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Halo Sport Ergonomic Effects on Older Adults' Cognitive and Motor Performance

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ABSTRACT

Background: Aging has been linked to a decline in cognitive and motor function due to inefficiencies in the central and peripheral nervous system. Any such technique which may improve the aforementioned difficulties in older adults may help their overall quality of life. The purpose of the current study was to determine if acute application of transcranial direct current simulation (tDCS), administered via the Halo Sport device, influences performance during a cognitive or motor task in healthy older adults. In addition, the purpose was to determine if tDCS altered prefrontal cortex (PFC) activation during any of the two (cognitive or motor) task domains.

Methods: Twelve healthy older adults (50.4 ± 5.3 years old) volunteered to participate in two separate trials of a cognitive (attention, processing speed and executive function) and a motor task (9-hole peg task) (9-hole peg 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 or dominant motor task following Halo Sport. There were also no changes in measurements in PFC activation during any of the cognitive or motor tasks.

Conclusions: These results indicate that the application of acute tDCS via Halo Sport does not induce changes in PFC activation or cognitive 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.

ARTICLE HISTORY

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Introduction

In the adult population, aging is often accompanied by an altered state of cognitive function, memory and recall, muscle activation, and motor function [1,2]. 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 [2,3]. Much of the reduction in the performance of these everyday tasks have largely been attributed to 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 [4,5]. Identifying specific mechanisms that may attenuate the loss of independence as well as cognitive and motor function among older adults 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).

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 [6]. These effects and proposed changes in performance can last up to 90 minutes following 10-20 minutes of stimulation [7]. Upon stimulation, the threshold of the neuron's membrane potential is altered and enhances the excitability of the neuron [8].When tDCS has been applied over the motor cortex (M1), studies indicate changes in performance and learning [9-11]. Halo Sport is a commercial product that delivers tDCS over the vertex of the individual's head, aiming to stimulate the M1. Changes in cognitive performance and motor learning have been reported when tDCS is applied to the M1 [12], the dorsolateral prefrontal cortex (DLPFC) [13], and the temporal lobes [14,15]. Although much research has been conducted in this area, the exact mechanisms that cause an alteration in performance as a result of application of tDCS are difficult to identify and still largely unknown.

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

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oxygenation via functional near-infrared spectroscopy (fNIRS) during neuromuscular fatigue via electrical muscle stimulation of the elbow flexors [16]. While the effect of tDCS on changes in PFC activation during cognitive and motor 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 [17]. This may provide mechanistic insight into how tDCS can alter PFC activation during cognitive and motor tasks in older adults as well as also shedding light on how neuromodulation from tDCS affects performance of cognition and motor tasks.

The present study sought to evaluate if tDCS (administered via the Halo Sport device) influences cognition 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 and motor-dexterity performance. Further, results may allow clinicians to utilize this technique to improve cognition or rehabilitation exercise performance and improve quality of life among the older population.

Methods

Participants

Participants were recruited from University of Northern Iowa (UNI) staff and via flyers posted at local rehabilitation centers and around UNI. Twelve (men = 6, women = 6) total participants volunteered to take part in this study (Table 1). All participants 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 UNI (data was collected between November 2020 and March 2021) 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

Procedures

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 single motor task was administered. See Figure 1 for a detailed view of procedure including duration between testing days.

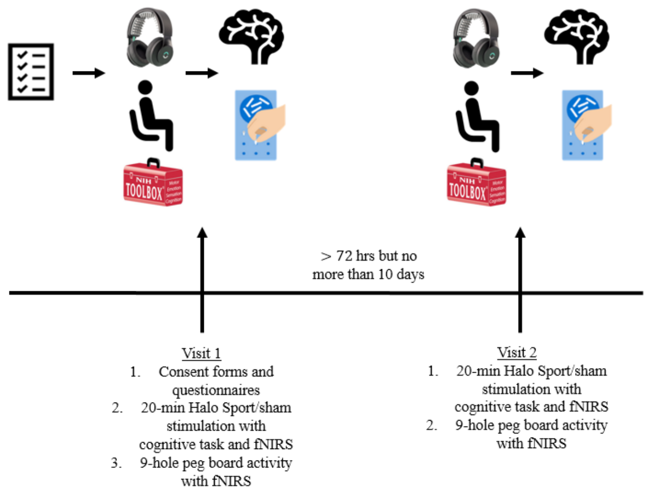

Figure 1: Detailed outline of the study's procedure.

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

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 M1. 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 [12,18].

Cognitive performance was evaluated using the National Institute of Health (NIH) Toolbox Fluid Cognition Battery administered via an iPad®. The battery included 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 [19]. 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 [19]. 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.

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-dexterity 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.

