexterity performance in healthy older individuals?

Hypothesis 2: tDCS application over the motor cortex will improve motor-dexterity performance in healthy older individuals.

Motor-dexterity performance increased following an acute bout of tDCS in healthy older adults (Boggio et al., 2006; Nitsche, Schauenburg et al., 2003; Stagg et al., 2011).

3. What is the impact of tDCS application (via the Halo Sport device) over the motor cortex on balance performance in healthy older individuals?

Hypothesis 2: tDCS application over the motor cortex will improve balance performance in healthy older individuals.

Studies found that when a-tDCS was applied over M1 as well as the cerebellum, acute static balance was increased in healthy older individuals (Baharlouei et al., 2020). Based on this research, it could be predicted that tDCS can affect dynamic balance

4. What is the impact of tDCS application (via the Halo Sport device) over the motor cortex on PFC oxygenation during cognitive, motor-dexterity, and balance tasks in healthy older individuals?

Hypothesis 4: tDCS application over the motor cortex will increase PFC oxygenation in healthy older individuals during a cognitive, motor-dexterity, and balance task

No research has been completed where PFC oxygenation is measured after/during an acute bout of tDCS is applied over the vertex of the head via the Halo Sport in any of the three task domains.

Definitions:

1. Adults and older adults: individuals that are over the age of 45.
2. Balance: a human's ability to maintain their center of gravity within their base width.
3. Postural equilibrium, which is defined as the ability to coordinate the sensory and motor systems due to any changes in an individual's stability (Horak, 2006).
4. Transcranial direct current stimulation (tDCS): the application of low electrical stimulus to the scalp using electrodes. Halo Sport Device is a way to apply tDCS. Many studies use traditional electrode application instead of a device like Halo Sport; however, they provide similar stimulations.
5. Functional near-infrared spectroscopy (fNIRS): a method to measure brain oxygenation and is used to determine cortical activity (Obrig & Villringer, 2003).

Limitations:

The following are the limitations for the study:

1. Using only one form of a dynamic balance task may limit the generalizability of the study. The findings may not apply to static or other forms of balance performance.

2. Unmeasurable physiological changes as a result of tDCS application. These changes potentially alter the performance of the measured variables within the study as a confounding variable.
3. Measurement of only regional PFC limited the measured brain oxygenation to only one portion of the activated brain.
4. The study sample will consist of healthy older adults from the Cedar Falls area. Therefore, the results of this study may not apply to individuals who are unhealthy or outside the age range (under 45 years).

Delimitations:

The following are delimitations of the current study:

1. Participants consisted only of healthy individuals of the age of 45 and older, that are able to stand and walk unassisted.
2. This study tests dynamic balance performance, and not static or other forms of balance
3. The National Institute of Health (NIH) toolbox app is used to test individuals' cognitive ability. The NIH toolbox tests multiple aspects of cognition and standardizes the individual's score to others in their population and demographics.

Assumptions:

Assumptions for this study include that the participants are all honest in their health report questionnaire. Self-reporting that they are healthy indicates that they do not have any significant past or present neurological or chronic disease. In addition, it is assumed that all participants will do their very best and give their full effort in all tasks throughout the study (cognitive, balance, and motor-dexterity).

CHAPTER TWO

LITERATURE REVIEW

Literature Review

Transcranial Direct Current Stimulation

Methodological factors. Transcranial direct current stimulation (tDCS) is a noninvasive technique that stimulates specific portions of the brain by applying low-level electrical current via scalp electrodes (Nitsche, Fricke et al., 2003; Nitsche & Paulus, 2000). tDCS has been found to change the excitability of the neurons in the specific area that has been stimulated and has an impact on physiological alterations within the brain. This can lead to a change in the participant's behavior or performance, depending on the methodology of tDCS application. Factors within the methodology of tDCS that impact the physiological changes include: polarity, duration of application, and relationship of tDCS application and the task (Martin et al., 2013; Nitsche, Fricke et al., 2003; Yavari et al., 2018). The two different polarities of the application include anodal tDCS (a-tDCS) and cathodal tDCS (c-tDCS) (Yavari et al., 2018). c-tDCS application has been found to decrease excitability of neurons while a-tDCS increases excitability (Nitsche, Fricke et al., 2003; Nitsche & Paulus, 2000). Application of tDCS typically includes a-tDCS and usually lasts 15-20 minutes. Other factors to consider include: the placement of the electrodes on the scalp, as well as the relationship of the electrodes compared to one another (Nitsche, Fricke et al., 2003; Yavari et al., 2018).

Chemical changes from tDCS. When tDCS is applied acute physiological changes occur in the cortical region due to changes in resting membrane potential (Angius, et al., 2017; Nitsche & Paulus, 2000). Nitsche, Fricke et al. (2003) also believed that anodal stimulation increases the utilization of calcium channels in the neuronal pathway. Overtime (up to 30 minutes), as tDCS is continuously applied, the amount of calcium was found to increase intracellularly. The increased intracellular concentration of calcium causes a specific receptor and ion channel, N-methyl-D-aspartate receptor (NMDA), to work more efficiently (Bennett, 2000; Nitsche, Fricke et al., 2003). Along with the NMDA receptor, Nitsche, Fricke et al. (2003) determined that the amount of sodium increases for a short amount of time when a-tDCS is applied, causing an increase in neuron excitement. tDCS can then lead increase neuroplasticity, which improves both the rate and ability at which one learns a motor skill as well as the actual performance of that skill (Bennett, 2000; Nitsche, Fricke et al., 2003; Nitsche & Paulus, 2000). The opposite effects were posed on receptors when c-tDCS was applied. c-tDCS diminishes the intracellular calcium levels and the ability for the NMDA receptor to work efficiently. c-tDCS inhibited the excitability of the neuron and was shown to decrease the motor evoked potential (Nitsche, Fricke et al., 2003; Nitsche & Paulus, 2000). MEP levels were found to increase after a-nodal stimulation was applied over the motor cortex. This shows that tDCS increases the excitability of the neurons that are involved with the area of the brain where tDCS was employed (Nitsche & Paulus, 2000).

The aforementioned physiological alterations are believed to be one of the leading causes in altering the performance of the cortical area that is being stimulated (Nitsche, Fricke et al., 2003; Nitsche & Paulus, 2000). In addition to having the ability to improve motor skill performance, tDCS has been found to increase cognitive performance when applied over the dorsolateral prefrontal cortex (DLFPC) and temporal lobe (Andrews et al., 2011; Ferrucci et al., 2008; Fertonani et al., 2014; Martin et al., 2013). It has also been found to increase motor performance when applied to the motor cortex (M1) (Boggio et al., 2006; Huang et al., 2019; Hummel et al., 2005; Nitsche, Schauenburg et al., 2003; Stagg et al., 2011; Yang et al., 2018). Therefore, tDCS has been used across various populations as an ergogenic aid in increasing motor, balance, and cognitive performance.

Halo Sport Device

General information. The Halo Sport device is a modern piece of technology which has been primarily used in athletic population. The Halo Sport is a portable, noninvasive device that applies low-level electrical current over M1 areas (Huang et al., 2019; Yang et al., 2018). It has become popular within the sports world to utilize before or during physical activity, specific motor tasks, or cognitive skills. This device is highly mobile and easy to use, changes have occurred as a result of its use in the research domain. A benefit of the Halo Sport device is its reliability and safety. The manufacture of the device researched the adverse effects that occur after 1010 individuals used Halo Sport (Halo Neuroscience, 2016). Halo Sport applied tDCS and sham stimulation over multiple regions of the brain, including the M1, dorsolateral prefrontal cortex (DLPFC), and right posterior parietal cortex (rPPC). In general, the findings concluded similar amounts of headaches and scalp pain between the tDCS and sham, regardless of the application site (Halo Neuroscience, 2016). Therefore, it can be assumed that Halo Sport is a safe way to apply tDCS, especially over the M1.

Halo Sport studies. Only two studies have utilized the Halo Sport device and found an improvement in cognitive performance after exercise, increased power output during cycling, and increased long-term balance when utilized before plyometric training (Huang et al., 2019; Yang et al., 2018). Huang et al. (2019) found that individuals who were given tDCS in comparison to a sham performed better on a cognitive test after a bout of cycling. To date only one study has investigated the effect of Halo Sport on balance (Yang et al., 2018). Therefore, this study is unique in the way that it will utilize the Halo Sport device to apply tDCS on older individuals. In addition, it will observe the effects tDCS has on acute balance and cognitive performances.

