

## **Case report**

### **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.**

#### **ABSTRACT**

**Objectives:** The aim of the present study was 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. **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.

## 7 INTRODUCTION

8 Cerebrovascular accident (stroke) is characterized by an acute neurological deficit  
9 persisting for at least 24 hours that results in brain lesions stemming from the interruption of  
10 blood supply to a particular area of the brain [1]. According to a study conducted with the  
11 participation of the World Health Organization to determine the index of disease burden on the  
12 global scale, stroke is the third most common cause of disability-adjusted years of life among the  
13 291 adverse health conditions and the major cause of chronic disability in both developed and  
14 developing countries [2].

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

30 Therapeutic resources have been developed to address these limitations in patients with  
31 hemiparesis, such as functional electrical stimulation (FES). FES is a rehabilitation technique  
32 that consists of the use of an external, low-frequency electrical current, the aim of which is to  
33 promote the depolarization of the intact inferior motor neuron to initiate and facilitate the

34 voluntary contraction of paretic muscles and produce functional movement. FES provides  
35 improvements in the fitness and strength of still intact motor units so that the patients can  
36 achieve better voluntary motor control and consequently the enhancement of the effect of  
37 training on such control. FES can also improve the flexibility and range of motion of the affected  
38 limb by leading to a reduction in spasticity of the antagonist muscle to the stimulus, thereby  
39 making voluntary efforts more effective [7]. Numerous studies have demonstrated the effect of  
40 FES, as described in a meta-analysis by Robins et al. (2006), a meta-analysis by Guimarães et al.  
41 (2013) and a recent review and meta-analysis by Howlett et al. (2015) [8-10].

42 Transcranial direct current stimulation (tDCS) is a novel therapeutic strategy focused on  
43 inducing plastic changes in the central nervous system. This technique has been gaining attention  
44 due to its capacity to promote motor learning, which is the primary goal of the therapeutic  
45 program [11]. TDCS promotes changes in cortical excitability [12], improving motor function in  
46 individuals affected by brain lesions [13] through changes in the dysfunctional excitability  
47 pattern so that physical therapy can mold the process through the activation of neural networks  
48 specific to a given task, which is the functional pattern of cortical activity [14]. Recent studies  
49 have reported the benefits of tDCS on motor and pre-motor regions [15], as well as  
50 improvements in both muscle strength and static postural stability [16]. However no study has  
51 been conducted to test the effect of tDCS on improving plantar distribution in these patients.

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

## 56 **CASE REPORT**

57 The present case report was conducted in compliance with the principles of Declaration  
58 of Helsinki and the Regulating Norms and Guidelines for Research Involving Human Subjects  
59 formulated by the Brazilian National Health Council, Ministry of Health, established in October  
60 1996. This study received approval from the Institutional Review Board of University Nove de  
61 Julho (São Paulo, Brazil) under process number 767.866.

62 A 60-year-old male with a diagnosis of stroke on May 25<sup>th</sup>, 2010 (history of 36 months)  
63 was selected for the present study. According to the clinical history, the patient remained  
64 hospitalized for 12 days and was then sent back to his family. However, he remained in a

65 wheelchair for three months, with no active movement of the left lower limb. The patient began  
66 physical therapy five months after being discharged from hospital, undergoing treatment for two  
67 years and eight months, with the gradual return of being able to remain in a standing position and  
68 walk, but with significant limitations and requiring the use of a cane.

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

81

## 82 **METHOD**

### 83 **Evaluation of plantar distribution**

84 For the evaluation of plantar distribution, a foot-pressure plate (TekScan, model  
85 MatScan) measuring 0.50 by 0.60 cm was used. The acquisition frequency of 50 Hz was  
86 captured by 2704 piezoelectric sensors measuring 7.62 by 7.62 millimeters, which allows the  
87 stabilometric analysis of foot contact with the ground. The acquisition signals (support surface  
88 (contact by area in cm<sup>2</sup>) of the right forefoot, left forefoot, right hindfoot and left hindfoot) were  
89 sent through an A/D converter with 16 bits of resolution and a sampling frequency of 250 Hz  
90 [17]. The signals were filtered using a band-pass filter with a cutoff frequency of 10 Hz. At the  
91 time of data collection, the patient was asked to remain still on the force plate, with the feet at the  
92 same distance as shoulder width. The first 60 seconds were used to calibrate the system based on  
93 the patient's body weight). During the reading, the patient remained standing for 60 seconds with  
94 his head aligned, focusing on a specific point of the wall at eye height [18]. The evaluation of  
95 plantar distribution was performed before and after each intervention protocol.

