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ORIGINAL ARTICLE

Effects of transcranial direct current stimulation on joint flexibility and pain in sedentary male individuals

Effets de la stimulation directe sur la des articulations et la douleur chez des personnes masculines

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KEYWORDS
Non-invasive brain stimulation;
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Flexibility;
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Summary The aim of this study was to analyze the effects of cathodal tDCS (c-tDCS) on joint flexibility and pain perception in a sedentary male. Eight male healthy, sedentary right-leg-dominant and novice in muscle stretching aged between 19 and 30 years (24.0 ± 4.0 years) were recruited. Subjects performed three experimental conditions in a randomized, double-blinded crossover design: anodal stimulation (a-tDCS), c-tDCS and sham-tDCS (2 mA for 20 minutes targeting the bilaterally motor cortex). Before and immediately after the experimental conditions (baseline and post-condition, respectively), subjects completed the range of motion (ROM) of right hip test and the Visual Analogic Scale for Pain (VAS pain; level of significance $P < 0.05$). In post-condition, c-tDCS was greater than to a-tDCS ($P < 0.001$), and sham-tDCS ($P < 0.001$) in the right hip ROM. Hip ROM increased in the post-condition compared to baseline in the c-tDCS condition ($P < 0.001$). In the a-tDCS condition, hip ROM decreased in the post-condition compared to baseline ($P < 0.001$). For VAS pain, in post-condition,

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c-tDCS was less than a-tDCS ($P < 0.001$), and sham-tDCS ($P < 0.001$). In the c-tDCS condition, the VAS pain decreased in the post-condition compared to baseline ($P < 0.001$). This study suggests that c-tDCS applied to SM1 may promote increased in ROM of the hip and decreased and perception of pain.

MOTS
Stimulation cérébrale non invasive ;
Stimulation

courant continu ;
Flexibilité ;
Douleur ;
Cortex moteur primaire

Le but de cette étude était d'analyser les effets du tDCS cathodique (c-tDCS) sur la flexibilité des articulations et la perception de la douleur chez un homme sédentaire. Huit hommes en bonne santé, sédentaires, dominants de la jambe droite et novices en étirement musculaire de 19 30 ans (24,0 ± 4,0 ans) ont été recrutés. Les sujets ont réalisé trois conditions expérimentales dans un plan croisé randomisé double insu : stimulation anodale (a-tDCS), c-tDCS et sham-tDCS (2 mA pendant 20 minutes en ciblant le cortex moteur bilatéral). Avant et immédiatement les conditions expérimentales (de base et post-condition, respectivement), les sujets ont complété l'amplitude de mouvement (ROM) du test de la hanche droite et l'échelle visuelle-analogique de la douleur (douleur EVA ; niveau de signification $p < 0,05$). En post-condition, c-tDCS était supérieur a-tDCS ($p < 0,001$) et sham-tDCS ($p < 0,001$) dans la ROM de la hanche droite. La ROM de la hanche a augmenté dans la post-condition par rapport aux valeurs de base dans la condition c-tDCS ($p < 0,001$). Dans la condition a-tDCS, la ROM sous hanche a diminué dans la post-condition par rapport au niveau de base ($p < 0,001$). Pour la douleur liée l'EVA, en post-condition, le c-tDCS était inférieur a-tDCS ($p < 0,001$) et au sham-tDCS ($p < 0,001$). Dans les conditions c-tDCS, la douleur liée l'EVA diminuait la condition par rapport la situation initiale ($p < 0,001$). Cette étude que le c-tDCS appliqué SM1 pourrait favoriser une augmentation de la ROM de la hanche et une diminution de la perception de la douleur.

1. Introduction

Stretching refers to a movement applied to increase the range of motion (ROM) of joints, i.e. flexibility, and have been used by sports coaches for performance enhancement and injury prevention by regaining joint ROM [1]. Traditionally, stretching exercises have been studied in relation to injury [2], performance [3], and muscle soreness [4]. The stretching is an effective method to chronically increase the joint range of motion [5]. This increase in ROM has been related to both neural [6,7] and mechanical [8] factors. More recently, a sensory theory has been proposed suggesting instead that increases in muscle extensibility are due to a modification of sensation only [9].

