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Immediate Effect of Transcranial Direct Current Stimulation Combined with Functional Electrical Stimulation on Plantar Distribution and Body Sway Frequency in a Patient with Hemiparesis from Stroke: A Case Report

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Authors' contributions

This work was carried out in collaboration among all authors. Author AMAF designed the study, performed the statistical analysis, wrote the case and the first draft of the manuscript. Authors FIC and JCFC managed all phases of the study. Author GCC collaborated data collection. All authors read and approved the final manuscript.

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Case Report

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ABSTRACT

Objectives: The present study aimed to evaluate the immediate effect of a single session of anodal transcranial direct current stimulation (tDCS) over the primary motor cortex (M1) combined with functional electrical stimulation (FES) of the tibialis anterior (TA) muscle on plantar distribution and body sway frequency in an individual with hemiparesis stemming from a stroke. A further aim was to determine whether the effects of the combination of stimulation techniques would lead to greater improvement than the techniques administered separately.

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Methods: The therapy was conducted with one 60-year-old male with right-side stroke and complete, but disproportional hemiparesis with brachial predominance on the left side, 42 months elapsed since the event and severe Fugl-Meyer score. The patient was submitted to four different randomly performed intervention protocols with a 48-hour intervention between sessions: 1) anodal tDCS + sham FES + active TA contraction; 2) sham tDCS + active FES + active TA contraction; 3) anodal tDCS + active FES + active TA contraction; 4) sham tDCS + sham FES + active TA contraction). TDCS was administered for 20 minutes with the anode over C4 and the cathode over the supraorbital region on the contralateral side and FES was administered over the left TA. The evaluation of plantar distribution was performed with a foot-pressure platform and body sway frequency was evaluated using a force plate before and after each protocol.
Results: Beneficial changes occurred in the area of contact of the left hindfoot and right forefoot following intervention protocols 1, 2 and 3 and a reduction in body sway frequency occurred under all data acquisition conditions after protocols 1 and 2.
Conclusion: The use of tDCS (combined and alone) and the use of FES contributed to improvements in plantar distribution and body sway frequency in a stroke survivor with hemiparesis. The use of tDCS either alone or combined with FES achieved better results than the use of FES alone.

Keywords: tDCS; FES; hemiparesis; plantar distribution.

1. INTRODUCTION

Cerebrovascular accident (stroke) is characterized by an acute neurological deficit persisting for at least 24 hours that results in brain lesions stemming from the interruption of blood supply to a particular area of the brain [1]. According to a study conducted with the participation of the World Health Organization to determine the index of disease burden on the global scale, stroke is the third most common cause of disability-adjusted years of life among the 291 adverse health conditions and the major cause of chronic disability in both developed and developing countries [2].

Neuromotor impairment stemming from a stroke depends on the aetiology, severity, location and extent of the lesion. Hemiparesis or hemiplegia is one of the classic manifestations of a stroke and consists of the partial or complete impairment of one side of the body [3]. Hemiparesis causes a lack of ability to produce and/or regulate voluntary movements, leading to the inadequate activation of the muscles and a reduction in joint mobility. It can, therefore, cause bodily asymmetry, in which the lower limbs alter plantar distribution, with a reduction in heel support, causing an increase in lateral support of the feet and difficulty supporting the weight of the affected side of the body, thereby interfering with the ability to maintain one's balance and postural control [4,5]. As stroke survivors experience a reduction in their plantar support base and this results in a deviation of the centre of mass, leading to a biomechanical imbalance and unfavourable postural control, there is a need to find better forms of treatment to improve ankle movements. In situations of perturbed balance, an individual produces a torque on the tibialis anterior (TA) muscle (dorsiflexor), which is used to reverse the direction of the movement, thereby causing an inverted pendulum effect and directing the centre of mass to its original position to reduce body sway [6].

Therapeutic resources have been developed to address these limitations in patients with hemiparesis, such as functional electrical stimulation (FES). FES is a rehabilitation technique that consists of the use of an external, low-frequency electrical current, the aim of which is to promote the depolarization of the intact inferior motor neuron to initiate and facilitate the voluntary contraction of paretic muscles and produce functional movement. FES provides improvements in the fitness and strength of still intact motor units so that the patients can achieve better voluntary motor control and consequently the enhancement of the effect of training on such control. FES can also improve the flexibility and range of motion of the affected limb by leading to a reduction in spasticity of the antagonist muscle to the stimulus, thereby making voluntary efforts more effective [7]. Numerous studies have demonstrated the effect of FES, as described in a meta-analysis by Robins et al. (2006), a meta-analysis by Guimarães et al. (2013) and a recent review and meta-analysis by Howlett et al. [8-10].