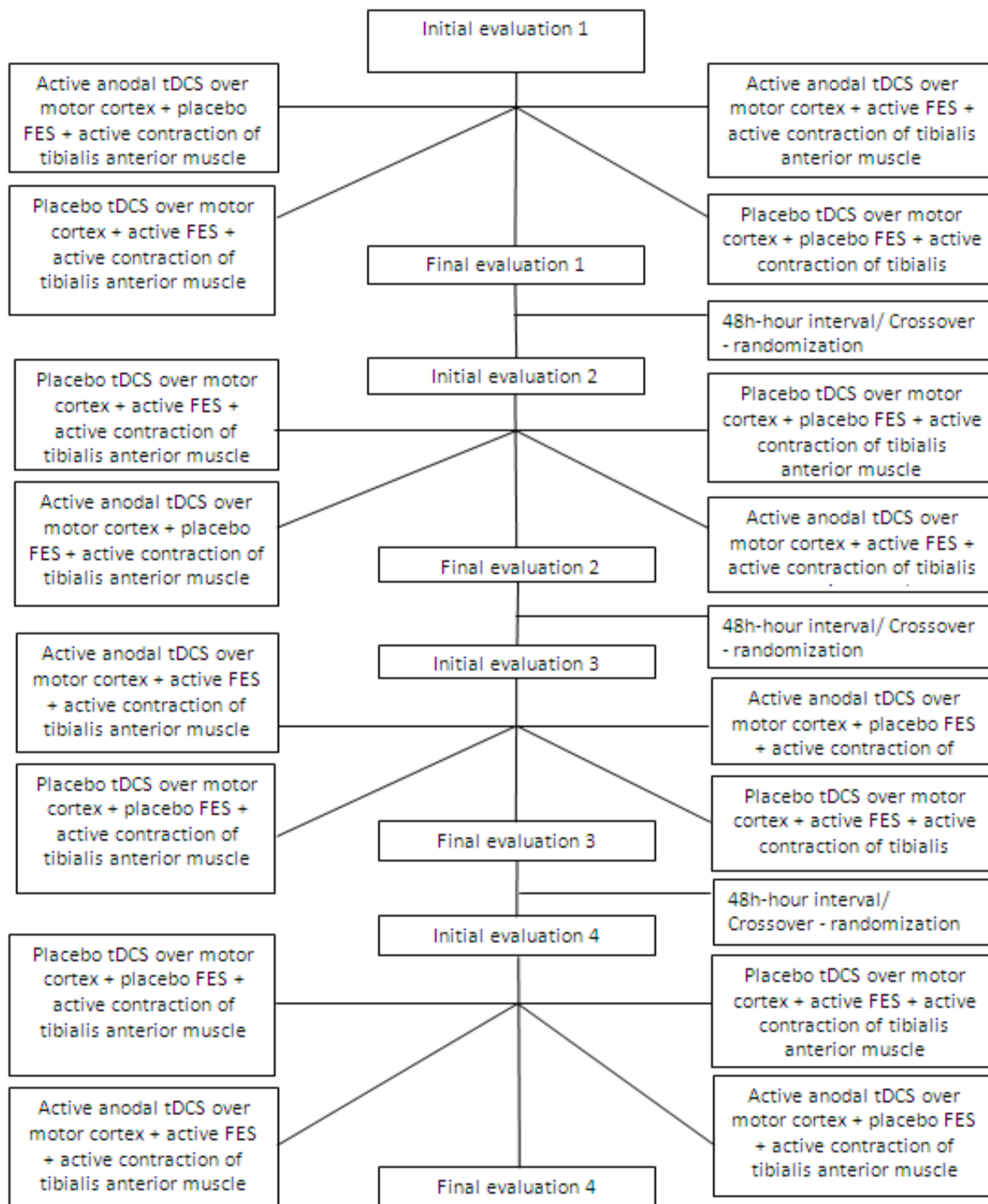
96 **Stabilometric analysis**

97 For the analysis of body sway frequency, a force plate (Kistler model 9286BA) was used,  
98 with an acquisition frequency of 50 Hz captured by four piezoelectric sensors measuring 400 by  
99 600 mm positioned at the ends of the platform. The postural oscillation frequency signals were  
100 filtered using a 10-Hz band-pass filter and subsequently interpreted using the SWAY program  
101 (BTS Engineering) integrated and synchronized to the SMART-D 140® system [19]. For each  
102 evaluation, the patient was asked to remain in quiet standing with the feet aligned on the  
103 platform under two 30-second acquisition conditions: eyes open with gazed fixed on the horizon  
104 and eye closed.

105

106 **INTERVENTION**

107 The study was developed following the flowchart presented in Figure 1. A period of 48 hours  
108 was respected between interventions to avoid the potential cumulative effect of stimulation [19].  
109 The order of the stimulation protocols was determined in a random fashion using a  
110 randomization table generated on the Excel™ program. During each protocol, the patient was  
111 initially submitted to the evaluations, followed by 20 minutes of treatment (active or sham  
112 stimulation of the two techniques employed) [19]. The patient underwent the evaluation a second  
113 time at the end of the session. Both the participant and raters were blinded to the intervention  
114 protocol employed.



115  
 116 Figure 1- Flowchart of study [19].

117  
 118

119 **tDCS**

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

132  
133 **FES**

134 FES was performed with low-frequency, biphasic, neuromuscular electrical stimulation  
135 currents. For such, a four-channel stimulation device (QUARK® FES VIF 995 DUAL) was  
136 used. Two electrodes were positioned: one on the motor point of the TA muscle and one on the  
