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Effects of Bihemispheric Motor Cortex Transcranial Direct Current Stimulation (tDCS) on Dual-Task Motor Performance in Chronic Stroke: case study

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Effects of Bihemispheric Motor Cortex Transcranial Direct Current Stimulation (tDCS) on Dual-Task Motor Performance in chronic stroke: case study

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Resumo

Enquadramento: O AVC é a principal causa de incapacidade adquirida em adultos. As sequelas variam amplamente e podem afetar vários domínios. Estes défices são, habitualmente, mais acentuados durante a realização de tarefas duplas. A dupla tarefa consiste no desempenho simultâneo de duas tarefas que requerem competências motoras e cognitivas. Recentemente, a estimulação transcraniana por corrente contínua tem adquirido um crescente interesse na reabilitação do AVC pela sua capacidade de modular a excitabilidade cortical.

Objetivo: Avaliar a eficácia de 9 sessões de tDCS bi-hemisférica, no córtex motor primário, no desempenho motor em dupla tarefa de indivíduos com sequelas de AVC em fase crónica.

Métodos: Neste estudo de caso, o indivíduo participou em 9 sessões de 20 minutos de tDCS bi-hemisférica, seguida das atividades de reabilitação tradicionais. Este foi submetido a 4 momentos de avaliação. Foram utilizados os seguintes instrumentos: questionário sociodemográfico e de caracterização clínica, Mini *Mental State Examination*, *Fugl-Meyer Assessment of Motor Recovery after Stroke*, Teste de Fluência Verbal, *Digit Span*, Dinamómetro Hidráulico Jamar, *Timed Up and Go* (TUG), *Functional Reach Test* (FRT), *Box and Block Test* (BBT)e *Stroke Upper Limb Capacity Scale* (SULCS).

Resultados: Analisando os valores da avaliação inicial e final, o participante obteve melhorias mais evidentes em tarefa dupla no BBT com um aumentou de 100% de blocos transferidos na mão parética e 125% na não parética. No TUG, o participante obteve melhorias mais evidentes em dupla tarefa, reduzindo o tempo necessário para completar a tarefa cerca de 28,69%. No FRT obteve melhores resultados em tarefa simples, com valores de 71,41% com pequenas alterações em tarefa dupla. Já no dinamómetro de *Jamar* foi observada uma ligeira redução tanto em tarefa simples como dupla, sendo esta menos acentuada em tarefa dupla, -0,42%.

Conclusão: Os resultados indicam que combinar tDCS bi-hemisférica com técnicas de reabilitação convencional pode ter efeitos positivos no desempenho motor em condição de dupla tarefa.

Palavras-chave: Acidente Vascular Cerebral, Estimulação Transcraniana por Corrente Contínua, Performance Motora, Dupla Tarefa

Abstract

Background: Stroke is the leading cause of acquired adult disability. It can cause multiple impairments and affect multiple domains. These deficits are usually more evident and impairing when performing dual tasks. Dual task is defined as the performance of two or more concurrent tasks simultaneously that require motor and cognitive skills. Recently, tDCS has acquired a growing interest on stroke rehabilitation given its potential to modulate cortical excitability.

Objective: Evaluate the effects of 9 bihemispheric tDCS sessions over the primary motor cortex in individuals with chronic stroke on dual-task motor performance.

Methods: In this study case, subject participated in 9 sessions of 20 minutes of bihemispheric tDCS, followed by his traditional rehabilitation activities. Participant was submitted to 4 evaluation moments. The following assessment tools were used: sociodemographic and clinical questionnaire, Mini Mental State Examination, Fugl-Meyer Assessment of Motor Recovery after Stroke, Verbal Fluency Test, Digit Span, Jamar Hydraulic Hand Dynamometer, Timed Up and Go (TUG), Functional Reach Test (FRT), Box and Block Test (BBT) e Stroke Upper Limb Capacity Scale (SULCS).

Results: When compared baseline and final assessment results, the participant showed better results under dual task in the BBT, with an improvement of 100% of blocks transferred with the paretic hand and 125% in the non-paretic hand. In TUG, the participant showed better results under dual task, reducing the time to complete the task in 28,69%. No FRT, results improved in single task, 71,41%, with slight changes in dual task. In the Jamar Hydraulic Hand Dynamometer, a slight reduction was registered in both single and dual task. This reduction was smaller under dual task, -0,42%.

Conclusion: Results show that combining bihemispheric tDCS with conventional rehabilitation techniques may have a positive effect in dual-task motor performance.

Keywords: Stroke, Transcranial Direct Current Stimulation; Motor performance, Dual task

Índice

1. Introduction

Stroke is a focal neurological disorder, of sudden onset, lasting more than 24 hours, and of presumed vascular origin(1-3). It is caused by impaired perfusion of brain tissue due to vessel occlusion (ischemic stroke) or, less frequently, intracerebral hemorrhage (hemorrhagic stroke)(2-5). About 85%-95% of all strokes are ischemic with the remaining 10%-15% being hemorrhagic (1, 3). Although hemorrhagic strokes are less common, they have higher mortality rates(1, 3).

Stroke induces direct damage to the brain tissue at the site of the lesion. It also has the potential to cause additional damage in the surrounding tissue and a long-range of dysfunction through the interruption of structural and functional pathways(2). This also leads to deregulation of cortical excitability and abnormal interhemispheric interaction. Stroke may thus induce many neurological changes that can result in functional disability or even death(2, 5).

Stroke has a high prevalence worldwide, being one of the leading causes of death in developed countries(3, 6, 7). Everyear about 15 million people have a stroke and, in Europe 1 million of new cases are registered each year (1, 3, 8). The emerge of chronic diseases and the aging population suggests that stroke incidence will continue to rise(2, 9). Stroke is the leading cause of acquired long-term adult disability worldwide (3, 6, 10). It is also one of the major causes of economic burden, being responsible for 2%-4% of healthcare expenses (6). A growing number of acute stroke treatments appeared in recent years, which led to a decrease in mortality rates. However, the number of patients left with physical and cognitive dysfunction increased (3, 11, 12). In Portugal, mortality rates decreased in 10,8% however, the number of patients with disability increased about 0,6% (13).