Different forms of stretching exercises are an effective way of improving ROM in healthy individuals [10,11] and other techniques have been proposed for improvement of the ROM as the yoga [12] and transcranial direct current stimulation [13]. Transcranial direct current stimulation (tDCS) consists of a non-invasive electrical stimulus that can promote excitation, through tonic depolarization of the membrane resting potential (anodal stimulus, a-tDCS), or cortical inhibition, by hyperpolarization of the membrane resting potential (cathodal stimulus, c-tDCS) [14,15]. This non-invasive neuromodulatory technique has been used as an ergogenic in healthy subjects to induce changes in physical performance, such as increase in muscular strength [16,17], and joint flexibility [18], and reduction in ratings perceived exertion [16,18], and pain [19].

Only one study investigated the effects of tDCS on joint flexibility in healthy subjects [13]. In this study, c-tDCS over the sensorimotor cortex (SM1), with a current of 10 minutes and intensity of 2.0 mA, resulted in a 10.5% increase in ROM of the ankle in eight male healthy [13]. The author's suggestion that the SM1 was involved in joint flexibility because the passive torque did not change and this may have been affected neural factors, such as perception of joint angle or pain. Corroborating this hypothesis, the c-tDCS applied over cortical regions of the pain neuromatrix, as the SM1, increased pain thresholds in healthy adults [20]. To test the hypothesis that the SM1 is involved in joint flexibility, we investigated whether c-tDCS over SM1 bilaterally modifies hip ROM and decrease pain perception in the sedentary male. Thus, the aim of this study was to investigate whether the effects of c-tDCS on joint flexibility and pain in sedentary male, would enhance hip ROM, and decrease pain perception in comparison to a-tDCS and sham-tDCS.

2. Methods

2.1. Subjects

Eight male healthy, sedentary [21] and novice in muscle stretching, right-leg-dominant, and aged between 19

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and 30 years (24.0 ± 4.0 years) were recruited. Regarding anthropometric measurements, participants averaged 84.1 ± 17.6 kg of body mass and 173.6 ± 4.1 cm of height. Were excluded subjects that had neuropsychiatric, cardiovascular, or osteoarticular diseases, used any kind of neuropsychiatric drugs, and used any caffeinated beverage on the day of the experiment or alcoholic beverages in the day before. The sample size was calculated using G*Power software (version 3.1). For analysis we use the following commands: Test family = F-tests, Statistical test = analysis of variance (Anova): repeated measures between factors, α error probability = 0.05, power (1-β error probability) = 0.80, and effect size was set with d = 0.54 [13]. This effect size was calculated according to the mean and standard deviation data of c-tDCS and sham-tDCS interventions [13]. A total of 5 participants in each condition were needed for this study. Each participant signed a written consent form, and the experiment was approved by the institutional ethics committee of the Salgado Oliveira University, according to the Norms of Conduct in Human Research (CNS resolution 466/2012).

2.2. Anthropometric measurements

Participants' body mass and height were measured with a weighing scale and stadiometer (Filizola model 31; Filizola S.A., Paulo, Brazil), following the recommendations proposed by the International Society for Advancement of Kinanthropometry [21].

2.3. Application of transcranial direct current stimulation (tDCS)

The subjects remained seated comfortably in a chair located within the laboratory. The electric current of 2 mA was applied using a pair of pads soaked in saline solution (NaCl 140 mmol dissolved in Milli-Q water) comprising the two 5 × 5 cm electrodes, connected to a direct current stimulation device (TCT, China) and positioned using elastics. The stimulation procedures had the duration of 20 minutes. The procedures for placing the electrodes followed the proposals of Mizuno et al. [13]. For c-tDSC, the cathode electrode is placed over the SM1 bilaterally and anode electrode was placed over the occipital cortex (OC), both located on electrode area Cz and Oz, in accordance with the international 10–20 system EEG [22]. For a-tDCS the anode was placed over the SM1 and cathode was placed over the OC. In the sham-tDCS condition, the electrodes were placed in the same positions of the a-tDCS. However, the stimulator was turned off after 30 seconds, acting as a placebo condition [23]. Patients usually report tingling sensations or itching from the initial electrical stimulation but there is evidence that there are no stimulation effects has the device is turned off during the remaining time. This procedure allows the subjects to become blinded to the type of stimulus that they will receive during the experiment [24]. All tDCS procedures were conducted by the same research assistant.