Cognition

Introduction of cognition. Complex cognitive and motor functions often work together within humans. The neural pathways that are involved with thinking and moving often overlap and function simultaneously (Leisman et al., 2016). The domains of cognition are vast and widespread. Domains of cognition include, but are not limited to: sensation, perception, motor imagery, memory, executive functions, and speed of task (Harvey, 2019). These domains work simultaneously to process incoming information and plan and create actions for the body to execute in order to perform a cognitive task (Harvey, 2019). The cortical structures that are heavily involved in cognitive tasks and activity include portions of the frontal lobe, temporal lobe, DLPFC, and premotor areas (Leisman et al., 2016; Stufflebeam & Rosen, 2007). As individuals age, portions of the brain utilized during cognition decrease in volume and experience white matter degeneration (Salat et al., 2004; Stufflebeam & Rosen, 2007). This could be a possible reason for a decrease in cognitive performance and tasks.

Cognition in older adults. Similar to motor tasks, cognitive task performance decreases as individuals age (Mattay et al., 2006). The performance of a working memory task (three leveled N-back test) was dependent on the participant's age (Mattay et al., 2006). During the first and easiest level (1-back) of the cognitive task, there was no statistical difference in accuracy between the younger and older adults tested (Mattay et al., 2006). As difficulty progressed throughout the test, older adults displayed a significant decrease in accuracy in comparison to the younger adults. Additionally, Mattay et al. (2006) discovered that older adults had a significantly longer reaction time throughout all levels of the test. One of the profound findings of this study was that when performing the first and easiest task, the PFC activity levels of the older subjects were significantly higher than that of their younger counterparts. Contrarily, there was lower PFC activation in the older participants compared to the younger individuals when they were completing more complicated tasks (Mattay et al., 2006). The authors in this study suggested that up to a certain cognitive load, additional activity within the PFC is used to meet the cognitive demand. However, as the cognitive demand continues to increase this additional PFC activity is pushed beyond a threshold by which no more physiological compensation is made. Therefore, cognitive performance decreases. This overcompensation in PFC activity during cognitive processing may be due to the lack of cortical structure, volume, and efficiency of neural firing.

tDCS effects on cognitive performance. Large variation in the findings of the effects that tDCS has upon cognition exist (Bystad et al., 2016; Ferrucci et al., 2008; Fertonani et al., 2014; Martin et al., 2013). Many of the studies conducted use individuals with neurological disorders (e.g., Alzheimer's disease (AD)). Two studies were conducted to test the working memory of older patients with AD (Bystad et al., 2016; Ferrucci et al., 2008). The cognitive tests given during each study varied: one was a verbal memory test while the other was a visual memory test. Bystad et al. (2016) reported no change in verbal memory functionality following tDCS stimulation of the M1 in comparison to sham stimulation. Specifically, the authors reported no significant change in any type of recall, including recognition, immediate recall, or delayed recall (Bystad et al., 2016). Although the other study involved patients with AD, completely different result emerged in the visual recognition memory test. Ferrucci et al. (2008) reported a significant increase in the accuracy of the written word task (WRT) when a-tDCS was applied. Patients made more mistakes within the WRT when c-tDCS was applied. Therefore, tDCS induced an increased excitability through the modulation of activity within the neurons enhancing cognition in individuals with neurological disease, such as AD. These two studies differ in the methodologies of applications of tDCS, while the placement of the electrodes was over the temporal lobe and temporoparietal cortex. They differed in their number of times (6 vs 1) and the amount of time an application of the stimulation (30 vs 15 min) was received. Cognitive test scores did not increase when 30 minutes of tDCS was applied for 6 days in a row before a neuropsychological post-test (Bystad et al., 2016). A-tDCS instead was applied during one single session 15 minutes in between a pre and post-test and was found to impact WRT performance and accuracy. These alterations in how and when tDCS was applied, changed the cognitive performance ability within patients with AD. This could be due to the neurological impairment of the temporoparietal areas, and when tDCS was placed precisely over this cortex, greater effects on cognition occurred.

Few studies have examined the relationship between cognition and tDCS within healthy older adults. One such study examined the relationship between age, stimulation type, time of stimulation, and cognition performance through a picture naming task (Fertonani et al., 2014). Older individuals had a significant decrease in reaction time when a-tDCS was applied compared to sham. Fertonani and colleagues (2014) also reported a decrease in reaction time when the individual received the a-tDCS during the picture naming task (online) rather than before the task (offline). This finding is similar to that of the previous study on the timing of tDCS application relative to cognitive tasks (Martin et al., 2013). Both studies had similar findings that cognitive performance was enhanced when a-tDCS was applied online in comparison to offline stimulation. The timing of tDCS was a significant determinant in the performance of the cognitive task (Fertonani et al., 2014; Martin et al., 2013). Based on this research, it is clear that the application timing of a-tDCS stimulation is vitally important to the relative changes in cognition. Specifically, the online a-tDCS application is preferential during cognition tasks (Fertonani et al., 2014; Martin et al., 2013).

<u>PFC activation in cognition.</u> During cognitive activities, the more thought and brain power that is necessary to accurately complete the task the more brain activation is

required (Fishburn et al., 2014). Fishburn and colleagues (2014) found an increase in PFC activation as the load of the cognitive task increased. Functional near-infrared spectroscopy (fNIRS) has been strongly supported aa a helpful and cost-effective tool to determine cortical activation throughout a task or series of tasks. It is a safe and accurate way to measure the brain activation during a variety of different tasks. This device will also help determine if tDCS impacts brain activation.

The exact mechanism by which tDCS impacts cognitive and motor performance are relatively unknown. The present study seeks to evaluate if tDCS (Halo Sport) influences motor (i.e., balance task) and cognitive (i.e., working memory, processing speed, attention, and executive tasks) performance among healthy older adults. In addition, the study will look to determine if the further aim to explore if the change in balance performance is associated with changes in PFC oxygenation (i.e., activation).

Motor

Performing motor task. Movement of any kind requires sensory intake, planning, muscle activation, and execution of the movement These activities require heavy stimulation and coordination within the neurons of the brain for proper execution. Many cortical structures are involved in motor activities due to their high complexity. Specifically, M1, premotor area, and pre-supplementary motor area (pSMA) are activated in motor tasks (Leisman, et al., 2016). While these areas are involved in motor skills or activities, each one differs in their specific capabilities. The M1 controls much of the body's fine motor skills as well as the planning of a movement. Hari et al. (1998) found that individuals who are observing another complete a fine motor task activated their precentral motor cortex and M1. Additionally, it was determined that when executing the small motor task themselves, the participants increased the activation with higher intensity than when they were watching the action alone. This shows that activation of the specific cortical areas is not only increased with the planning of motor skills, but also when performing them. Therefore, since motor movements require activation within the motor cortex and surrounding areas, we can conclude that stimulation of the M1 with tDCS has the ability to influence motor task performance.

Motor tasks in older individuals. As individuals age, neurological and physical changes occur within the brain. These changes are readily studied and known to occur not only in individuals with chronic disease, but also in healthy individuals (Mattay et al., 2002; Salat et al., 2004). Over time the brain atrophies, causing the cortical structures to shrink (Salat et al., 2004). Salat et al. (2004) used functional magnetic resonance imaging (fMRI) to reveal that healthy individuals in the middle-aged group (mean = 48.6 years of age) had a significantly smaller brain volume in comparison to the younger group (mean = 22.8 years of age). Specifically, they found a significant thinning of cortical structures, such as the primary sensory, primary somatosensory, primary motor, visual, and association cortices in middle aged individuals and older individuals (mean = 76.6 years of age). A negative linear relationship between the thickness of cortical structures of the primary motor and visual and age could be a reason for reduced fluidity when performing many motor skills.

The direct consequences of this decrease in volume and thinning of cortical structures are multifaceted. One outcome of cortical shrinkage is neurochemical changes

(Salat et al., 2004). Neural connectivity, neural chemicals, and activation are needed in order to conduct and execute movement. The degradation of the brain, as well as the aging process, cause changes in the activation of the brain when performing motor tasks. Mattay et al. (2002) studied 10 young (mean = 30 years of age) and 12 older individuals (mean = 59 years of age) and determined the difference in cortical responses during a visual-motor task. Significantly more activity was found in the older subjects' motor cortex, premotor, and supplementary motor areas (Mattay et al., 2002). Each of the aforementioned affected areas is necessary during motor processing and motor planning. Although this study also demonstrated that age did not influence performance accuracy, reaction time was significantly higher in older adults when compared to young adults (Mattay et al., 2002). Based on these findings, an inference could be made that due to a lack of brain volume and neurochemical alterations that occur with aging, the brain has to overcompensate with greater cortical activation in order to complete a simple motor task accurately (Mattay et al., 2002). Due to the need for increased cortical activation, it would be logical to assume that tDCS could increase motor performance when applied over M1, premotor, or supplementary motor areas.

tDCS effects on motor tasks. Many studies have researched the effects of tDCS over M1 and found it has a drastic impact on an individual's ability to learn a motor task as well as their performance of that particular task (Hummel et al., 2005; Nitsche, Schauenburg et al., 2003; Stagg et al., 2011; Yang et al., 2018). Nitsche, Schauenburg et al. (2003) compared the performance and implicit learning of a small motor task over eight blocks, to tDCS (anodal, cathodal, and sham) application site in 80 healthy young adults. tDCS was applied over multiple cortices including M1, premotor cortex, lateral PFC, and medial PFC. tDCS (anodal and cathodal) when applied over M1 increased task performance, while stimulation of the other cortices had no significant increase in performance. In addition, over the eight blocks, a-tDCS over M1, increased learning of the motor task (Nitsche, Schauenburg et al., 2003). Therefore, not only is M1 important for executing motor task performance but can also enhance the initial learning process of a motor task through increase cortical excitation and consolidation of information (Nitsche, Schauenburg et al., 2003).