1.1. Stroke and motor impairment

After stroke, a wide range of impairments can appear. These are intimately related to the affected brain area and the extent of the lesion(11, 14-16). Between 80%-86% of stroke survivors suffer from some sort of disability(1, 10). Disability after stroke can be classified into 6 domains: motor, sensory, language, visual, cognitive, and affective(1). Stroke survivors can present a wide range of deficits but motor (1, 2, 8, 11, 17, 18) and cognitive (1, 8, 11) deficits are the most commonly reported (7). Cognitive deficits include attention, visuospatial, memory, and executive impairments (1, 11, 19). Motor deficits include muscle weakness (5, 18, 19), spasticity (19), hemiparesis, hemiplegia (6, 10), motor incoordination, apraxia (19), loss of upper limb function (5), unstable balance, gait abnormalities and difficulties in trunk control (5). Commonly, stroke survivors present slowed and segmented movements and dysmetria, which can ultimately lead to disuse of upper limb (19).

The motor cortex is the only control center that is able to communicate directly with other structures involved in motor control such as, basal ganglia, thalamus, brainstem, and thalamus [20]. It also receives inputs from neocortical and subcortical areas from the basal fore brain and thalamus[20]. The primary motor cortex (M1) is responsible for overall motor decisions and movements [21]. It is one of the major brain areas responsible for planning and execution of motor commands, coordination, and dexterous movements [20, 22]. Besides its prominent role in motor planning and execution, the primary motor cortex is also crucial to motor skill learning, which consists in improving speed, accuracy, and consistency [20, 22]. Primary motor cortex is essential for acquisition and maintenance of motor sequences [22]

Motor deficits in stroke result from interhemispheric inhibition deficits which changes inhibition of damaged cerebral hemisphere while increasing excitability of the non-affected hemisphere [4, 18]. After stroke, resulting in upper limb impairment, cortical excitability shifts in both the ipsilesional and contralesional motor cortices [23]. Following stroke ipsilesional cortical excitability decreases and contralesional excitability increases [9]. In the chronic phase, the ipsilesional primary motor cortex shows decreased cortical excitability and decreased interhemispheric inhibition. Contrarily, the contralesional primary motor cortex shows increased excitability and increased interhemispheric inhibition [23]. Individuals with poorer upper limb function show higher levels of contralesional excitability [23]. The increased contralesional excitability results in increased inhibition from the contralesional hemisphere to the ipsilesional hemisphere, thus decreasing even more the excitability of the ipsilesional motor region [7, 23-25]. Thus, rebalancing interhemispheric interactions may be beneficial for post-stroke motor recovery [2, 18].

Functional impairment of upper limb affects up to 85% of the stroke survivors and persist in 30%-60% of cases, 6 months after stroke onset [26]. Between 30%-66% experience upper limb paralysis 6 months after stroke onset [27]. Despite receiving rehabilitation, approximately 60% of stroke survivors suffer from chronic upper limb dysfunction [19]. These deficits lead to difficulties in performing activities of daily living independently, reduced quality of life [4, 10, 28, 29], reduced participation in leisure and social activities and less chances of successful professional reintegration [10].

Besides upper limb dysfunction, gait, balance, and postural control also change drastically after stroke [30, 31]. In the chronic phase, about 80% of stroke patients are able to walk independently but most of are left with atypical gait padrones [32, 33]. Even though, gait and balance problems persist in the chronic phase, affecting individual´s quality of life [33]. These deficits may result in falls and only 30% to 50% of people are able to deambulate in the community [30-33].

Deficits observed in individuals after stroke are usually more evident and impairing when performing dual tasks [34].

1.2. Dual-task and motor performance in stroke

Dual task is defined as the performance of two or more concurrent tasks simultaneously, one primary and one secondary, that involve competing demands for cognitive and physical resources [29, 35, 36]. Dual task can be motor - motor, motor – cognitive or cognitive – cognitive [35, 37, 38]. Dual tasks are considered to be destabilizing because they involve competing demands for cognitive and physical resources [35]. Usually, the individual prioritizes one of the tasks which can deteriorate performance of either one or both tasks, when compared to performing single tasks [35, 39, 40]. This impairment is called dual task interference and occurs because performance capacity, either cognitive or motor performance, is limited by the concurrent task [19, 39, 40]. The dual task paradigm is used to investigate whether and to what extent motor actions require attentional resources [19].

Dual task theories suggest that directing attention to movement control, which is automatic, can disrupt performance as a result form attentional limitation of human cortex [37, 41].

Neuroimaging studies suggest that dual task performance is associated with the prefrontal cortex and the dorsolateral prefrontal cortex, which play an important role in executive functions such as attention and multi-tasking [29, 35, 39]. The pre-frontal cortex is an important mediator of dual task being more activated during dual tasks [29]. However, the activity of other brain areas such as the primary motor cortex has been less studied and is less characterized [29, 37]. A functional connection between the motor cortex and the pre-frontal cortex may alter motor cortex function during dual task [42]. Corp and colleagues [37] demonstrated that performing and additional task results in a decreased primary motor cortex inhibition [37]. Voluntary movement control requires a balance between two concurrent mechanisms of cortical inhibition: (1) competitive resolution, which suppresses activation of non-selected areas of the motor cortex, so that movement is no produced in undesired muscles and, (2) impulse control, which activates the desired region of the motor cortex to produce movement in the desired muscles.[42]. Dual-task performance deficits may result from increased attentional load and some variability in primary motor cortex inhibition [37].