2.4. ROM of the hip (hip ROM)

To evaluate the range of motion of the joint hip, an angular test was used, as proposed by the American College of Sports Medicine (ACSM) [21], with the use of a digital goniometer (IGAGING®, Paulo, Brazil). The subject was positioned in dorsal decubitus, with the hip at zero degrees of flexion, extension, adduction, abduction, and rotation. A first evaluator kept the subject's contralateral leg fixed to the stretcher while passively raised the other to the highest level of discomfort or pain reported by the subject, keeping the knee extended, and the foot in a neutral position by a single attempt. Then, the second evaluator performed the measurement of the angle reached by the maximum ROM in the joint right hip. The goniometer was positioned as follows: Fulcrus = major trochanter of the femur; Stabilization branch = lateral midline of the pelvis; Mobile branch = lateral midline of the femur, using the lateral epicondyle as the reference point.

2.5. Visual Analogic Scale for Pain (VAS pain)

The VAS pain is a unidimensional measure of pain intensity valid, reliable and appropriate for use in clinical practice [25]. For pain intensity, the scale is most commonly anchored by ''no pain'' (score of 0) and ''pain as bad as it could be'' or ''worst imaginable pain'' (score of 10 [100-mm scale]) [26].

2.6. Experimental procedures

Each participant had 4 visits to the laboratory. On the first visit, subjects assigned the consent form, completed a socio-demographic questionnaire, and were submitted to anthropometric measurement. The subjects had to perform a warm-up on the cycle ergometer, with duration of 5 minutes, 70 rpm and the initial load (kg) was adjusted according to body weight before performing the ROM of the right hip test. After warm-up, the subjects performed the ROM of the right hip test and during the maximum Hip ROM, the pain scale was measured through the VAS Pain [26]. The procedures of the first visit were used as familiarization to the later experimental procedures. Following the initial visit, with 48 to 72 hours of the intervals between the visits, subjects attended the lab for the three experimental conditions (c-tDCS, a-tDCS, or sham-tDCS), with session order randomly counterbalanced across participants. The randomization scheme was generated by using the Web site Randomization.com (http://www.randomization.com). Before and after the experimental conditions (baseline, and post-stimulation), subjects performed the warm-up, ROM of the hip (hip ROM) and the VAS pain during test performance (Fig. 1). All sessions were performed in the afternoon (i.e., 14:00–17:00-hour p.m.) to avoid circadian effects on the flexibility. The ambient temperature ranged from 21° C to 23° C and relative humidity ranged from 55 to 70%. Subjects were also informed to maintain their regular food and hydration diet before performing the visits and were discouraged to consume ergogenic beverages like coffee. The Hip ROM and VAS Pain were conducted by two researchers and tDCS was conducted for another research assistant.

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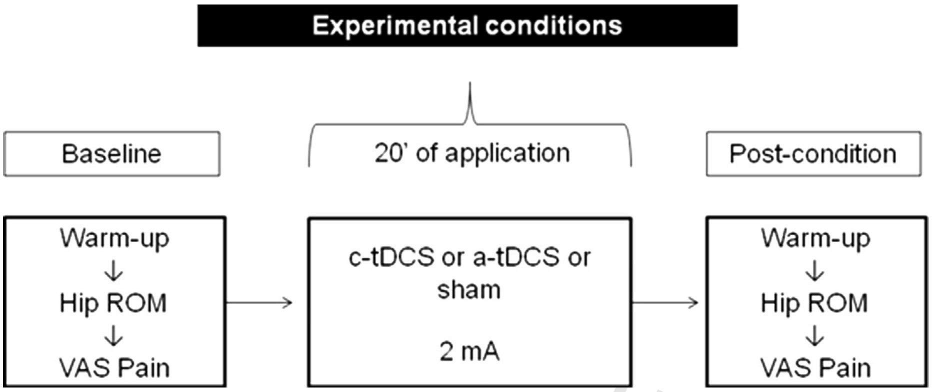

Figure 1 Experimental design.