Many of these additional studies compared a-nodal to c-tDCS or a sham. The findings were similar amongst each of them, even though their populations differed. Hummel et al. (2005) used the Jebsen Taylor-Test (JTT), a collection of functional hand tests, to determine motor functionality. Hummel and his colleagues (2005) discovered that stroke patients performed JTT faster when receiving tDCS over their motor cortex compared to the sham. The participants' accuracy within the test did not differ between treatments, even though performance time decreased (Hummel et al., 2005). It can be assumed that because a tradeoff between errors and speed did not occur, tDCS is an ergogenic aid that increased neural stimulation that allowed for improvement in performance along with the efficiency of the motor tasks (Hummel et al., 2005). This finding supports the idea that tDCS can improve ability in a variety of motor tasks.

Similar to the previous study, Stagg et al. (2011) discovered that a-tDCS administered over the M1 improved healthy adults' motor performance and learning. Additionally, the reaction time of the sequence pressing test decreased at a faster rate throughout the trials when the a-tDCS was applied, compared to sham (Stagg et al., 2011). This suggests that when anodal tDCS is applied over the M1 the amount of time to learn a task was decreased, therefore increasing acute motor performance. Even with individuals who have had a neurological impairment, tDCS can lead to an alteration within their nervous system and improve performance (Hummel et al., 2005). Based upon this past research, it could be predicted that application of tDCS over the M1 might have a similar effect on motor performance in healthy older individuals.

Mechanisms of tDCS on motor. As alluded to previously, tDCS applied over the M1 alters motor task performance (Hummel et al., 2005; Nitsche, Schauenburg et al., 2003; Stagg et al., 2011). When individuals are asked to perform a task, the brain must send action potentials through a network of neurons to get the muscle to contract and execute the movement. Yang et al. (2018) utilized the Halo Sport device to administer tDCS over the motor cortex, before daily plyometric exercises, for eight weeks. Electromyography (EMG) activity of the individual muscle (vastus lateralis) significantly increased when individuals were administered tDCS over the eight weeks, compared to the sham (Yang et al., 2018). This illustrates that t-DCS can increase muscle activation when applied in a chronic fashion.

A possible underlying mechanism for this includes greater muscle excitation increasing the amount of activity delivered to the muscle and the amount of motor units activated (Nitsche & Paulus, 2000). Muscle excitation has been tested using values of motor evoked potential (MEP) from EMG data. Research has shown that a-tDCS elicited a 40% increase in MEP, while c-tDCS decreases EMP values (Nitsche & Paulus, 2000).

As the brain is stimulated through tDCS, and muscle activity increases, it would be assumed that muscle neurons have larger excitability after being stimulated. Increased excitation of the neurons could be a possible mechanism for the increased performance of motor tasks. This increase in motor tasks could translate to an increase in balance ability.

PFC activation in motor tasks. Although speculative, a mechanism that may occur during tDCS, and potentially improve performance during a motor skill after stimulation, is that of increased blood activation (oxygenation) in the brain. Cortical oxygenation can be measured using a fNIRS or functional magnetic resonance imaging (fMRI), electroencephalography (EEG), among other methods (Obrig & Villringer, 2003). fNIRS is a new technique that allows for absorption of oxygenated and deoxygenated hemoglobin to be monitored and used as a way of measuring brain activity. Khan et al. (2013) monitored hemodynamic changes using fNIRS during a motor task, during tDCS, and post stimulation. They studied the speed and the accuracy of a wrist flexion test and discovered that upon tDCS, change occurred in cortical activity patterns by increasing bilateral connections, overall increasing the cortical activity. The authors suggest that this increase in cortical activity from the tDCS application may have led to a decrease in speed and an increase in accuracy during the task. Future research is warranted to determine the impact of cortical changes from tDCS within small motor tasks as well as identifying the exact mechanism by which tDCS impacts individuals performing a large motor task such as balance.

Balance

Balance in older individuals. Balance for older individuals is an essential aspect of health, wellbeing, and safety. Older individuals with the ability to maintain balance can complete everyday tasks with less assistance, with a decrease in the number of falls (Berg et al., 1992). Starting at the age of 30, alterations in physiological and biomechanical mechanisms within the body impact the ability to balance (Balogun et al., 1994). Some of these included were muscle weakness and decreased proprioception sensation, as well as decreased rate of neuronal firing (Roos et al., 1997). This has been demonstrated with individuals' one-legged static balance performance in healthy individuals beginning at the age of 20-29 for males and 30-39 for females (Balogun et al., 1994). This decrease in balance ability as age increased shows physiological changes may be due to aging physical decline. The brain changes that occur include the reduction of brain volume and motor cortical thinning which could have a negative effect on balance (Salat et al., 2004). Along with morphological changes in the brain, aging also causes neuromuscular changes as well.

Collins et al. (1995) researched the Center of Pressure (CoP) differences between youth and older individuals to measure postural control patterns and balance performance. Older individuals had a greater amount of postural sway in both directions than young adults, causing greater instability (Collins et al., 1995). A mechanism related to the decrease in stability was that older individuals used an open-loop postural control system when maintaining balance for a short amount of time. This open-loop control system means that the older individuals have constant output of motor action potentials without sensory feedback to aid in recruitment. The authors noted a possible reason for an increase in postural sway was related to the constant activation of muscles that need to be contracted in order to maintain stability. This constant activation of and lack of sensory feedback and motor performance is due to an over-activation of cortical areas.

The aforementioned activation is due to changes in the cortical activation areas (Mouthon et al., 2018). Overall, cortical activation has been found to be significantly higher in older individuals when compared to young adults (under 65 years of age) (Mouthon et al., 2018). Differences in the activations of cortical regions increase muscle activity due to the need to maintain equilibrium because they lack the sensorimotor integration to aid in postural control. For these reasons, tDCS poses to be a beneficial aid in increasing balance by increasing excitability of motor and sensory neurons.

<u>tDCS effects on balance.</u> The direct effects of tDCS on balance, either static or dynamic, have not been extensively tested. It has been found that motor tasks that involve fine motor skill or activation of smaller muscle groups have shown to elicit a more significant positive effect on performance when a-tDCS is applied (Hummel et al., 2005). This may be a reason that tDCS effects on balance have not been readily studied, because balance utilizes many large muscle groups. However, two recent studies with similar procedures have found differing results of the effect of t-DCS on balance on differing populations, older and younger healthy individuals (Kaminski, Hoff et al., 2017; Kaminski, Steele et al., 2016). Each study asked individuals to keep a dynamic balance board as horizontal as possible for 30 seconds, for 10 rounds. In healthy adults (26.04 ± 3.14 years), when the individuals received a-tDCS, the participants maintained the

horizontal position for a longer extended amount of time than when they had a sham stimulation (Kaminski et al., 2016). They found contradicting results with healthy older adults (67.7 ± 6 years). Specifically, no differences emerged in balance board performance in older adults who had a-tDCS stimulation compared to a sham (Kaminski et al., 2017). This, however, was one of the only studies to research tDCS with older individuals and dynamic balance performance. Cortical volume decrease, neural connectivity, and postural control patterns may be a reason for the difference in balance performance (Collins et al., 1995; Salat et al., 2004). However, the methodology of tDCS application was precisely the same between both groups. It could be possible that in order to elicit changes in older adults' balance performance, a different amount of tDCS application time, different electrode positioning, or a different time in relation to the task may need to be implemented (Kaminski, Hoff et al., 2017; Kaminski, Steele et al., 2016).

Contrary to Kaminski et al. (2017), a recent study has found that older individuals' acute balance can be improved after one application of tDCS over M1 (Baharlouei et al., 2020). Baharlouei et al. (2020) tested older individuals' (older than 60 years old) ability to maintain balance on a force plate for 60 seconds. Researchers measured the CoP to measure the participants' ability to balance and discovered that when receiving tDCS over M1 and the cerebellum, the participants were able to increase static balance when compared to the sham stimulation (Baharlouei et al., 2020). While this is a static balance test in comparison to the dynamic balance task (Kaminski et al., 2017), the test does provide reasonable evidence that tDCS can alter older individuals' balance.