Stroke survivors may experience greater dual task interference and more pronounced performance decrements in one or both tasks then healthy subjects, because stroke tends to cause both cognitive and motor impairments making dual task performance even more difficult [4, 19, 29, 40, 43]. Dual task performance plays a central role in daily living. In their daily routine, individuals are frequently challenged by situations in which they need to perform dual tasks such as walking while talking on the phone, watching traffic, writing, and carrying a bag. Thus, the ability to perform more than one task simultaneously is a necessary skill in our daily routine [19, 29, 40]. For instance, deficits in dual-task walking is essential for functional mobility [29]. Cognitive tasks considerably affect upper limb function [4]. Many daily upper limb activities involve cognitive – motor dual task. Reach and hand grasp, fundamental to object manipulation, are frequently performed with concurrent cognitive tasks [4, 19]. Performing two simultaneous tasks, one of them involving manual dexterity, causes greater decrease in both tasks, when compared to other tasks that do not involve manual dexterity[44]. Importantly, deficits in dual-task performance may negatively influence stroke survivors´ reintegration in community, because limits the individuals´ to rapidly adapt to changing environments [4].

Considered the important role that dual-task plays in individuals daily routines there has been an increasing interest in dual-task interventions, especially for people with stroke [43, 45]. Recently, dual-task training emerged as a new rehabilitation method for individuals with stroke [45-47]. Dual-task training consists in executing two tasks simultaneously [45, 47]. This method can be divided in cognitive-motor and motor dual-task training in which a task involving cognitive, or motor interference is performed at the same time as another basic task [46, 47]. It is thought that dual-task training promotes task automatization by improving the ability to process information and has the potential to improve individuals ability to allocate attentional resources during dual-task performance [43]. It has been suggested that dual-task training is an effective intervention method and might have greater efficacy improving dual-task performance when compared to single-task training [29, 45].

1.3. tDCS in stroke rehabilitation

Non-invasive brain stimulation (NIBS) techniques show strong therapeutic potential to improve motor recovery after stroke, when combined with conventional therapies [2, 7, 9]. These techniques have the ability to modulate cortical excitability and to induce brain plasticity [2, 6, 7].

Among NIBS techniques, transcranial direct current stimulation (tDCS) has gained a particular interest in stroke rehabilitation [7, 10, 30, 48]. tDCS is a non-invasive brain stimulation technique that delivers a constant weak current to the scalp, aiming to modulate cortical excitability of the targeted brain region [6, 10, 18, 26, 39].

Current is delivered by two electrodes involved in a saline soaked sponge, the anode, and the cathode, with dimensions between 20-35 cm^2, fixed to the scalp by a rubber band and connected to a stimulator [6-8, 15, 16, 49]. A low intensity, continuous current, between 0,5- 2 mA, can be applied in single or multiple sessions with variable duration, between 8-30 minutes [2, 7, 49]. The administered current penetrates skin, skull, and cerebrospinal fluid to stimulate underlying brain regions, increasing or decreasing cortical excitability[50]. In general, it is possible to distinguish 3 types of stimulation, anodal, cathodal, and bilateral tDCS [8, 27, 44]. Usually, anodal tDCS increases cortical excitability, making neurons more ready to fire. Contrarily, cathodal tDCS, decreases cortical excitability, making neurons less ready to fire [4, 6, 7, 27, 39, 48]. Bilateral tDCS, stimulates both hemispheres simultaneously combining effects of both anodal and cathodal stimulation [2, 8, 27]. However, neurons are not modulated in the same manner. Deep cortical layers are often inhibited by anodal stimulation and activated by cathodal stimulation, suggesting that neurons orientation relatively to the electric field is critical to their response to stimulation [51]. Other parameters such as intensity and duration can influence tDCS efficacy [2, 7, 39].

tDCS induces immediate effects, related with the modulation of neurons´ resting membrane potentials, and may induce long-term effects on neuroplasticity [7].

Immediate effects are related with the modulation of neural resting potentials, changes in membrane permeability and alterations in neurons state of excitability facilitating depolarization or hyperpolarization without inducing action potentials [10, 30, 48, 52, 53]. When membranes are depolarized, less activity is necessary to induce action potentials, increasing spontaneous activity and if it is hyperpolarized spontaneous activity is reduced [51, 54]. Usually, anodal tDCS facilitates depolarization of neural membranes resting potential, thus enhancing cortical excitability. Contrarily, cathodal tDCS hyperpolarizes neural membranes resting potentials, thus inhibiting cortical excitability [4, 6, 7, 27, 39, 48].

tDCS can produce long-term effects, which can last from minutes to more than 24 hours depending on stimulation parameters such as duration and intensity [2, 54-56]. Aftereffects seem to be related with glutamatergic receptors, specifically N-methyl-D-aspartate (NMDA) receptors. Blocking NMDA receptors prevented excitability changes induced by both cathodal and anodal tDCS [51, 54, 55]. The NMDA-mediated calcium flux is a critical component of synaptic plasticity suggesting that intracellular calcium dynamics are involved in the aftereffects [55]. This supports the idea that neuroplasticity induced by tDCS is both calcium and NMDA dependent [51, 54, 55]. Another explanation is related with modifications in neurotransmitters concentrations [51, 55]. After anodal tDCS, GABA concentration decreases significantly, when compared to sham stimulation, and after cathodal stimulation glutamate concentrations also decrease. tDCS may also influence the modulation of serotonergic and dopaminergic systems [55]. Thus, it seems plausible that tDCS aftereffects are related not only with NMDA receptors, but GABA may also play a key role in tDCS aftereffects [51, 54, 55].

tDCS is an easy to use and low-cost stimulation tool that is well-tolerated by patients, painless and with limited side effects [2, 7, 26, 39]. Reported side effects are usually mild and most occur during stimulation. These include, tingling, itching, discomfort, burning sensation, pain, and metallic taste. After stimulation can appear headaches, nausea, insomnia, fatigue, and skin irritation [57, 58].