Transcranial direct current stimulation (tDCS) is a novel therapeutic strategy focused on inducing plastic changes in the central nervous system.

This technique has been gaining attention due to its capacity to promote motor learning, which is the primary goal of the therapeutic program [11]. TDCS promotes changes in cortical excitability [12], improving motor function in individuals affected by brain lesions [13] through changes in the dysfunctional excitability pattern so that physical therapy can mould the process through the activation of neural networks specific to a given task, which is the functional pattern of cortical activity [14]. Recent studies have reported the benefits of tDCS on the motor and pre-motor regions [15], as well as improvements in both muscle strength and static postural stability [16]. However, no study has been conducted to test the effect of tDCS on improving plantar distribution in these patients.

The present study aimed to evaluate the immediate effect of a single session of anodal tDCS over the primary motor cortex combined with FES of the TA muscle on plantar distribution and body sway frequency in an individual with hemiparesis stemming from a stroke.

2. CASE REPORT

The present case report was conducted in compliance with the principles of Declaration of Helsinki and the Regulating Norms and Guidelines for Research Involving Human Subjects formulated by the Brazilian National Health Council, Ministry of Health, established in October 1996. This study received approval from the Institutional Review Board of University Nove de Julho (São Paulo, Brazil) under process number 767.866.

A 60-year-old male with a diagnosis of the stroke on May 25th, 2010 (history of 36 months) was selected for the present study. According to the clinical history, the patient remained hospitalized for 12 days and was then sent back to his family. However, he remained in a wheelchair for three months, with no active movement of the left lower limb. The patient began physical therapy five months after being discharged from hospital, undergoing treatment for two years and eight months, with the gradual return of being able to remain in a standing position and walk, but with significant limitations and requiring the use of a cane.

On March 17th, 2015, after being evaluated for the eligibility criteria (diagnosis of hemiparesis stemming from a stroke, absence of reduced ankle mobility due to a history of fracture, pins in the ankle and/or equinovarus (adult club foot deformity) and absence of contraindications to the use of tDCS or FES), the patient was asked to participate in the study, agreeing to do so by signing a statement of informed consent. An identification chart was filled out addressing the following information: personal data, topographic diagnosis of stroke (right-side ischemic lesion), time elapsed since event (36 months), evaluation of cognitive status (Mini-Mental State Examination: 27 points), anthropometric data (weight: 60 kg; height: 1.59 m; body mass index: 23.73 Kg/m^2), evaluation of motor impairment using Fugl-Meyer scale (45 points – classified as severe impairment) and the modified Ashworth scale (grade 3 spasticity of triceps surae). The evaluation of plantar distribution was performed with a foot-pressure platform and body sway frequency was evaluated using a force plate.

3. METHODS

3.1 Evaluation of Plantar Distribution

For the evaluation of plantar distribution, a foot-pressure plate (TekScan, model MatScan) measuring 0.50 by 0.60 cm was used. The acquisition frequency of 50 Hz was captured by 2704 piezoelectric sensors measuring 7.62 by 7.62 millimetres, which allows the stabilometric analysis of foot contact with the ground. The acquisition signals (support surface (contact by area in cm^2) of the right forefoot, left forefoot, right hindfoot and left hindfoot) were sent through an A/D converter with 16 bits of resolution and a sampling frequency of 250 Hz [17]. The signals were filtered using a band-pass filter with a cutoff frequency of 10 Hz. At the time of data collection, the patient was asked to remain still on the force plate, with the feet at the same distance as shoulder width. The first 60 seconds were used to calibrate the system based on the patient's body weight). During the reading, the patient remained standing for 60 seconds with his head aligned, focusing on a specific point of the wall at eye height [18]. The evaluation of plantar distribution was performed before and after each intervention protocol.

3.2 Stabilometric Analysis

For the analysis of body sway frequency, a force plate (Kistler model 9286BA) was used, with an acquisition frequency of 50 Hz captured by four piezoelectric sensors measuring 400 by 600 mm positioned at the ends of the platform. The postural oscillation frequency signals were