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). Optode placement was based on the modified international electroencephalogram 10–20 system [20]. 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 µmol 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 [16,17,20]. The raw data obtained from the fNIRS was averaged in both PFC regions and analyzed in GraphPad Prism 9 after filtering it with a lowpass 0.1 Hz filter in order to eliminate any data points with high frequency due to physiological changes (e.g. 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 [16,17].

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 [12] in a crossover study with repeated measures design. Therefore, we aimed to include a larger sample than those described in this previous study [12] to ensure accurate analysis of the effects of the Halo Sport intervention. All statistical analyses were performed using GraphPad Prism 9 in April 2021. Paired student's t-tests were used to compare PFC oxygenation changes from baseline (0µmol) 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 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 $p<0.05$.

Results

NIH Toolbox Performance

No statistically significant differences were found in any of the cognitive 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 & motor 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)
Motor (dexterity: dominant)	58 (14)	58 (11)
Motor (dexterity: non-dominant)	58 (11)*	50 (9)

Prefrontal Cortex Oxygenation

The fNIRS measurement of ΔO_2Hb and ΔHbdiff took place while participants completed the cognitive and motor tasks. Regions of interest were the RPFC and LPFC. No differences in RPFC or LPFC were detected during the cognitive or motor tasks in measurements of O_2Hb or ΔHbdiff ($p<0.05$) (Table 3).

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. 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 ($r=0.60$, $p=0.03$) (Figure 2). 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.

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 (Δµmol)		Left Prefrontal Cortex ΔO_2Hb (µmol)	
Task	**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)
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)***	
Task	**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)
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)

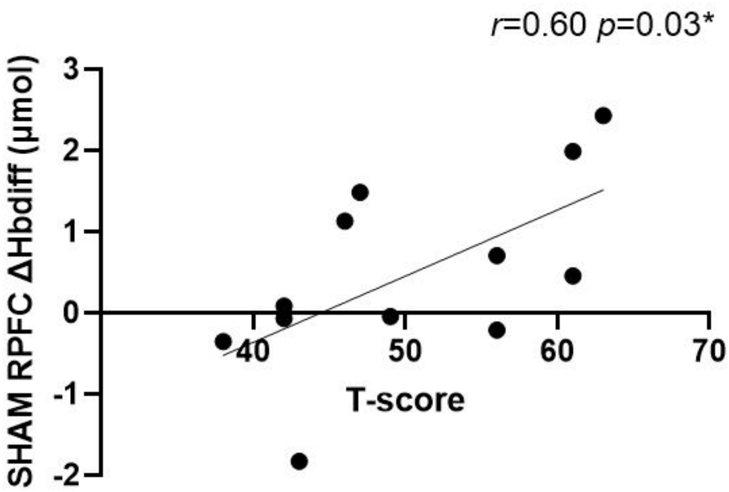

Figure 2: Correlation between right prefrontal cortex hemoglobin difference and T-score during the non-dominant hand motor task.
Note: Hbdiff= Hemoglobin difference, T-score= fully corrected T-score, RPFC= Right Prefrontal Cortex.

Discussion

The main purpose of this study was to determine if tDCS (applied via a Halo Sport device) altered the performance of cognitive 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 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 [21].

Measuring motor task performance following a bout of tDCS has been widely studied [11,21,22]. Boggio *et al.* [21] had similar findings to the present study, whereby there was an improvement in performance of a motor task with the non-dominant hand following a-tDCS over the M1 but no improvement in performance of the dominant hand. 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 [21,23]. tDCS has been found to increase the threshold of the neuron's membrane potential and increase the excitability of the neuron [8]. 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.* [21], 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 [23].

There is limited research investigating the impact tDCS has on PFC oxygenation during motor and cognitive tasks. In the current study, there were no differences between the Sham and Halo stimulation trials in PFC (right or left) ΔO_2Hb and ΔHbdiff, both measurements of cortical oxygenation and activation, during any of the two task domains (motor or cognitive). 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 [24]. This may also be a possible reason that PFC activation during the motor task 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.

The present study's findings showed that there was a significant and positive correlation between RPFC Hbdiff 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.

Investigating changes in cognitive performance following various forms of tDCS application have also been researched [14,15,25,26]. Between these studies, there have been inconclusive findings on how tDCS influences 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 [15], language [26], and processing speed [25]. Bystad *et al.* [25] reported there to be no changes in immediate or delayed recall in older individuals with Alzheimer's disease following six 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. Conversely, previous studies have found an increase in cognitive performance when healthy older individuals received a bout of tDCS during a cognitive task [15,26]. Specifically, Martin *et al.* [15] 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. 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.* [15]. 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 [27,28], may lead to greater changes in cognitive performance.

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 the 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 [29]. 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 [29]. 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 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.

Conclusions

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.

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