Yang et al. (2018) found outcomes similar to those in the dynamic balance youth study conducted by Kaminski et al. (2016). Yang and colleagues (2018) had young soccer players (19.73 ± 9 years) conduct plyometric training for 30 minutes a day, five times a week, with goals to improve balance and power. Additionally, they used chronic application of tDCS via the Halo Sport and plyometrics to determine if there was a significant increase in the improvement of muscular activation and balance compared to the sham group. The center of mass balance of the individuals who utilized the Halo Sport device increased significantly, compared to those who received the sham. This finding illustrates that tDCS can increase long-term balance performance when used consistently before training and aligns with the positive effects of acute tDCS in dynamic balance performance by Kaminski and colleagues (2016). In young individuals, tDCS is shown to increase not only acute balance performance but also retention of balance tasks (Kaminski et al., 2016; Yang et al., 2018). This helps demonstrate the idea that tDCS can enable individuals to learn tasks and improve their performance at a higher rate.

PFC activation in balance tasks. To the author's knowledge, research using fNIRS to measure changes in PFC brain oxygenation after tDCS stimulation during a dynamic balance activity has not been thoroughly researched. The effect of tDCS on small motor task and balance performance has been readily explored; however, the impact of tDCS on cortical oxygenation changes during different tasks has not. This research will allow for insight into a possible mechanism that allows tDCS to influence balance performance. Therefore, investigation into monitoring the PFC changes in older adults during a dynamic balance task, following an acute tDCS session, will add to published literature in this area. Contrary to this, tDCS prior or during cognition tasks, and the concurrent measurement of brain oxygenation has been researched.

CHAPTER THREE

METHODS

Methods

Participants

Participants were recruited from university staff and via flyers posted at local rehabilitation centers and around the university. Twelve (men = 6, women = 6) total participants volunteered to take part in this study (Table 1). All completed a health questionnaire, and procedures, discomforts, and risks were discussed before written informed consent was obtained. Healthy older adults between the ages of 45-65, who were able to stand and walk unassisted were recruited. Individuals were excluded from the study if they had any neurological or neuromuscular diseases or were outside the age range. The participants also reported no cardiovascular, pulmonary, or metabolic disorders. All study procedures were performed in the Exercise Physiology Laboratory at the University of Northern Iowa (UNI) and the protocol (21-0026) was approved by the UNI Institutional Review Board for Human Subject Research.

Table 1 Subject Characteristics. Mean ± SD

Characteristic	**N = 12 (6 male, 6 female)**
Age (years)	50.41 ± 5.31
Height (cm)	170.65 ± 9.19
Weight (kg)	81.74 ± 9.39
Body fat (%)	32.25 ± 10.18
Body Mass Index (kg/m^2)	28.15 ± 3.48

Procedure

Study protocol. All participants served as their own control in a placebo-controlled, counterbalanced, crossover study using a repeated measures design. Participants were assigned to either the Sham condition, where they received 20 minutes of Sham tDCS through the Halo Sport device, or the stimulation condition, where tDCS was applied via the Halo Sport device for 20 minutes. Each trial was separated by at least 72 hours but no more than 10 days and began with the completion of a COVID-19 screening questionnaire. Baseline measurements included height and weight in addition to body composition. Each trial began with the Halo Sport device being placed securely on the individual over the crown of their head. During the first 10 minutes of Halo Sport activation, the participants were asked to be seated, and remain still. A set of cognitive tasks was given on an iPad during the final 10 minutes of Halo Sport activation. Following this, the Halo Sport device was taken off the participant's head and a set of five balance tasks and a single motor task were administered. See Figure 1 for a detailed view of procedure including duration between testing days.

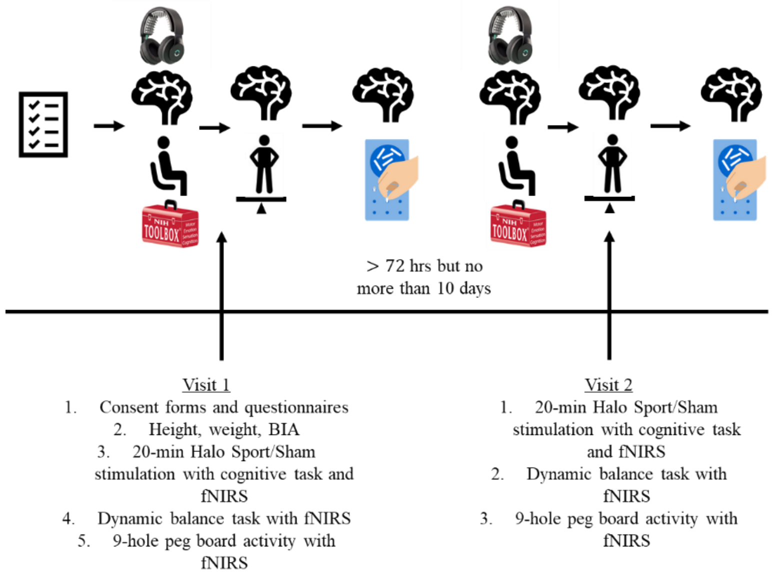

Figure 1: Detailed outline of the study's pocedure

Anthropometric and body composition baseline measurements. Prior to the first testing session, height (cm) and body weight (kg) were measured using a stadiometer and floor scale, respectively. In addition, body composition (body fat percentage) was estimated using bioelectrical impedance analysis (InBody 720, Cerretos, CA, United States).

Instruments

Halo Sport device. The Halo Sport (San Francisco, CA, United States) device is a commercially produced tDCS device, made by Halo Neuroscience. The Halo Sport device is shaped and worn like headphones with the electrodes attached to the underside of the headband. Specifically, the electrodes are positioned right over the head's crown and descend to each side toward the ears, maintaining direct contact. The positioning of the electrodes is aimed to apply tDCS over the motor cortex. The electrodes were wetted with water prior to stimulation to ensure conductivity. For the time of application, the participants were seated in a chair, in a resting state while the researcher controlled the Halo application on an iPhone. During the Halo Sport stimulation group, 2.0 mA electric current stimulation was applied for 20 minutes. In the Sham group, intensity was turned up to 2.0 mA for 30 seconds and then ramped down to 0 mA. Halo Sport is a reliable, portable, and safe method to apply tDCS (Huang et al., 2019; Yang et al., 2018).

Motor-balance battery. To test balance performance, the National Institute of Health (NIH) Toolbox Motor-Balance Battery was used. Through this battery individuals are asked to hold 5 different positions as still as possible for 50 seconds. The five different positions included: 1.) eyes open feet together on ground, 2.) eyes closed feet together on ground, 3.) eyes open feet together on foam pad, 4.) eyes closed feet together on foam pad, and 5.) tandem stance on the ground with eyes open. Individuals were allowed to take a one-minute break in between each position. An accelerometer through the NIH Balance Pod App via iPhone® was used to determine the sway acceleration during the various positions. The accumulated balance score was calculated by the NIH Toolbox app and takes into consideration the total path of sway of the individuals and the ability to maintain the position for the entirety of the 50 seconds. The test has been validated for individuals over the age of 7 years old (National Institutes of Health, 2020). The NIH Toolbox motor-balance task have been administered to different ages, sexes, races/ethnicity, and educational history to create fully corrected T-scores, which are based upon T-score metric created by NIH and has a mean of 50 with a standard deviation of 10. The fully corrected T-scores allow for comparison between multiple individuals and correct for the effect of characteristics such as age, gender, education, race, or ethnicity.

Cognitive battery. Cognitive performance was evaluated using the National Institute of Health (NIH) Toolbox Fluid Cognition Battery administered via an iPad®. The battery includes the following three assessments: 1.) the Flanker inhibitory control and attention test measures executive function and attention, 2.) the pattern comparison test measuring processing speed, and 3.) the dimensional change card sort measuring executive function. The NIH toolbox cognition tasks has been validated with individuals age 3-85 years by the NIH and has been found as a reliable method in determining cognition ability (National Institutes of Health, 2020). Cognitive tests within the NIH toolbox have been administered to different ages, sexes, races/ethnicity, and educational history to create fully corrected T-scores for each test. This allows individuals' performances to be compared to other individuals within their group to determine their overall cognitive abilities (National Institutes of Health, 2020) All three tasks are scored based on both the amount of time it takes the individual to answer and task accuracy. The three tests that were given during the experiment took approximately 10 minutes.