In recent years, tDCS has gained a growing interest in stroke rehabilitation, when combined with conventional therapies [8, 49]. In 2021, Fregni et al [30], reviewed existing literature of tDCS in neurological and psychiatric disorders. They found that all types of tDCS might be effective when used in the chronic phase (level B evidence), but studies presented high heterogeneity in results. This heterogeneity in results was also found by Lefaucheur et al, in 2017 [24]. These authors were not able to make recommendations of the use of tDCS in stroke rehabilitation [24]. Hoorneweder et al[7], also reviewed tDCS efficacy when combined with conventional therapies. They found that combining tDCS with conventional therapies leads to upper limb improvements, especially in the chronic phase [7]. Alisar et al [16] tested bilateral tDCS efficacy when combined with occupational therapy and physical therapy in upper limb rehabilitation and found significant improvements in the Functional Independence Measure [16]. Kim et al [4] verified the efficacy of bilateral tDCS over the primary motor cortex (M1) when combined with modified constrained-induced movement therapy for upper limb rehabilitation in chronic stroke patients [4]. They found that the experimental group showed higher improvements that the control group [4].

Although some studies show positive results in stroke rehabilitation, methods, stimulation parameters and results are highly variable. Therefore, there is the need to conduct more studies to verify the efficacy of tDCS in stroke rehabilitation.

1.4. Study goals

The goal of this study is to evaluate the effects of 9 bihemispheric tDCS sessions over the primary motor cortex in individuals with chronic stroke on dual-task motor performance. Thus, we hypothesize that:

-Motor performance will improve after 9 bihemispheric tDCS sessions.

-Dual-task motor performance will display larger improvements in comparison to single-task motor performance.

-Effects on dual-task motor performance will be driven by motor-related improvements rather than cognitive improvements.

3. Results

3.1. Case Characterization

Assessment results at baseline are presented in tables 1-3. The participant scored 18 points out of 30 in the MMSE which corresponds to 0 schooling years, or mild cognitive impairment. In the Fugle-Myer Assessment, upper limb subscale the participant scored 33 points, out of 66 which corresponds to moderate impairment of the upper extremity movement (Table 1).

Table 1: Results from characterization variables

Mini Mental State Examination	18	Minimum: 0 points Maximum: 30 points
Fugle-Meyer Assessment	33	Minimum: 0 points Maximum: 66 points

Regarding primary outcomes, in table 2 the participant scored 21,33 Kg in the handgrip strength test, under single-task condition and 16,67 Kg under dual-task condition. This corresponds to reduced handgrip strength more pronounced under dual-task condition.

In the TUG, the participant needed 16,07 sec. to complete the task in single-task condition, which means he is mostly independent and 26,78 sec. in dual-task condition, which corresponds to a variable mobility. In both cases, the participant showed functional mobility alterations more pronounced under dual-task condition.

In the FRT, the participant reaches 7,10 cm in single-task condition and 8,37 cm in dual-task condition. In both the participant shows a poor balance and postural control, but contrarily to the other measures the decline is more pronounced in single-task condition.

In the BBT, the participant transferred 30 blocks with the non-paretic hand, in single-task and 8 in dual-task condition. With the paretic hand, the participant transferred 7 blocks in single-task condition and 4 blocks in dual task condition. The participant showed an impairment of manual dexterity under dual task condition, especially in the paretic hand.

Table 2: Primary outcome results

Single task	Dual task
Jamar Hydraulic Hand Dynamometer (Kg)	
21,33	16,67
Timed Up and Go (sec.)	
16,07	26,78

Functional Reach Test (cm)			
7,10		8,35	
Box and Block test			
Single Task		**Dual-Task**	
Non-Paretic Hand	**Paretic Hand**	**Non-paretic Hand**	**Paretic Hand**
30	7	8	4

Concerning the secondary outcomes, in table 3 the participant scored 5 points which means basic hand functioning.

In the Digit Span, the subject scored 5 points in the Digit Span Forward and 2 points in the Digit Span Backwards. In both tests, the participant has a low score for his age and education level.

In the Verbal Fluency Test, the subject scored 5 points in Semantic Fluency and in the Phonetic Fluency scored 0 points in the letter R and 3 points in the letter P. In all the tests, the participant has scores lower that what is considered normative, considering his age.

Table 3:Secondary outcome results

Stroke Upper Limb Capacity Scale (SULCS)		
5		
Digit Span		
Digit Span Forward	**Digit Span Backwards**	
5	2	
Verbal Fluency Test		
Semantic Fluency	**Phonetic Fluency**	
	R	**P**
5	0	3

3.2. Intervention Effects

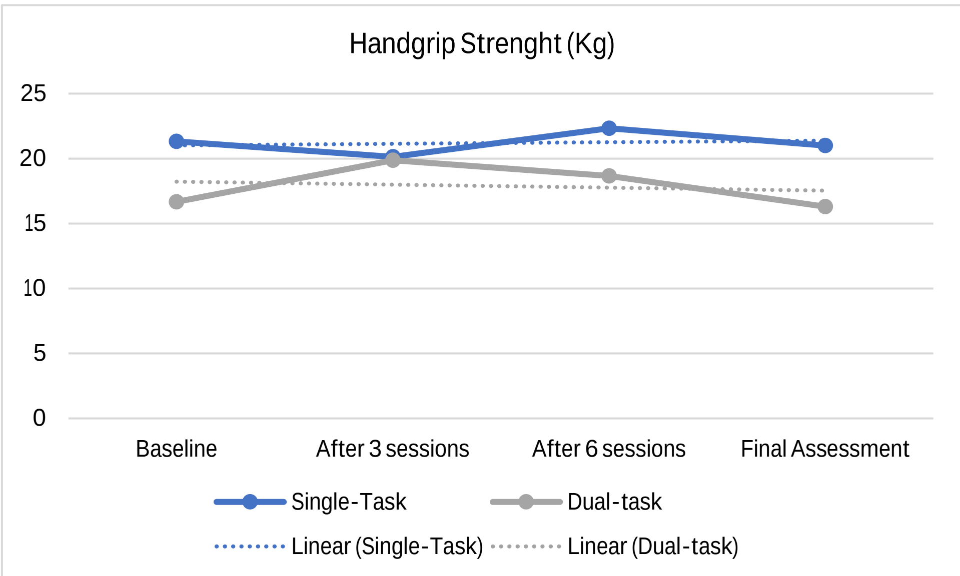
Regarding handgrip strength, in table 4, a slight reduction is observed in both single and dual task condition, with this reduction being smaller under dual task. In single task, handgrip strength went from 21,33 Kg at baseline to 21,00 Kg in the final evaluation, which corresponds to a 1,55% reduction (table 5). In dual task, handgrip strength went from 16,67 Kg at baseline to 16,60 Kg in the final evaluation, which corresponds to a 0,42% reduction.