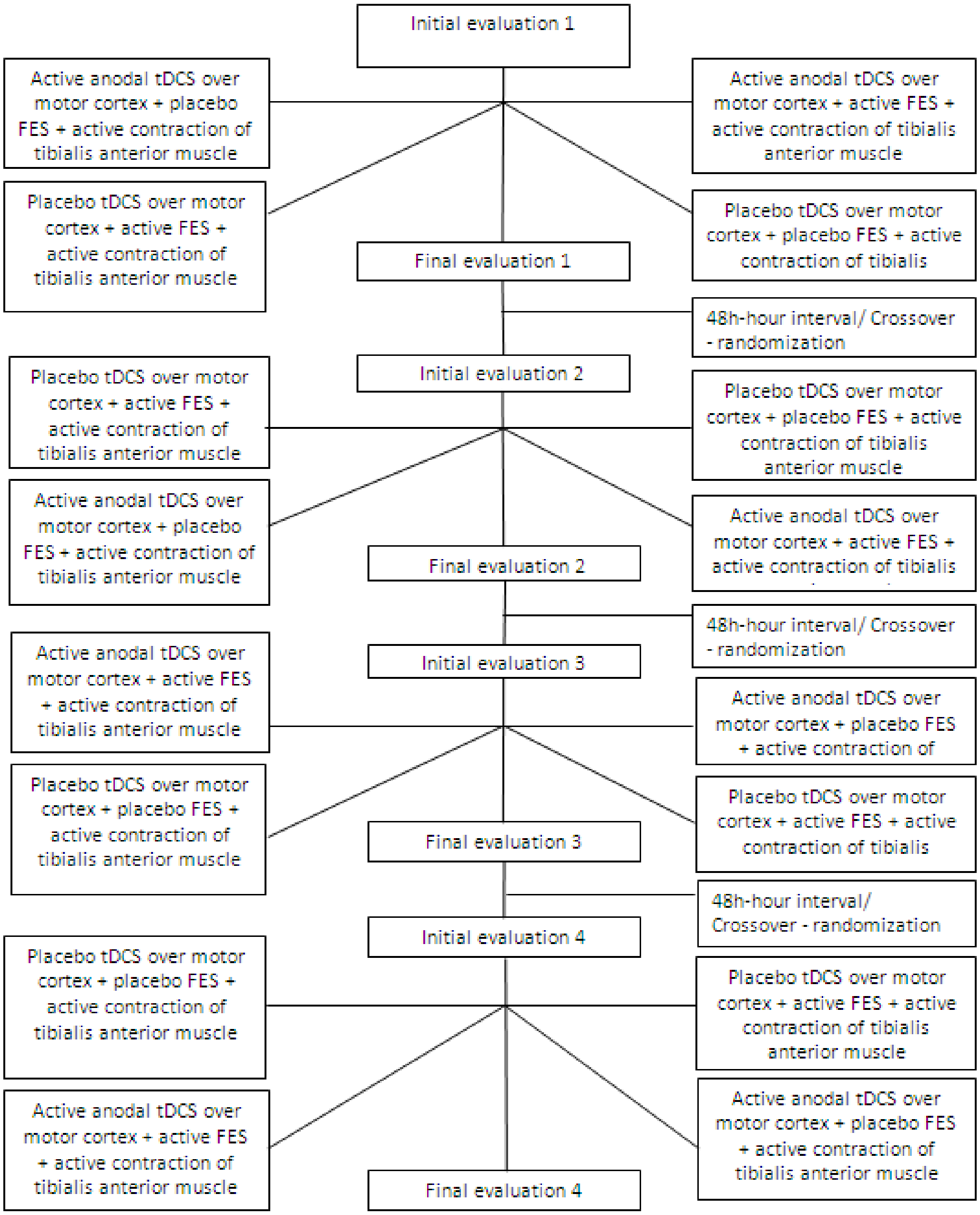

Fig. 1. Flowchart of study [19]

filtered using a 10-Hz band-pass filter and subsequently interpreted using the SWAY program (BTS Engineering) integrated and synchronized to the SMART-D 140® system [19]. For each evaluation, the patient was asked to remain in quiet standing with the feet aligned on the platform under two 30-second acquisition conditions: eyes open with gaze fixed on the horizon and eye closed.

3.3 Intervention

The study was developed following the flowchart presented in Fig. 1. A period of 48 hours was respected between interventions to avoid the potential cumulative effect of stimulation [19]. The order of the stimulation protocols was determined in a random fashion using a randomization table generated on the Excel^{TM}

program. During each protocol, the patient was initially submitted to the evaluations, followed by 20 minutes of treatment (active or sham stimulation of the two techniques employed) [19]. The patient underwent the evaluation a second time at the end of the session. Both the participant and raters were blinded to the intervention protocol employed.