9-hole pegboard. In order to measure motor dexterity performance a 9-hole pegboard was used (Warrenville, IL, USA). The test was administered using the NIH Toolbox motor-dexterity test. The purpose of this task was to determine how fast and well the individual can work with their dominant and non-dominant hand in a small motor task. The NIH Toolbox motor-balance task has been administered to different ages, sexes, races/ethnicity, and educational history to create fully corrected T-scores for the speed at which the individual is able to complete the task. The NIH Toolbox creates a fully corrected T-score for both the dominant and non-dominant hand.

Functional Near-Infrared Spectroscopy. To measure activity within the prefrontal cortex, an 8-channel continuous wave functional Near-Infrared Spectroscopy (fNIRS) system (Octamon, Artinis Medical Systems, Elst, Netherlands) was used. Four LED optodes combined with one receiver were placed over the right (4 transmitters, 1 receiver) and left (4 transmitters, 1 receiver) hemispheres of the prefrontal cortex (RPFC and LPFC) (8 x 2 configuration). The fNIRS optodes shine infrared light into the PFC regions and, based on the amount of light that is reflected, are able to determine the concentration of oxygenated and deoxygenated hemoglobin in the blood (Huppert et al., 2013). Optode placement was based on the modified international electroencephalogram 10–20 system (Huppert et al., 2013). The measurement locations were identified by locating the naison site and placing the edge of the cap 2 cm above this point (approximately 1 cm above the brow line) and centering. Inter-optode distance was 3.5 cm and data were recorded at 10 Hz. The baseline was defined as 0 mol and found using the first 30 seconds after a rest period of 1 minute of rest between each portion of the experiment. Oxyhemoglobin change (ΔO_2Hb) and hemoglobin difference change (ΔHbdiff) were used as indicators of PFC oxygenation and activation (Ferrari et al., 2011; Huppert et al., 2013; Obrig & Villringer, 2003). The raw data obtained from the fNIRS was averaged in both PFC regions and analyzed in GraphPad Prism 8 after filtering it with a lowpass 0.1 Hz filter in order to eliminate any data points with high frequency due to physiological changes. These physiological changes include heart rate, respiration, and speaking. The fNIRS cap is a noninvasive, portable, universal device that has been used in other studies and has shown to be a reliable way to measure brain oxygenation (Ferrari et al., 2011; Obrig & Villringer, 2003).

Data Analysis

Sample size was determined based on *a priori* calculation with power set to 0.80 and alpha level of 0.05 (G*power, Dusseldorf, Germany). In a previous study in which the Halo Sport device was used to enhance cognitive function during the Stroop task in healthy adults, researchers reported significant results ($p < 0.05$) with a total of 9 participants (Huang et al., 2019) in a crossover study with repeated measures design. Therefore, we aimed to include a larger sample than those described in this previous study (Huang et al., 2019) to ensure accurate analysis of the effects of the Halo Sport intervention. All statistical analyses were performed using GraphPad Prism 9. Paired student's t-tests were used to compare PFC oxygenation changes from baseline (0 μmol) within each task domain (Halo or Sham) using data from the LPFC (fNIRS channels 1-4 averaged) and RPFC (fNIRS channels 5-8 averaged). Paired student's *t*-tests were also used to compare differences between balance, cognitive, and motor task T-scores between the Halo and Sham stimulation. Pearson correlational analyses were also used to observe the relationship between the change in PFC oxygenation (both LPFC and RPFC) and motor-dexterity performance of the non-dominant hand (T-scores for each task– Halo and Sham). All results are expressed as means (standard deviation) with a significance level of $p<0.05$.

CHAPTER FOUR

RESULTS

Experimental Findings

NIH Toolbox Performance

No statistically significant differences were found in any of the cognitive or balance tasks when comparing T-scores after a bout of tDCS via the Halo Sport device to the T-scores following a bout of Sham stimulation (p>0.05, Table 2). Performance of the motor task using the dominant hand also showed no significant difference in performance (p>0.05). However, performance of the motor task using the non-dominant hand showed a significant increase in performance (p=0.04) following a bout of Halo stimulation (Table 2).

Table 2. Results from the NIH Toolbox Performance

Cognitive test (construct)	**Halo**	**Sham**
Flanker (attention)	46 (6)	47 (9)
Pattern comparison (processing speed)	62 (12)	58 (14)
Card sort (executive function)	62 (12)	60 (12)
Balance	45 (7)	51 (13)
Motor (dexterity: dominant)	58 (14)	58 (11)
Motor (dexterity: non-dominant)	58 (11)	50 (9)*

*p = <.05, Halo vs. Sham, Mean (SD), N = 12.

Prefrontal Cortex Oxygenation

The fNIRS measurement of ΔHbdiff and ΔO_2Hb took place while participants completed the cognitive, balance, and motor tasks. Regions of interest were the RPFC and LPFC. No differences in RPFC or LPFC were detected during the cognitive, balance, or motor tasks in measurements of ΔO_2Hb or ΔHbdiff ($p<0.05$) (Table 3).

Table 3 Halo and Sham summary table for changes in left and right PFC oxyhemoglobin (ΔO_2Hb) and hemoglobin difference (ΔHbdiff) responses during task testing.

	Right Prefrontal Cortex ΔO_2Hb ($\Delta\mu mol$)		***Left Prefrontal Cortex ΔO_2Hb (μmol)***	
Cognitive test	**Halo Mean (SD)**	**Sham Mean (SD)**	**Halo Mean (SD)**	**Sham Mean (SD)**
Flanker (attention)	0.39 (0.89)	0.92 (1.12)	0.68 (1.16)	0.69 (0.97)
Pattern comparison (processing speed)	1.09 (1.08)	1.33 (1.67)	1.08 (1.22)	1.41 (1.09)
Card sort (executive function)	1.34 (0.89)	1.71 (1.32)	1.48 (1.26)	1.52 (1.20)
Balance (flat eyes open)	0.80 (0.71)	0.3 (1.3)	0.35 (0.83)	0.50 (0.73)
Balance (flat eyes closed)	0.66 (1.1)	0.74 (1.08)	0.94 (0.81)	1.19 (1.41)
Balance (pad eyes open)	0.96 (1.2)	1.03 (1.70)	0.98 (0.77)	1.33 (0.86)
Balance (pad eyes closed)	1.52 (1.41)	1.68 (2.12)	1.88 (1.21)	2.5 (1.3)
Balance (pad eyes open)	0.93 (1.49)	0.99 (1.58)	1.18 (1.18)	1.56 (0.98)
Motor (dexterity: dominant)	0.23 (1.72)	0.68 (2.72)	0.84 (0.82)	0.84 (1.50)
Motor (dexterity: non-dominant)	0.58 (1.88)	0.37 (1.26)	0.86 (0.87)	0.19 (0.93)
	Right Prefrontal Cortex ΔHbdiff (μmol)		***Left Prefrontal Cortex ΔHbdiff (μmol)***	
Cognitive test	**Halo Mean (SD)**	**Sham Mean (SD)**	**Halo Mean (SD)**	**Sham Mean (SD)**
Flanker (attention)	0.80 (0.96)	1.30 (1.66)	0.91 (1.08)	0.89 (1.12)
Pattern comparison (processing speed)	1.57 (1.15)	2.02 (1.86)	1.59 (1.16)	1.75 (1.36)
Card sort (executive function)	1.97 (0.96)	2.20 (1.69)	1.99 (1.05)	2.01 (1.47)
Balance (flat eyes open)	0.40 (0.84)	0.41 (1.74)	0.29 (0.89)	0.57 (0.94)
Balance (flat eyes closed)	1.06 (1.0)	0.82 (1.63)	1.02 (0.82)	1.50 (1.0)
Balance (pad eyes open)	1.45 (1.2)	1.09 (1.90)	1.18 (0.83)	1.85 (1.11)
Balance (pad eyes closed)	1.98 (1.51)	1.9 (2.41)	2.13 (1.29)	2.97 (1.7)
Balance (tandem eyes open)	1.25 (1.83)	1.02 (1.73)	1.42 (1.32)	2.16 (1.24)
Motor (dexterity: dominant)	0.38 (1.60)	1.04 (1.95)	0.80 (0.92)	0.72 (1.61)
Motor (dexterity: non-dominant)	0.71 (1.89)	0.48 (1.16)	0.96 (0.95)	0.32 (1.14)

PFC Oxygenation and Performance

Correlational analyses were completed to evaluate the relationship between PFC oxygenation measurements (ΔO_2Hb and ΔHbdiff) and performance scores for non-dominant hand motor task performance (Figure 2). Findings showed that there was a significant and positive correlation between RPFC ΔHbdiff and non-dominant motor task performance following a bout of Sham stimulation (r=0.60, p=0.03). All other correlations were found to be non-significant when comparing RPFC and LPFC ΔO_2Hb or ΔHbdiff and non-dominant motor performance. There were multiple strong and positive correlations within the motor tasks however they were not shown to be statistically significant.