2.7. Statistical analyses

A two-way analysis of variance (Anova) with repeated measures with the entrance for condition (c-tDCS, a-tDCS, and sham) and time (baseline, and post-condition) were performed for the hip ROM and VAS pain. The sphericity assumption was tested using the Mauchly's test and the Greenhouse-Geisser correction was used whenever data sphericity was violated. Post-hoc comparisons were performed using the Bonferroni correction. Values were reported with mean and standard deviation. The level of significance was set at $P \leq 0.05$. The analysis was undertaken using SPSS 23,0.

A bivariate Pearson correlation (r) was performed, in order to determine a possible association between hip ROM and VAS pain measures for the c-tDCS and a-tDCS conditions. This association was determined between post-condition-minus baseline scores in both measures.

Effect size analysis was conducted to report the magnitude of differences between the c-tDCS and a-tDCS conditions compared to sham for hip ROM and VAS pain. Effect sizes were computed using the equation proposed by Morris and De Shon [27], on the G*Power software (version 3.1). Effect sizes were classified as trivial ($d < 0.19$), small ($d = 0.20$–0.49), moderate ($d = 0.50$–0.79), large ($d = 0.80$–1.29), and very large ($d > 1.30$) [28]. In each condition, a descriptive analysis was performed for responders vs. non-responders. To be considered responder, each participant need to simply respond to the training protocol used in the study, and non-responder is the participant that simply do not respond to the training but that doesn't necessarily mean they would not respond to any training program [29]. We use changes from of the baseline to post-condition in each subject for the hip ROM and VAS pain. The absolute values were expressed for each subject.

3. Results

Two-way repeated measures Anova's showed significant interactions between condition and time ($F(2,14) = 140.36$; $P < 0.001$), and main effect for condition ($F(2,14) = 60.17$; $P < 0.001$) in hip ROM. There was no significant main effect for time ($F(1,7) = 3.01$; $P > 0.05$). There were no significant differences between the conditions in the baseline (c-tDCS: $109.0 \pm 4.3°$; a-tDCS: $109.8 \pm 4.7°$; sham-tDCS: $110.1 \pm 4.6°$, $P > 0.05$). In post-condition, c-tDCS ($123.9 \pm 4.1°$) was greater than a-tDCS ($100.4 \pm 1.2°$, $P < 0.001$), and sham-tDCS ($110.7 \pm 4.2°$, $P < 0.001$). At this time, sham-tDCS was greater than a-tDCS ($P < 0.001$). There was baseline to post-condition changes in both c-tDCS and a-tDCS conditions. The hip ROM increased in the post-condition compared to baseline in the c-tDCS condition (baseline: $109.0 \pm 4.3°$, post-condition: $123.9 \pm 4.1°$, $P < 0.001$). In the a-tDCS condition, the hip ROM decreased in the post-condition compared to baseline (baseline: $109.8 \pm 4.7°$, post-condition: $100.4 \pm 1.2°$, $P < 0.001$) (Fig. 2).

For VAS pain, two-way repeated measures Anova's showed significant interactions between condition and time ($F(2,14) = 57.49$; $P < 0.001$), main effect for condition ($F(2,14) = 94.25$; $P < 0.001$), and main effect for time ($F(1,7) = 56.70$; $P < 0.001$). There were no significant differences between the conditions in the baseline (c-tDCS: 9.5 ± 0.7; a-tDCS: 9.6 ± 0.5; sham-tDCS: 9.6 ± 0.5, $P > 0.05$) for pain perception. In post-condition, the pain perception in the c-tDCS (5.1 ± 0.8) was less than a-tDCS (9.5 ± 0.5, $P < 0.001$), and sham-tDCS (9.6 ± 0.5, $P < 0.001$). In the c-tDCS condition, the VAS pain decreased in the post-condition compared to baseline (baseline: 9.5 ± 0.7, post-condition: $5.1 \pm 0.8°$, $P < 0.001$) (Fig. 3).