137 belly of the muscle [19]. The patient remained in the same position as during the intervention  
138 with tDCS. FES was administered for 20 minutes, with a pulse width of 250 µs, modulated at  
139 frequency of 50 Hz, with one to two cycles of stimulation (six seconds on and 12 seconds off)  
140 [21], in sequential mode with the intensity increased until reaching the motor threshold and the  
141 patient was instructed to perform active contraction of the muscle during the stimulation times.  
142 Sham FES used the same parameters as the active form, but the equipment was switched on for  
143 20 seconds, followed by a reduction in intensity until reaching 0 mA. The patient was informed  
144 that he may feel a slight initial tingling, which might reduce, disappear or remain for the entire  
145 intervention period [22].

146  
147 **RESULTS**

148 Table 1 displays the changes with regard to the area of foot contact (left forefoot and left  
149 hindfoot) before and after each intervention protocol. Protocols 3 and 4 led to a reduction in the

150 area of the left forefoot after treatment and protocols 1, 2 and 3 led to an increase in the area of  
151 the left hindfoot after treatment.

152

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

155

	<b>Left forefoot (cm<sup>2</sup>)</b>		<b>Left hindfoot (cm<sup>2</sup>)</b>	
	Before	After	Before	After
Protocol 1	45.50	46.56	0.47	<b>8.44</b>
Protocol 2	33.08	41.10	0.14	<b>3.18</b>
Protocol 3	41.28	<b>33.60</b>	3.31	<b>17.38</b>
Protocol 4	50.62	<b>35.27</b>	0.02	0.02

156

157 *Legend: Protocol 1: sham FES + active tDCS + active contraction of TA muscle; Protocol 2:*  
158 *active FES + sham tDCS + active contraction of TA; Protocol 3: active FES + active tDCS +*  
159 *active contraction of TA muscle; Protocol 4: sham FES + sham tDCS + active contraction of TA*  
160 *muscle.*