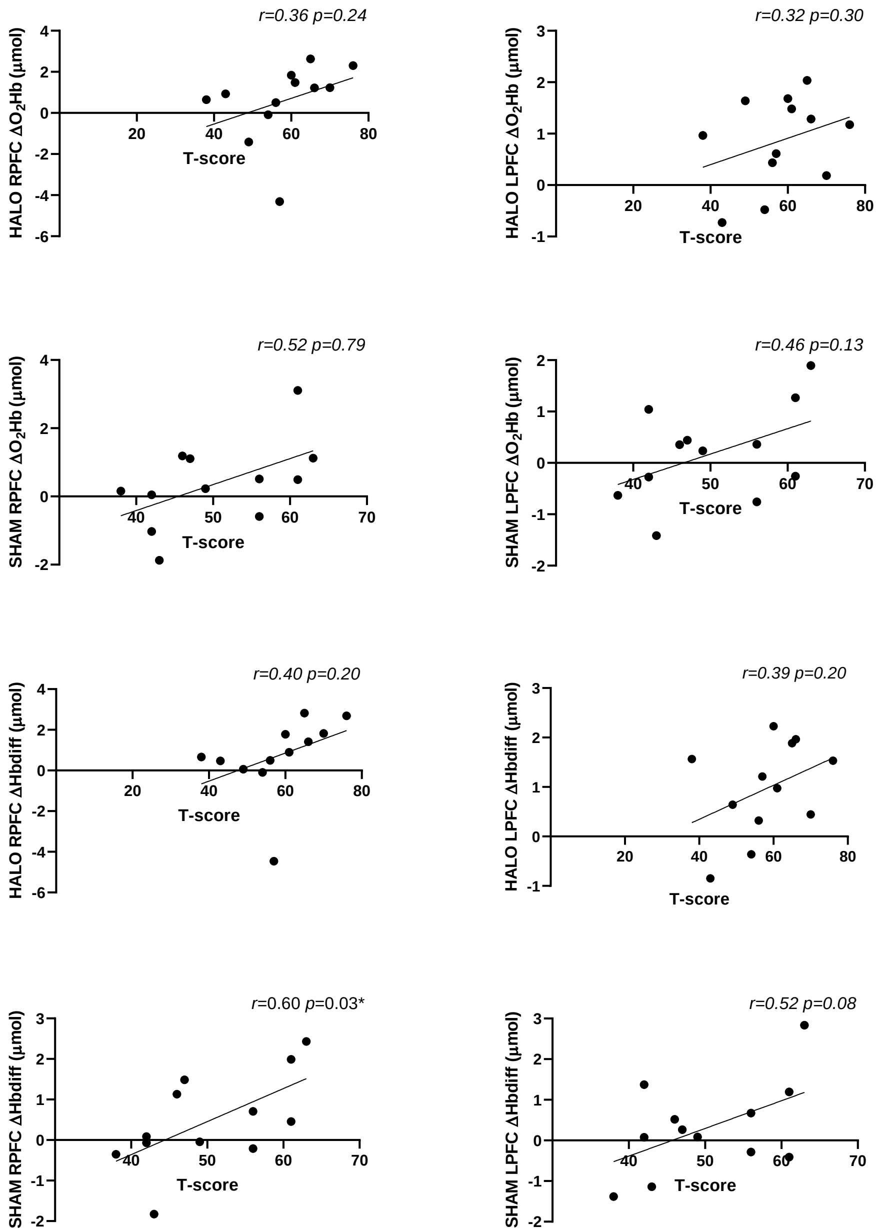

Figure 2 Regional PFC oxygenation correlation with the non-dominant hand motor task performance.

Note: O_2Hb=oxygenated hemoglobin, Hbdiff= Hemoglobin difference, T-score= fully corrected T-scores, RPFC= Right Prefrontal Cortex, LPFC= Left Prefrontal Cortex.

CHAPTER FIVE

DISCUSSION

Discussion

Purpose and Results of the Study

The main purpose of this study was to determine if tDCS (applied via a Halo Sport device) altered the performance of cognitive, balance, and motor performance in healthy older adults. In addition, this study aimed to determine if a potential mechanism for altered performance was a change cortical oxygenation, specifically in the prefrontal cortex (PFC). The key findings in the current study were that (1) there was an improvement of performance in the non-dominant hand motor task skill after Halo Sport stimulation and (2) there was a strong correlation between RPFC ΔHbdiff and the non-dominant hand motor task performance following Sham stimulation. Taken together, these findings support the idea that tDCS could be used in a rehabilitation setting to increase use of non-dominant hand (Boggio et al., 2006).

Motor Performance

Measuring motor task performance following a bout of tDCS has previously been studied by multiple researchers (Boggio et al., 2006; Nitsche, Schauenburg et al., 2003; Stagg et al., 2011). Boggio et al. (2006) found an increase in performance of a motor task with the non-dominant hand following a-tDCS over the M1. They did not find a significant increase in performance of the dominant hand (Boggio et al., 2006). The findings in Boggio et al. (2006) are identical to the findings in the present study, where there was an increase in performance of the non-dominant hand motor task but no change in the dominant hand motor task performance when comparing the Halo vs Sham stimulation. One possible reason for this unilateral difference in motor task performance is due to repeated use of the dominant hand. Motor tasks of the right hand are controlled by the left hemisphere of the M1 and vice versa. As an individual utilizes one hand more, they repeatedly activate the same motor units creating a dominant neural pattern. The asymmetrical use of hands causes the dominant hand to have a lower motor threshold than the non-dominant hand (Boggio et al., 2006; De Gennaro et al., 2004). tDCS has been found to increase the threshold of the neuron's membrane potential and increase the excitability of the neuron (Nitsche & Paulus, 2000). Individuals performing a non-dominant motor task following tDCS stimulations are able to reach the naturally elevated motor threshold and activate the motor neurons. This may be a possible reason for an improvement in performance. In agreement with Boggio et al. (2006), a possible reason that tDCS did not increase the performance of a dominant hand motor task in the present study was that the neural pathway is naturally maximally activated over the motor threshold when performing task with the dominant hand with or without stimulation. Therefore, any increase in excitability of the neurons from the tDCS would not cause a significant increase in performance (De Gennaro et al., 2004).

PFC Oxygenation

There is limited research investigating the impacts tDCS has on PFC oxygenation during motor, cognitive, and balance tasks. In the current study, there were no differences between the Sham and Halo stimulation trials in PFC (right or left) ΔHbO_2 and $\Delta Hbdiff$, both measurements of cortical oxygenation and activation, during any of the three task domains (motor, cognitive, or balance). The tasks of the present study were all very short in nature and not intended to induce fatigue. Since higher activation (and possibly greater mental effort) of the PFC occurs during cognitively challenging tasks, it may be the case that the specific cognitive tasks administered in the present study were not demanding or challenging enough to elicit a significant change in brain activation (Fishburn et al., 2014). This may also be a possible reason that PFC activation during the motor and balance tasks was not altered by Halo stimulation. It may also be the case that the stimulus provided by the Halo Sport device was not sufficient to elicit any additional activation of the PFC. Perhaps a greater intensity of stimulus is needed to see changes in cortical oxygenation.

PFC Correlation to Dominant Motor Performance

The present study's findings showed that there was a significant and positive correlation between RPFC ΔHbdiff and non-dominant hand motor task performance following a bout of Sham stimulation (*r*=0.60, *p*=0.03). Additionally, there were other moderate positive correlations between PFC oxygenation and non-dominant motor task T-score after Sham, however they were not significant. Motor performance after the Sham stimulation was related to greater brain oxygenation in order to increase performance. This relationship did not emerge during the non-dominant hand. This pattern leads to the analysis that increased performance after tDCS may be due to an increased efficiency in the cortical activation. Simply put, an individual's non-dominant hand is able to perform better without having to significantly increase brain activation when tDCS is applied before the motor task compared to without stimulation.

<u>Cognitive Performance</u>

Monitoring changes in cognitive performance following various forms of tDCS application have been utilized in previous studies (Bystad et al., 2016; Ferrucci et al., 2008; Fertonani et al., 2014; Martin et al., 2013). Between these studies there have been inconclusive findings on how tDCS impacts cognitive performance due to the various cognitive domains and methodology of tDCS application. Domains of cognition that have been tested include executive function, working memory (Martin et al., 2013), language (Fertonani et al., 2014) processing speed (Bystad et al., 2016). Bystad et al. (2016) reported there to be no changes in immediate or delayed recall in older individuals with Alzheimer's disease following 6 tDCS sessions. While the methodology was different from the present study, due to the cognitive task being more focused on memory and there were multiple sessions of tDCS applied, the findings were similar (Bystad, et al., 2016). Conversely, previous studies have found an increase in cognitive performance when healthy older individuals received a bout of tDCS during a cognitive task (Fertonani et al., 2014; Martin et al., 2013). Specifically, Martin et al. (2013) found that individuals receiving tDCS during a cognitive training of working memory had an increase in overall performance and difficulty of task. Interestingly, the number of errors was higher, when compared to tDCS being applied prior to the cognitive task. The increase of errors was credited to the level of difficulty increasing. In agreement with this, Fertonani et al. (2014) found that healthy older adults had an increase in performance of a picture naming task (cognitive domain of language) when tDCS was applied to DLPFC during the task in comparison to before the task or a sham stimulus.