No correlations was showed between post-condition-minus baseline scores in the hip ROM and VAS pain measures for the c-tDCS ($r = 0.02$, $P > 0.05$) and a-tDCS ($r = -0.12$, $P > 0.05$) conditions.

Means and standard deviation values are shown in Table 1. Effect size was very large in the c-tDCS condition compared to sham-tDCS ($d = 2.38$) and trivial in the a-tDCS condition compared to sham-tDCS ($d = 0.07$) in hip ROM. For VAS pain, effect size was very large in the c-tDCS condition compared to sham-tDCS ($d = -5.05$) and trivial in the a-tDCS condition compared to sham-tDCS ($d = 0.16$) (Table 1).

Regarding responders and non-responders was showed that the c-tDCS condition provided an increase in the hip ROM in all subjects (range: 7.9 to 23.5°). The a-tDCS condition provided a decrease in hip ROM in all subjects (range: −3.2 to −17.5°). In the sham-tDCS condition occurred a small increase (range: 1 to 3°) and decrease (range: −1.7 to −2°) in hip ROM (Fig. 4).

Responders and non-responders were showed that the c-tDCS condition provided a decrease in VAS pain in all subjects

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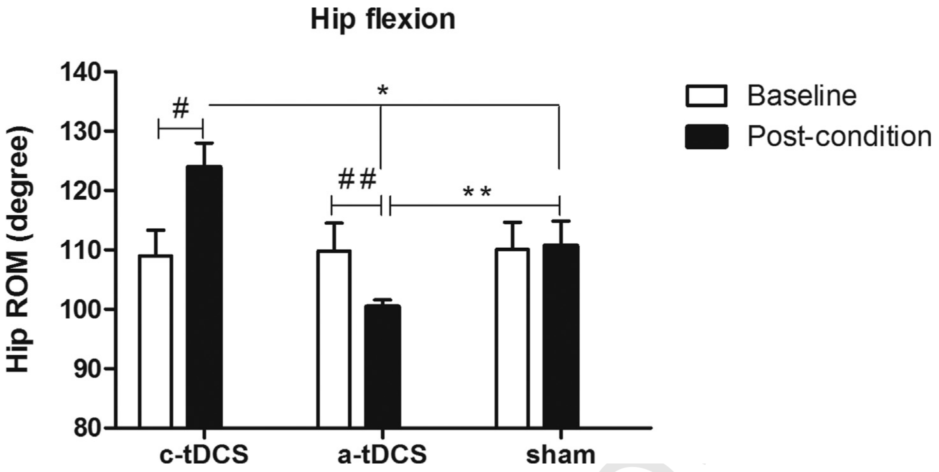

Figure 2 Effects of tDCS on Hip ROM. *c-tDCS > a-tDCS ($P < 0.001$), and sham ($P \leq 0.001$); **sham > a-tDCS ($P \leq 0.001$); $^{\#}$c-tDCS in the post-condition > c-tDCS in the baseline ($P < 0.001$); $^{\#\#}$a-tDCS in the baseline > a-tDCS in the post-condition ($P \leq 0.001$).