161

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

166

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

	<b>Right forefoot (cm<sup>2</sup>)</b>		<b>Right hindfoot (cm<sup>2</sup>)</b>	
	Before	After	Before	After
Protocol 1	46.30	<b>39.73</b>	35.61	<b>27.29</b>
Protocol 2	53.24	<b>46.96</b>	29.80	30.80
Protocol 3	36.96	<b>31.49</b>	40.10	<b>24.39</b>



Protocol 4	41.36	53.08	31.64	35.23
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169

170 *Legend :Protocol 1: sham FES + active tDCS + active contraction of TA muscle; Protocol 2:*  
 171 *active FES + sham tDCS + active contraction of TA; Protocol 3: active FES + active tDCS +*  
 172 *active contraction of TA muscle; Protocol 4: sham FES + sham tDCS + active contraction of TA*  
 173 *muscle.*

174

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

179

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

181

	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	<b>9.58</b>	33.00	<b>30.56</b>	27.12	<b>13.53</b>	24.51	<b>24.33</b>
Protocol 2	6.19	11.03	18.10	18.88	2.85	6.21	16.34	<b>15.56</b>
Protocol 3	15.20	<b>12.84</b>	32.01	<b>26.75</b>	27.90	<b>16.03</b>	24.87	<b>21.52</b>
Protocol 4	6.69	10.34	22.33	<b>20.08</b>	6.14	15.49	6.11	22.81

182

183 *Legend: AP: anteroposterior direction; ML: mediolateral direction; EO: eyes open; EC: eyes*  
 184 *closed; Protocol 1: sham FES + active tDCS + active contraction of TA muscle; Protocol 2:*  
 185 *active FES + sham tDCS + active contraction of TA; Protocol 3: active FES + active tDCS +*  
 186 *active contraction of TA muscle; Protocol 4: sham FES + sham tDCS + active contraction of TA*  
 187 *muscle.*

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192 **DISCUSSION**

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

201 Currently, numerous studies have demonstrated the effect of FES on these problems in  
202 stroke survivors with hemiparesis [8-10]. However, few studies have demonstrated the  
203 immediate effect of tDCS on balance in healthy individuals [24,25] or those with neurological  
204 impairments [17]. Moreover, no study has demonstrated the effect of tDCS on plantar  
205 distribution in healthy individuals or those with some type of neurological impairment. The aim  
206 of the present case report, however, was to evaluate the immediate effects of a session of anodal  
207 tDCS over the primary motor cortex combined with the use of FES for the TA muscle on plantar  
208 distribution and body sway frequency in an individual with hemiparesis stemming from a stroke.

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

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

223 improvements in static balance in children with cerebral palsy following tDCS combined with  
224 treadmill training [20].

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

235 FES applied alone led to an increase in contact of the left hindfoot (affected limb), which  
236 consequently adjusted the contract area of the right forefoot and hindfoot (non-affected limb),  
237 thereby favoring a reduction in the load on the latter foot. These findings are in agreement with  
238 data described in a study by Mesci et al. (2009), who administered FES to 40 patients with  
239 chronic hemiparesis stemming from a stroke and found an increase in the range of motion of  
240 ankle dorsiflexion, a reduction in spaticity of the plantar flexors and an increase in the functional  
241 mobility of the lower extremity [28]. However, FES alone was only capable of reducing body  
242 sway frequency in the ML direction with eyes closed. This finding is in disagreement with data  
243 described in a study by Chung et al. (2015), who evaluated 10 stroke survivors and found that  
244 FES administered concomitantly with ankle dorsiflexion training led to significant improvements  
245 in balance under all evaluation conditions [29].

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

250

## 251 **CONCLUSION**

252 The use of tDCS alone or combined with FES led to improvements in therapeutic and  
253 motor effects regarding plantar distribution and body sway frequency in an individual with

254 hemiparesis stemming from a stroke. Moreover, the administration of tDCS either alone or  
255 combined with FES led to greater improvements in comparison to FES alone. However, further  
256 studies with a larger number of patients are needed to confirm the present findings.

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## 260 **COMPETING INTERESTS**

261 The authors declare that they have no conflicts of interest.

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