After 3 tDCS sessions, results significantly improved in dual task, 19,20 % relatively to baseline. However, reduced in single task, -5,63%, and improvements in this condition were only observed after 6 tDCS session, 4,69% relatively to baseline (table 5).

These results confirm linear tendency lines, observed in graphic 1, for dual task condition, which predicted a slight reduction, but contrasts with prediction for single task condition, which predicted a slight improvement.

Table 4: Handgrip Strength results and percentage relatively to previous and baseline assessments

Handgrip strength (Kg)						
	Single Task			Dual task		
	Result	% to previous evaluation	% to baseline assessment	Result	% to previous evaluation	% to baseline assessment
Baseline	21,33	-	-	16,67	-	-
After 3 sessions	20,13	-5,63	-5,63	19,87	19,20	19,20
After 6 sessions	22,33	10,93	4,69	18,67	-6,04	12,00
Final	21,00	-5,96	-1,55	16,60	-11,09	-0,42



Graphic 1: Handgrip Strength results and linear tendency

Regarding the BBT, paretic hand, in table 6, results improve in dual task, 100% when compared to baseline but slightly reduce in single task, less 14,29%. In the non-paretic hand, table 5, results improved in both single and dual task conditions. In single task, the participant transferred 7 blocks with the paretic hand and 30 blocks with the non-paretic hand at baseline assessment. In dual task condition, the participant transferred 4 blocks with the paretic hand and 8 blocks with the non-paretic hand.

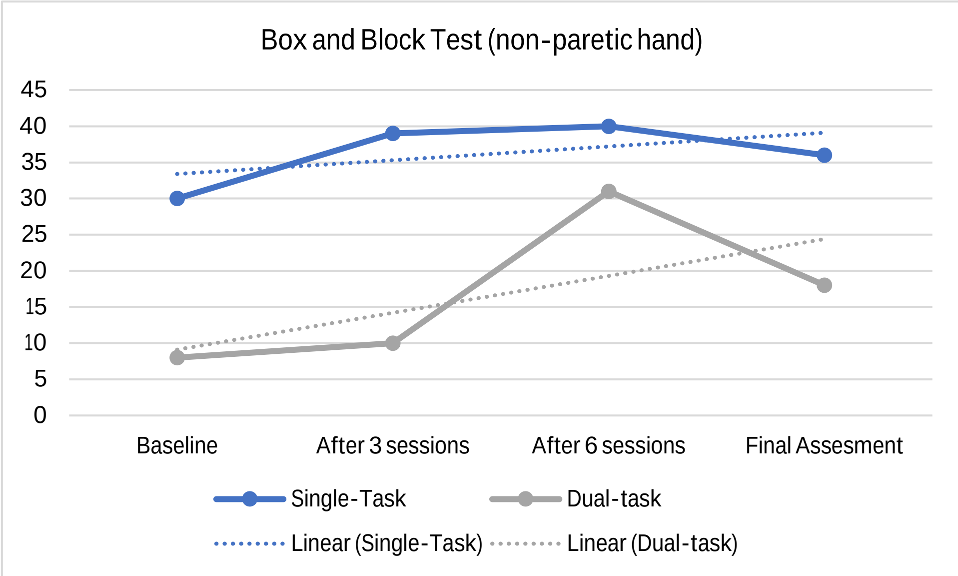
Linear tendency lines for the non-paretic hand seen in graphic 2, show that results should improve over time. Table 5 support these results showing that percentage relatively to previous and baseline assessments improve.

Linear tendency lines for the paretic hand seen in graphic 3, show that results should improve over time in single and dual task. Table 6 results do not support these because single tasks performance slightly reduces in the last assessment, 14,19% when compared to baseline.

These results show that participant´s gross manual dexterity improved under dual-task condition in the paretic hand

Table 5: Box and Block Test results and Percentage relatively to previous and baseline assessments (non-paretic hand)