3.4 tDCS

Transcranial stimulation was administered using the tDCS device (Tct Research 1 CH tdcs Simulator model 101). The anodal electrode was positioned over the primary motor cortex (C4) on the injured hemisphere and the cathode was positioned over the supraorbital region on the contralateral side (Fp1), following the recommendations of the 10-20 International System [20]. During the intervention, the patient remained positioned on a chair with the knee at 90° and the ankle in the neutral position. The current intensity was 2 mA. The patient was instructed to perform active contraction of the TA muscle with one to two contraction cycles (active contraction for six seconds followed by 12 seconds of rest), as instructed by the therapist during the 20 minutes of the administration of the protocol [19]. For sham stimulation, all the same, procedures were used, but the stimulator only remained switched on for the first 20 seconds. The patient was informed that he may feel a slight initial tingling, which might reduce, disappear or remain for the entire 20 minutes [12].

3.5 FES

FES was performed with low-frequency, biphasic, neuromuscular electrical stimulation currents. For such, a four-channel stimulation device (QUARK® FES VIF 995 DUAL) was used. Two electrodes were positioned: one on the motor point of the TA muscle and one on the belly of the muscle [19]. The patient remained in the same position as during the intervention with tDCS. FES was administered for 20 minutes, with a pulse width of 250 µs, modulated at frequency of 50 Hz, with one to two cycles of stimulation (six seconds on and 12 seconds off) [21], in sequential mode with the intensity increased until reaching the motor threshold and the patient was instructed to perform active contraction of the muscle during the stimulation times. Sham FES used the same parameters like the active form, but the equipment was switched on for 20 seconds, followed by a reduction in intensity until reaching 0 mA. The patient was informed that he may feel a slight initial tingling, which might reduce, disappear or remain for the entire intervention period [22].

4. RESULTS

Table 1 displays the changes in the area of foot contact (left forefoot and left hindfoot) before and after each intervention protocol. Protocols 3 and 4 led to a reduction in the area of the left forefoot after treatment and protocols 1, 2 and 3 led to an increase in the area of the left hindfoot after treatment.

Table 2 displays the changes about the area of foot contact (right forefoot and right hindfoot) before and after each intervention protocol. Protocols 1, 2 and led to a reduction in the area of the right forefoot after treatment and protocols 1 and 3 led to an increase in the area of the right hindfoot after treatment.

Table 3 demonstrates a reduction in body sway frequency both directions (AP and ML) in the post-treatment evaluation of protocols 1 and 3. However, protocol 2 led to a reduction in body sway frequency only under the condition of ML-EC and protocol 4 led to a reduction only under the condition of AP-EC.

5. DISCUSSION

According to Vandervoort (1999), ankle mobility is of considerable importance to humans, exerting a direct influence on balance, as greater ankle movement translates to a greater capacity to maintain one's balance [4]. However, stroke survivors often encounter problems with balance and stability due to the reduction in dorsiflexor muscle strength (TA muscle) and spasticity of the plantar flexor (triceps surae muscle), which causes poor alignment of the ankle, leading to equinovarus foot deformity. This situation causes a change in weight distribution of the lower limbs in the support phase of the gait cycle, thereby increasing the stress of the foot against the ground [23].

Currently, numerous studies have demonstrated the effect of FES on these problems in stroke survivors with hemiparesis [8-10]. However, few studies have demonstrated the immediate effect of tDCS on balance in healthy individuals [24,25] or those with neurological impairments [17]. Moreover, no study has demonstrated the effect of tDCS on plantar distribution in healthy

Table 1. Area of left forefoot and hindfoot contact before and after protocols with FES and tDCS

	Left forefoot (cm²)		Left hindfoot (cm²)	
	Before	**After**	**Before**	**After**
Protocol 1	45.50	46.56	0.47	8.44
Protocol 2	33.08	41.10	0.14	3.18
Protocol 3	41.28	33.60	3.31	17.38
Protocol 4	50.62	35.27	0.02	0.02

Legend: Protocol 1: sham FES + active tDCS + active contraction of TA muscle; Protocol 2: active FES + sham tDCS + active contraction of TA; Protocol 3: active FES + active tDCS + active contraction of TA muscle; Protocol 4: sham FES + sham tDCS + active contraction of TA muscle

Table 2. Area of right forefoot and hindfoot contact before and after protocols with FES and tDCS

	Right forefoot (cm²)		Right hindfoot (cm²)	
	Before	**After**	**Before**	**After**
Protocol 1	46.30	39.73	35.61	27.29
Protocol 2	53.24	46.96	29.80	30.80
Protocol 3	36.96	31.49	40.10	24.39
Protocol 4	41.36	53.08	31.64	35.23

Legend :Protocol 1: sham FES + active tDCS + active contraction of TA muscle; Protocol 2: active FES + sham tDCS + active contraction of TA; Protocol 3: active FES + active tDCS + active contraction of TA muscle; Protocol 4: sham FES + sham tDCS + active contraction of TA muscle