The present study's methodology had the application of tDCS in a different location, over the vertex of the head, however the timing of application (during the cognitive task) was similar. No significant change in cognitive performance during the present study may be attributed to the T-score being a sum of the accuracy and reaction time for each cognitive task as well as tDCS placement. Therefore, it is unknown whether one of the cognitive domains used during one of the tasks was impacted. It is also possible that due to tDCS reaction time could increase and in turn possibly decrease accuracy as seen in Martin et al. (2013). Other possible explanations for the varied results across the multiple studies is the differences of cognitive tasks and tDCS application sites. Stimulation over other lobes of the brain that aid in cognition such as frontal lobe, temporal lobe, dorsolateral PFC, (Leisman et al., 2016; Stufflebeam & Rosen, 2007), may lead to greater changes in cognitive performance.

Balance Performance

In the balance task, there were no differences in performance when comparing the Halo stimulation to the Sham stimulation. This finding was similar to a study in which elderly individuals' dynamic balance performance after sham and a-tDCS was found to not be statistically different (Kaminski et al., 2017). Contrary to the current study and Kaminski et al. (2017), previous research has also shown that that dynamic balance performance of younger adults increased when followed by a bout of a-tDCS (Kaminski et al., 2016). These studies both differ from the current one in their methodologies. Firstly, the mean age of the participants in the current study was significantly older than the individuals in Kaminski et al. (2016), however much younger than the individuals within the study done by Kaminski et al. (2017). In addition, the application of a-tDCS was specifically over the M1 leg area (Kaminski, Hoff et al., 2017; Kaminski, Steele et al., 2016), in comparison to the current study of the tDCS being applied over the vertex of the head. The current study also utilized both static and dynamic balance tasks whereas the previous studies have only utilized dynamic tasks. Changes in methodology could be a possible reason there are differences in the balance performance across studies. Further research is needed to determine the age range of which tDCS can improve acute balance performance. In addition, it may be worth looking at applying tDCS over the M1 leg area as well as the supplementary motor area because balance is a combination of sensation and motor execution.

Application

Based on the findings of the current study it could be supported that tDCS application via the Halo Sport device would be a beneficial way to acutely increase motor performance of a non-dominant hand. This could be utilized in realms of rehab, or motor learning. For individuals who are recovering from a stroke or injury that affects their dominant limb, increased utilization of a non-dominant motor could be beneficial in improving quality of life and gaining independence. In addition, it could be utilized prior to a session of cross education rehabilitation. Cross education is a mechanism that has been utilized within the rehabilitation setting when one limb is immobilized for a certain reason (Ruddy & Carson, 2013). When individuals have an immobilized limb, studies have found that training motor or strength of the mobile limb increases the motor and strength capability of the immobilized limb (Ruddy & Carson, 2013). The findings of this study could be beneficial when individuals injure a dominant limb. Training motor tasks of the non-dominant hand after tDCS could lead to more significant improvement in motor abilities of the injured dominant limb when they are healed.

Limitations

Several limitations in the current study must be considered when interpreting the reported results. One possible limitation of the study which may include the subjects' age range (45-60) and low sample size. The findings of this study may not apply to individuals that are unhealthy or outside of the age range of the participants of the current study. A limitation of the present study is that the Halo Sport aimed to apply tDCS over the general area of the motor cortex, however, individuals having various skull and brain structures so the placement over the motor cortex may not always be accurate. Another limitation of the study is the measurement of only PFC oxygenation. Oxygenation of other cortices within the brain may be different than what was found in this study. Specifically, within the motor and balance task, measurement of the M1 oxygenation may be beneficial to determine if mechanistic differences from tDCS is greater in the cortical areas where the tDCS is applied. Additionally, there are physiological changes that occur as a result of tDCS that are unmeasurable that could influence task performance and therefore are considered a confounding variable.

Conclusion

The findings of the current research concludes that there was an increase in performance in motor dexterity of the non-dominant hand following an acute bout of tDCS via the Halo Sport device in healthy older adults. This improvement shows promise for the application of this device among those in rehabilitation or elderly individuals. Future research could aim to look at cortical oxygenation of the M1 area during dominant and non-dominant handed motor tasks as well as investigate the utilization of the Halo Sport device in rehabilitation scenarios to determine its impact on cross limb transfer.

REFERENCES

Abdelmoula, A., Baudry, S., & Duchateau, J. (2016). Anodal transcranial direct current stimulation enhances time to task failure of a submaximal contraction of elbow flexors without changing corticospinal excitability. *Neuroscience, 322*, 94–103. https://doi.org/10.1016/j.neuroscience.2016.02.025

Andrews, S. C., Hoy, K. E., Enticott, P. G., Daskalakis, Z. J., & Fitzgerald, P. B. (2011). Improving working memory: The effect of combining cognitive activity and anodal transcranial direct current stimulation to the left dorsolateral prefrontal cortex. *Brain Stimulation, 4*(2), 84–89. https://doi.org/10.1016/j.brs.2010.06.004

Angius, L., Hopker, J., & Mauger, A. R. (2017). The ergogenic effects of transcranial direct current stimulation on exercise performance. *Frontiers in Physiology, 8*(90), 1-7. https://doi.org/10.3389/fphys.2017.00090

Baharlouei, H., Saba, M. A., Shaterzadeh Yazdi, M. J., & Jaberzadeh, S. (2020). The effect of transcranial direct current stimulation on balance in healthy young and older adults: A systematic review of the literature. *Neurophysiologie Clinique, 50*(2), 119–131. https://doi.org/10.1016/j.neucli.2020.01.006

Balogun, J. A., Akindele, K. A., Nihinlola, J. O., & Marzouk, D. K. (1994). Age-related changes in balance performance. *Disability and Rehabilitation, 16*(2), 58–62. https://doi.org/10.3109/09638289409166013

Bennett, M. R. (2000). The concept of long-term potentiation of transmission at synapses. *Progress in Neurobiology, 60*(2), 109–137. https://doi.org/10.1016/S0301-0082(99)00006-4

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., & Wood-Dauphinee, S. L. (1992). Clinical and laboratory measures of postural balance in an elderly population. *Physical Medicine and Rehabilitation, 73*(11), 1073–1080.

Bergen, G., Stevens, M. R., & Burns, E. R. (2016). Falls and fall injuries among adults aged ≥65 years - United States, 2014. *Morbidity and Mortality Weekly Report, 65*(37), 938–983. https://doi.org/10.15585/mmwr.mm6537a2

Boggio, P. S., Castro, L. O., Savagim, E. A., Braite, R., Cruz, V. C., Rocha, R. R., ... & Fregni, F. (2006). Enhancement of non-dominant hand motor function by anodal transcranial direct current stimulation. *Neuroscience Letters, 404*(1-2), 232-236.

Bystad, M., Grønli, O., Rasmussen, I. D., Gundersen, N., Nordvang, L., Wang-Iversen, H., & Aslaksen, P. M. (2016). Transcranial direct current stimulation as a memory enhancer in patients with Alzheimer's disease: A randomized, placebo-controlled trial. *Alzheimer's Research and Therapy, 8*(13). https://doi.org/10.1186/s13195-016-0180-3

Collins, J. J., de Luca, C. J., Burrows, A., & Lipsitz, L. A. (1995). Age-related changes in open-loop and closed-loop postural control mechanisms. *Experimental Brain Research, 104*(3), 480–492. https://doi.org/10.1007/BF00231982

De Gennaro, L., Cristiani, R., Bertini, M., Curcio, G., Ferrara, M., Fratello, F., Romei, V., & Rossini, P. M. (2004). Handedness is mainly associated with an asymmetry of corticospinal excitability and not of transcallosal inhibition. *Clinical Neurophysiology*, *115*(6), 1305-1312.

Ferrari, M., Muthalib, M., & Quaresima, V. (2011). The use of near-infrared spectroscopy in understanding skeletal muscle physiology: Recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *369*(1955), 4577-4590.