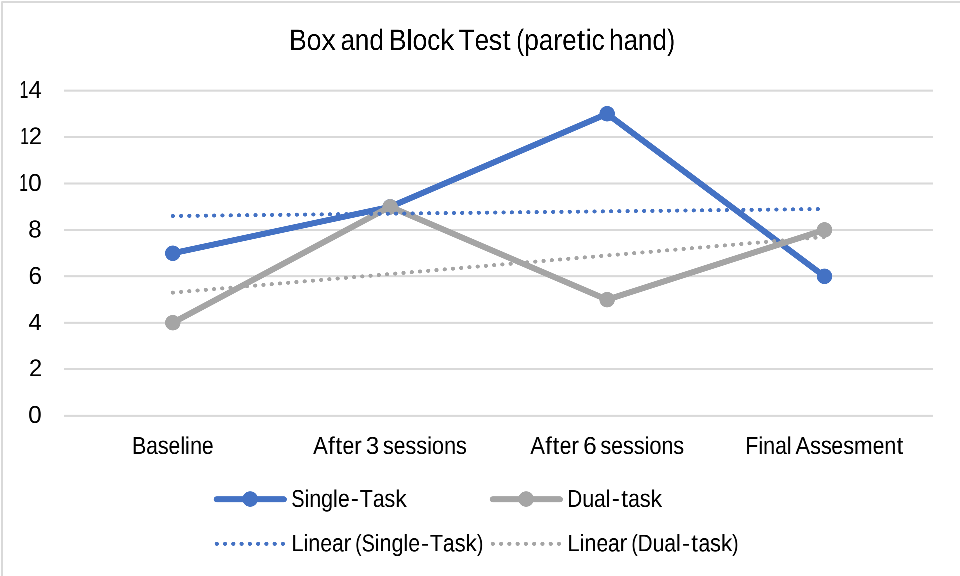
Box and Block Non-paretic hand						
	Single Task			Dual task		
	Result	% to previous evaluation	% to baseline assessment	Result	% to previous evaluation	% to baseline assessment
Box and Block Non-paretic hand						
Baseline	30	-	-	4	-	-
After 3 sessions	39	30,00	30,00	9	25,00	25,00
After 6 sessions	40	2,56	33,33	5	210,00	287,50
Final	36	-10,00	20,00	8	-41,94	125,00



Graphic 2: Box and Block Results (non-paretic hand) and linear tendency

Table 6: Box and Block test results and percentage relatively to previous and baseline assessments (paretic hand)

Box and Block Paretic hand						
	Single Task			Dual task		
	Result	% to previous evaluation	% to baseline assessment	Result	% to previous evaluation	% to baseline assessment
Baseline	7	-	-	4	-	-
After 3 sessions	9	28,57	28,57	9	125,00	125,00
After 6 sessions	13	44,44	85,71	5	-44,44	25,00
Final	6	-53,85	-14,29	8	60,00	100,00



Graphic 3: Box and Block Results (single Task) and linear tendency

Relatively to TUG, in table 7, results improved in both single and dual task condition, with these being higher in dual task, 28,86% when compared to baseline. In single task, subject took 16,07 sec. to complete the task at baseline and 13,78 sec. in the final assessment. In dual task, at baseline the participant took 26,78 sec. to complete the task and 19,10 sec. at the final assessment. Even though, results improved between baseline and final assessments, in dual task condition participant´s performance declined between the third and fourth evaluation.

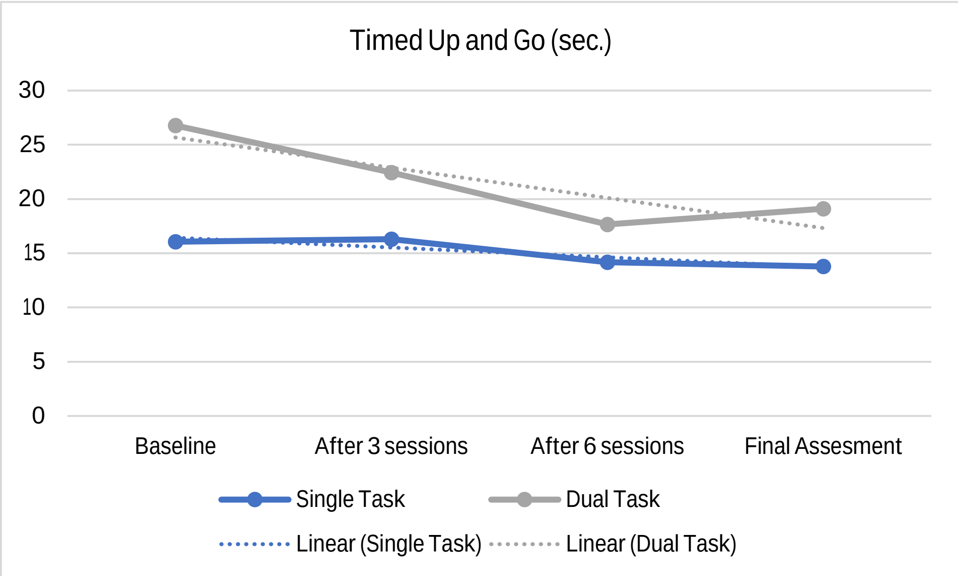
Linear tendency lines presented in graphic 4, show that the time the participant took to complete the task should reduce gradually over time in both single and dual task conditions. This is supported by the results presented in table 7, that show that percentages relatively to previous evaluations and to baseline assessment reduce in both cases.

These results show that subsect's functional mobility improved.

Table 7: Timed Up and Go results and percentage relatively to previous and baseline assessments

Timed Up and Go (sec.)						
	Single Task			Dual task		
	Result	% to previous evaluation	% to baseline assessment	Result	% to previous evaluation	% to baseline assessment
Baseline	16,07	-	-	26,78	-	-
After 3 sessions	16,30	1,43	1,43	22,45	-16,17	-16,17

Timed Up and Go (sec.)						
After 6 sessions	14,17	-13,07	-11,82	17,66	-21,34	-34,06
Final	13,78	-2,75	-14,25	19,10	8,15	-28,69