Table 3. Mean sway frequency (Hz) before and after protocols with FES and tDCS

	Sway frequency AP (EO)		Sway frequency AP (EC)		Sway frequency ML (EO)		Sway frequency ML (EC)	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Protocol 1	14.80	9.58	33.00	30.56	27.12	13.53	24.51	24.33
Protocol 2	6.19	11.03	18.10	18.88	2.85	6.21	16.34	15.56
Protocol 3	15.20	12.84	32.01	26.75	27.90	16.03	24.87	21.52
Protocol 4	6.69	10.34	22.33	20.08	6.14	15.49	6.11	22.81

Legend: AP: anteroposterior direction; ML: mediolateral direction; EO: eyes open; EC: eyes closed; Protocol 1: sham FES + active tDCS + active contraction of TA muscle; Protocol 2: active FES + sham tDCS + active contraction of TA; Protocol 3: active FES + active tDCS + active contraction of TA muscle; Protocol 4: sham FES + sham tDCS + active contraction of TA muscle

individuals or those with some type of neurological impairment. The aim of the present case report, however, was to evaluate the immediate effects of a session of anodal tDCS over the primary motor cortex combined with the use of FES for the TA muscle on plantar distribution and body sway frequency in an individual with hemiparesis stemming from a stroke.

The combined use of tDCS and FES led to a reduction in the contact area of the left forefoot of the affected side of the body, relatively distributing this load to the left hind foot, which was not previously able to offer support, and consequently adjusting the contract area of the right forefoot and right hindfoot (non-affected limb), thereby favouring the distribution of load on this leg. Moreover, improvements were found in body sway frequency under all evaluation conditions (AP and ML directions with eyes open and eyes closed), possibly due to the improvement in plantar distribution.

The use of tDCS administered jointly with FES demonstrated superior effects in comparison to the techniques applied in an isolated fashion, which is in agreement with previous studies. Kaski et al. (2013) submitted nine individuals with leukoaraiosis to tDCS combined and compared to physical training and found significant improvements in gait and balance when the techniques were combined [26]. Grecco et al. (2014) found improvements in gait velocity and oscillations of the centre of pressure in children with cerebral palsy following the administration of tDCS combined with treadmill training [27]. Likewise, Duarte et al. (2014) found improvements in static balance in children with cerebral palsy following tDCS combined with treadmill training [20].

In the present study, tDCS administered alone also led to changes in plantar distribution, increased the area of contact of the left hindfoot and reduced the area of contact of the right forefoot and hindfoot (non-affected limb). A reduction in body sway frequency also occurred under all conditions (AP and ML with eyes open and eyes closed). These findings are in agreement with data described in previous studies. Sohn et al. (2013) investigated the immediate effect of anodal tDCS over the injured primary motor cortex in 11 individuals with hemiparesis and found a significant improvement in general static postural stability [16]. ZHOU et al. (2014 found positive effects of tDCS on gait speed and a significant reduction in the area and velocity of oscillations of the centre of pressure during a dual cognitive task applied to healthy young individuals [25].

FES applied alone led to an increase in contact of the left hindfoot (affected limb), which consequently adjusted the contract area of the right forefoot and hindfoot (non-affected limb), thereby favouring a reduction in the load on the latter foot [28]. These findings are in agreement with data described in a study by Mesci et al. (2009), who administered FES to 40 patients with chronic hemiparesis stemming from a stroke and found an increase in the range of motion of ankle dorsiflexion, a reduction in spasticity of the plantar flexors and an increase in the functional mobility of the lower extremity [29]. However, FES alone was only capable of reducing body sway frequency in the ML direction with eyes closed. This finding is in disagreement with data described in a study by Chung et al. [30], who evaluated 10 stroke survivors and found that FES administered concomitantly with ankle dorsiflexion training led to significant improvements in balance under all evaluation conditions [31].

The sham intervention achieved a reduction in contact area only for the left forefoot, However, increases in area were found in the right forefoot and hindfoot (non-affected limb), which consequently led to an increase in body sway frequency under all conditions, except the AP direction with eyes closed, for which the area of contact was reduced.

6. CONCLUSION

The use of tDCS alone or combined with FES led to improvements in therapeutic and motor effects regarding plantar distribution and body sway frequency in an individual with hemiparesis stemming from a stroke. Moreover, the administration of tDCS either alone or combined with FES led to greater improvements in comparison to FES alone. However, further studies with a larger number of patients are needed to confirm the present findings.

CONSENT

As per international standard or university standard written patient consent has been collected and preserved by the author(s).

ETHICAL APPROVAL

As per international standard or university standard written ethical approval has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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