Ferrucci, R., Mameli, F., Guidi, I., Mrakic-Sposta, S., Vergari, M., Marceglia, S., Cogiamanian, F., Barbieri, S., Scarpini, E., & Priori, A. (2008). Transcranial direct current stimulation improves recognition memory in Alzheimer disease. *Neurology, 71*, 493–498. https://doi.org/10.1212/01.wnl.0000317060.43722.a3

Fertonani, A., Brambilla, M., Cotelli, M., & Miniussi, C. (2014). The timing of cognitive plasticity in physiological aging: A tDCS study of naming. *Frontiers in Aging Neuroscience, 6*. https://doi.org/10.3389/fnagi.2014.00131

Fishburn, F. A., Norr, M. E., Medvedev, A. V., & Vaidya, C. J. (2014). Sensitivity of fNIRS to cognitive state and load. *Frontiers in Human Neuroscience*, *8*(76), 1-11. https://doi.org/10.3389/fnhum.2014.00076

Halo Neuroscience. (2016). *Safety of non-invasive brain stimulation delivered via the halo neurostimulation system in healthy human subjects*. Retrieved March 19, 2020, from https://halo-website-static-assets.s3.amazonaws.com/whitepapers/safety.pdf

Hari, R., Forss, N., Avikainen, S., Kirveskari, E., Salenius, S., & Rizzolatti, G. (1998). Activation of human primary motor cortex during action observation: A neuromagnetic study. *Proceedings of the National Academy of Sciences*, *95*(25), 15061–15065.

Harvey, P. D. (2019). Domains of cognition and their assessment. *Dialogues in Clinical Neuroscience, 21*(3), 227–237. https://doi.org/10.31887/DCNS.2019.21.3/pharvey

Herman, T., Mirelman, A., Giladi, N., Schweiger, A., & Hausdorff, J. M. (2010). Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 65*(10), 1086-1092. https://doi.org/10.1093/gerona/glq077

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing, 35*, 7–10. https://doi.org/10.1093/ageing/afl077

Huang, L., Deng, Y., Zheng, X., & Liu, Y. (2019). Transcranial direct current stimulation with halo sport enhances repeated sprint cycling and cognitive performance. *Frontiers in Physiology, 10*(118), 1–7. https://doi.org/10.3389/fphys.2019.00118

Hummel, F., Celnik, P., Giraux, P., Floel, A., Wu, W. H., Gerloff, C., & Cohen, L. G. (2005). Effects of non-invasive cortical stimulation on skilled motor function in chronic stroke. *Brain, 128*(3), 490–499. https://doi.org/10.1093/brain/awh369

Huppert, T., Schmidt, B., Beluk, N., Furman, J., & Sparto, P. (2013). Measurement of brain activation during an upright stepping reaction task using functional near-infrared spectroscopy. *Human Brain Mapping, 34*, 2817–2828. https://doi.org/10.1002/hbm.22106

Kaminski, E., Hoff, M., Rjosk, V., Steele, C. J., Gundlach, C., Sehm, B., Villringer, A., & Ragert, P. (2017). Anodal transcranial direct current stimulation does not facilitate dynamic balance task learning in healthy old adults. *Frontiers in Human Neuroscience, 11*, 16. https://doi.org/10.3389/fnhum.2017.00016

Kaminski, E., Steele, C. J., Hoff, M., Gundlach, C., Rjosk, V., Sehm, B., Villringer, A., & Ragert, P. (2016). Transcranial direct current stimulation (tDCS) over primary motor cortex leg area promotes dynamic balance task performance. *Clinical Neurophysiology, 127*(6), 2455–2462. https://doi.org/10.1016/J.CLINPH.2016.03.018

Khan, B., Hodics, T., Hervey, N., Kondraske, G., Stowe, A. M., & Alexandrakis, G. (2013). Functional near-infrared spectroscopy maps cortical plasticity underlying altered motor performance induced by transcranial direct current stimulation. *Journal of Biomedical Optics, 18*(11). https://doi.org/10.1117/1.jbo.18.11.116003

Leisman, G., Moustafa, A., & Shafir, T. (2016). Thinking, walking, talking: Integratory motor and cognitive brain function. *Frontiers in Public Health, 4*. https://doi.org/10.3389/fpubh.2016.00094

Martin, D. M., Liu, R., Alonzo, A., Green, M., & Loo, C. K. (2013). Use of transcranial direct current stimulation (tDCS) to enhance cognitive training: Effect of timing of stimulation. *International Journal of Neuropsychopharmacology, 232*, 3345–3351. https://doi.org/10.1007/s00221-014-4022-x

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Berman, K. F., Das, S., Meyer-Lindenberg, A., Goldberg, T. E., Callicott, J. H., & Weinberger, D. R. (2006). Neurophysiological correlates of age-related changes in working memory capacity. *Neuroscience Letters, 392*(1–2), 32–37. https://doi.org/10.1016/j.neulet.2005.09.025

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Das, S., Callicott, J. H., & Weinberger, D. R. (2002). Neurophysiological correlates of age-related changes in human motor function. *Neurology, 58*(4), 630–635. https://doi.org/10.1212/WNL.58.4.630

Mouthon, A., Ruffieux, J., Mouthon, M., Hoogewoud, H. M., Annoni, J. M., & Taube, W. (2018). Age-related differences in cortical and subcortical activities during observation and motor imagery of dynamic postural tasks: An fMRI study. *Neural Plasticity, 2018*. https://doi.org/10.1155/2018/1598178

National Institutes of Health. (2020). *Intro to NIH toolbox*. Retrieved March 19, 2020, from http://www.healthmeasures.net/explore-measurement-systems/nih-toolbox/intro-to-nih-toolbox

Nitsche, M. A., Fricke, K., Henschke, U., Schlitterlau, A., Liebetanz, D., Lang, N., Henning, S., Tergau, F., & Paulus, W. (2003). Pharmacological modulation of cortical excitability shifts induced by transcranial direct current stimulation in humans. *Journal of Physiology, 553*(1), 293–301. https://doi.org/10.1113/jphysiol.2003.049916

Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *The Journal of Physiology, 527*(3), 633–639. https://doi.org/10.1111/j.1469-7793.2000.t01-1-00633.x

Nitsche, M. A., Schauenburg, A., Lang, N., Liebetanz, D., Exner, C., Paulus, W., & Tergau, F. (2003). Facilitation of implicit motor learning by weak transcranial direct current stimulation of the primary motor cortex in the human. *Journal of Cognitive Neuroscience, 15*(4), 619-626.

Obrig, H., & Villringer, A. (2003). Beyond the visible - Imaging the human brain with light. *Journal of Cerebral Blood Flow and Metabolism, 23*(1), 1–18. https://doi.org/10.1097/01.WCB.0000043472.45775.29

Roos, M. R., Rice, C. L., & Vandervoort, A. A. (1997). Age-related changes in motor unit function. *Muscle and Nerve*, *20*(6), 679–690. https://doi.org/10.1002/(SICI)1097-4598(199706)20:6%3C679::AID-MUS4%3E3.0.CO;2-5

Ruddy, K. L., & Carson, R. G. (2013). Neural pathways mediating cross education of motor function. *Frontiers in Human Neuroscience, 7,* 397. https://doi.org/10.3389/fnhum.2013.00397

Salat, D. H., Buckner, R. L., Snyder, A. Z., Greve, D. N., Desikan, R. S. R., Busa, E., Morris, J. C., Dale, A. M., & Fischl, B. (2004). Thinning of the cerebral cortex in aging. *Cerebral Cortex, 14*(7), 721-730. https://doi.org/10.1093/cercor/bhh032

Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging*, *30*(4), 507–514. https://doi.org/10.1016/j.neurobiolaging.2008.09.023

Stagg, C. J., Jayaram, G., Pastor, D., Kincses, Z. T., Matthews, P. M., & Johansen-Berg, H. (2011). Polarity and timing-dependent effects of transcranial direct current stimulation in explicit motor learning. *Neuropsychologia*, *49*, 800–804. https://doi.org/10.1016/j.neuropsychologia.2011.02.009

Stufflebeam, S. M., & Rosen, B. R. (2007). Mapping cognitive function. *Neuroimaging Clinics of North America, 17*(4). https://doi.org/10.1016/j.nic.2007.07.005

Yang, D. J., Park, S. K., & Uhm, Y. H. (2018). Influence of transcranial direct current stimulation on lower limb muscle activation and balance ability in soccer player. *The Journal of Korean Physical Therapy*, *30*(6), 211–217. https://doi.org/10.18857/JKPT.2018.30.6.211

Yavari, F., Jamil, A., Mosayebi Samani, M., Vidor, L. P., & Nitsche, M. A. (2018). Basic and functional effects of transcranial electrical stimulation (tES)—An introduction. *Neuroscience and Biobehavioral Reviews, 85*, 81–92. https://doi.org/10.1016/j.neubiorev.2017.06.015