Graphic 4: Timed Up and Go results and linear tendency

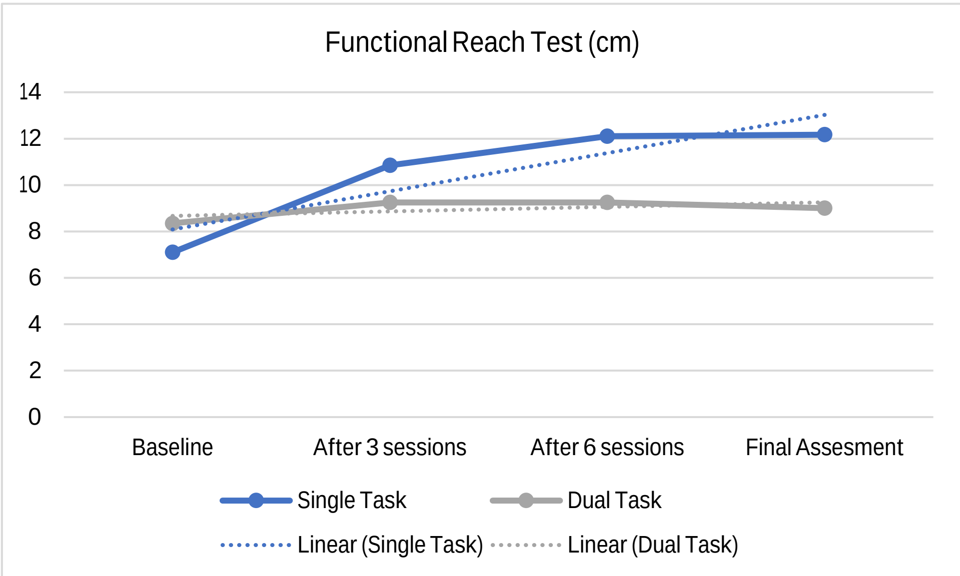
Regarding the FRT, in table 8, results improve in both single and dual task condition when compared to baseline, 71,41% and 7,78% correspondingly. Single task improvements are significant but dual task is only slight improvements. In single-task, participant reached 7,10 cm at baseline and 12,17 cm in the final assessment. In dual task, reached 8,35 cm at baseline and 9,00 cm in the final assessment. The biggest evolution was seen after 6 tDCS sessions, 52,82% in single task and 10,79% in dual task.

Linear tendency lines presented in graphic 5 show that functional reach should gradually improve over time. These results are supported by the results presented in table 8, that show that percentage relatively to previous evaluation and to baseline improve.

These results show that participant´s functional reach improved.

Table 8: Functional Reach Test Results and percentage relatively to previous and baseline assessments

Functional Reach Test (cm)						
	Single Task			Dual task		
	Result	% to previous evaluation	% to baseline assessment	Result	% to previous evaluation	% to baseline assessment
Baseline	7,10	-	-	8,35	-	-
After 3 sessions	10,85	52,82	52,82	9,25	10,79	10,79
After 6 sessions	12,10	11,52	70,42	9,25	0	10,79
Final	12,17	0,59	71,41	9,00	-2,70	7,78



Graphic 5: Functional Reach Test results and linear tendency lines

Table 9 compares secondary outcome results ate baseline and final assessment. Participant presents the same results in SULCS and in the Verbal Fluency Test in the baseline and final assessment. In the Digit Span there is a small difference between results in the Digit Span Forward but results from the Digit Span Backwards are equal.

Table 9: Secondary Outcome Results (baseline vs final assessment)

<table>
<tr><th colspan="6">Stroke Upper Limb Capacity Scale (SULCS)</th></tr>
<tr><th colspan="3">Baseline Assessment</th><th colspan="3">Final Assessment</th></tr>
<tr><td colspan="3">5</td><td colspan="3">5</td></tr>
<tr><th colspan="6">Digit Span</th></tr>
<tr><th colspan="3">Baseline Assessment</th><th colspan="3">Final Assessment</th></tr>
<tr><th>Digit Span Forward</th><th colspan="2">Digit Span Backwards</th><th>Digit Span Forward</th><th colspan="2">Digit Span Backwards</th></tr>
<tr><td>5</td><td colspan="2">2</td><td>6</td><td colspan="2">2</td></tr>
<tr><th colspan="6">Verbal Fluency Test</th></tr>
<tr><th colspan="3">Baseline Assessment</th><th colspan="3">Final Assessment</th></tr>
<tr><th>Semantic Fluency</th><th colspan="2">Phonetic Fluency</th><th>Semantic Fluency</th><th colspan="2">Phonetic Fluency</th></tr>
<tr><td rowspan="2">5</td><th>R</th><th>P</th><td rowspan="2">5</td><th>R</th><th>P</th></tr>
<tr><td>0</td><td>3</td><td>1</td><td>2</td></tr>
</table>

4. Discussion

The goal of this study is to evaluate the effects of 9 bihemispheric tDCS sessions over the primary motor cortex in individuals with chronic stroke on dual-task motor performance.

Several studies have been trying to demonstrate that tDCS combined with conventional therapies are effective in motor performance [8, 15, 16, 24, 49, 67, 102-105].Although, there is a lack of studies that investigate tDCS efficacy in dual task motor performance. Alisar and colleges [16] combined 15 sessions of bihemispheric tDCS over the primary motor cortex with physical and occupational therapy and found positive effects on upper limb motor performance [16]. Saeys et al [106]found that combining 16 tDCS sessions with occupational therapy intervention improves balance and postural control after stroke. Lindenberg at al.[104] also combined 5 bihemispheric tDCS sessions with physical and occupational therapy and found that upper limb motor performance improves after 5 tDCS sessions [104]. Kang et al. [107] reviewed tDCS effects in stroke rehabilitation and found that tDCS protocols are effective in motor recovery in chronic phase of stroke [107]. Hoornweder and colleges [7] also reviewed tDCS effects in upper limb function and found positive results after tDCS sessions [7].

In this study, after 9 sessions of tDCS subject´s results in handgrip strength, functional mobility, balance, and gross manual dexterity improved both in single and dual-task condition suggesting that bihemispheric tDCS combined with conventional therapies might be effective to improve dual-task motor performance.

Regarding handgrip strength, participant´s results increased until the sixth session of tDCS but slightly decreased in the last assessment. Prados-Romam [108] found that individual´s in chronic phase showed significant reduced handgrip strength. Fusco et al [109] compared different types of tDCS and did not found significant improvements in handgrip strength after tDCS. Goodwill et al [103] did not found significant improvements in handgrip strength but retention of motor function gains were higher in the experimental group.

Regarding gross manual dexterity, assessed by the BBT, results increased significantly in dual task (100%) but the same was not observed for single task, were the participant results decreased 14,29%. Abualait [110] found that bilateral tDCS over the primary motor cortex improves manual dexterity. Fusco et al [109] found that improvements for manual dexterity.

Results show that gross manual dexterity improved, even thought, handgrip strength did not improve significantly. Goodwill et al [103] found that motor function improves after bihemispheric tDCS but handgrip strength did not suffered any changes, indicating that the mechanisms that modulate motor function and strength may be independent. Therefore, tDCS combined with occupational therapy may improve gross manual dexterity and not handgrip strength.

Regarding functional mobility, assessed by the TUG, results decreased during the participation in this study, meaning that the time that the participant took to complete the task reduced. These improvements were seen in both single, 14,25%, and dual task, 28,69%. Improvements were higher in dual task condition. These findings are similar to those found in existing literature. Enzinger et al [111] found that bihemispheric tDCS over the primary motor cortex improve functional mobility in the chronic phase. Andrade et al [112] found similar results in acute phase [112]. Wong and colleagues [105] compared the three types of tDCS in dual task walking and found that bilateral tDCS significantly improves dual-task walking.

Regarding balance, assessed by the FRT, results improved in both single (54,93%) and dual task condition (1,80%). Improvements were more significant in single task condition. These are similar to those found in existing literature. As stated preciously, Saeys et al [106]found that combining 16 tDCS sessions with occupational therapy intervention improves balance and postural control after stroke. Improvements in balance are also confirmed by the results the participant had in TUG, although, balance is not the primary measure, balance is inherent to the task. Guo et al [113] concluded form their literature review that bilateral tDCS has the potential to improve balance control in older adults. Moura et al [114]also found that tDCS over the primary motor cortex improve balance and postural control.

After stroke, the motor and cognitive functions that are essential for dual-task performance, are impaired. Thus, tasks that are usually automatic in a normal condition may require attentional control, after brain damage, causing dual-task performance more difficult [4, 19, 29, 40, 43]. Dual task theories suggest that directing attention to movement control, which is usually automatic, cause a significant disruption in performance as a result from attentional limitations of the human cortex [37, 41]. Executing two tasks simultaneously may disrupt performance in one or both tasks, meaning that the task is no longer automatic [19, 39, 40]. This may justify the different results in TUG and FRT in dual task, even though, both assess balance. TUG includes gait and dynamic balance, two tasks performed in daily life and automatic. Contrarily, FRT is not an automatic task, therefore may require more attentional resources than TUG.

The interhemispheric competition model postulates that motor deficits after stroke result from deficits in interhemispheric inhibition with the ipsilesional cortex excitability decreasing while contralesional cortex excitability increases [4, 18, 23]. The primary motor cortex is responsible for overall motor decisions and movements [21] and plays a crucial role not only in motor planning, execution but also in skill learning[20, 22]. tDCS has the potential to increase cortical excitability of the ipsilesional motor cortex and decrease excitability of contralesional motor cortex [103], reactivating ipsilesional motor cortex which is associated with better functional outcomes in stroke [104]. In this study, the participant improved dual-task motor performance, but cognitive performance (Verbal Fluency Test and Digit Span) was very similar between the first and the last assessments. We postulate that these improvements were driven by motor learning and motor task automation rather than cognitive improvements. Liu and colleagues [29] proposed that conventional rehabilitation might improve motor capacity and reduce the attention needed to perform motor tasks [29].

Currently, tDCS parameters such as number of sessions, frequency, duration, current density, and electrodes used, are widely variable. Some authors have been trying to establish protocols for different conditions, but none were able to determine optimal stimulation parameters [7, 24, 30, 52]. Fregni et al [30], reviewed existing literature of tDCS in neurological and psychiatric disorders. They found that all types of tDCS might be effective when used in the chronic phase (level B evidence), but studies have high heterogeneity in results. Hoorneweder et al[7], also reviewed tDCS efficacy when combined with conventional therapies. They found that combining tDCS with conventional therapies leads to upper limb improvements, especially in the chronic phase [7]. Therefore, it is very difficult to determine optimal stimulation parameters for tDCS application in chronic stroke phase. tDCS sessions from this study were thought taking into consideration existing recommendations and similar studies, which were 20-minute sessions at 2 mA delivered by 30 cm^2 electrodes [24, 115, 116].

Strengths of this study include the use of an innovative technique and may contribute to verify tDCS efficacy in stroke rehabilitation in the chronic phase in dual task performance. It may contribute to the development and implementation of a new rehabilitation technique, were there are more limited offers. We also used instruments validated and with good psychometric properties and widely used in research.

Limitations of this study include a reduced sample size (only one subject). It also does not allow to confirm that improvements are related to combining traditional rehabilitation with tDCS sessions. Finally, it is not possible to confirm if stimulation was delivered to the primary motor cortex because tDCS still lacks precision. Other factors such as the medication the patient took regularly may influence tDCS efficacy [24, 50, 57].

Future studies should verify the efficacy of this protocol in large, randomized control trials including a larger number of patients and be performed in multiple centers at the same time in order to collect data from a representative sample of the population. Follow-up evaluations should be included in order to determine lasting tDCS effects. Optimal stimulation parameters such number of sessions, duration and intensity should be studied in other to offer stroke patients uniform treatment protocols.

5. Conclusion

Our findings indicate that transcranial direct current stimulation combined with traditional rehabilitation (physical and occupational therapy) may improve dual-task motor performance in chronic stroke. These results are important because they support the use of neuromodulation technique that can be used in chronic phases of stroke where there is little evidence of functional improvements.

In order to include tDCS in stroke rehabilitation it is important to identify variables that may influence tDCS efficacy and determine optimal stimulation parameters for each phase.

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