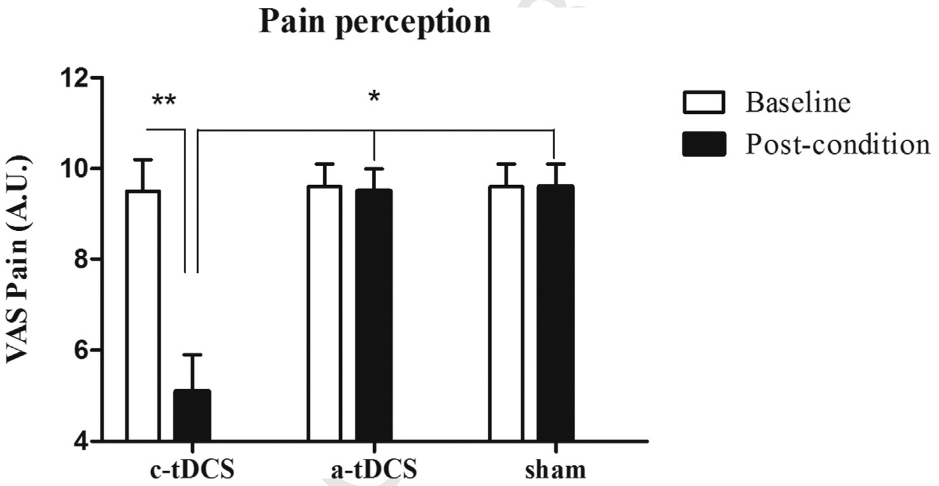

Figure 3 Effects of tDCS on pain perception. *c-tDCS > a-tDCS ($P < 0.001$), and sham ($p \leq 0.001$); **c-tDCS in the post-condition < c-tDCS in the baseline ($P < 0.001$).

Table 1 Descriptive statistics and effect sizes for ROM of the right hip, and pain perception.

Measures	Baseline(M ± SD)	Post-condition(M ± SD)	ES vs. sham(classification)
ROM (degrees)			
c-tDCS	109.0 ± 4.3	123.9 ± 4.1	2.38 (very large)
a-tDCS	109.8 ± 4.7	100.4 ± 1.2	0.07 (trivial)
sham	110.1 ± 4.6	110.7 ± 4.2	
VAS Pain (mm)			
c-tDCS	9.5 ± 0.7	5.1 ± 0.8	−5.05 (very large)
a-tDCS	9.6 ± 0.5	9.5 ± 0.5	0.16 (trivial)
sham	9.6 ± 0.5	9.6 ± 0.5	

A.U.: Arbitrary Unit.

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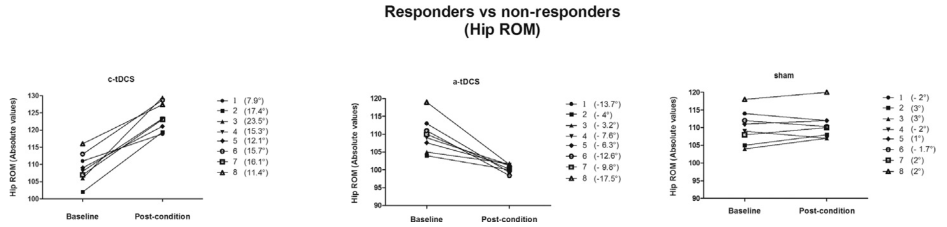

Figure 4 Responders vs. non-responders for Hip ROM.

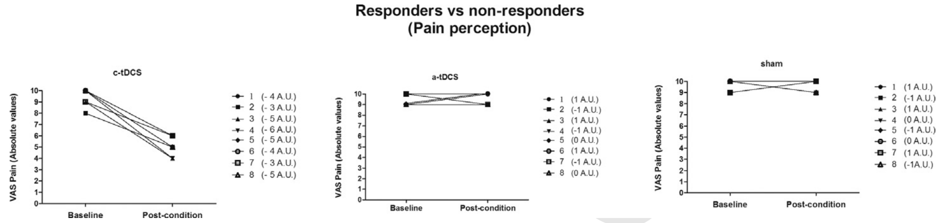

Figure 5 Responders vs. non-responders for pain perception. A.U.: Arbitrary Unit.

(range: −3 to −6 A.U.). The a-tDCS condition showed an increase in two subjects (3, and 6; 1 A.U. for each one), a decrease in three subjects (2, 4, and 7; −1 A.U. for each one), and three remained unaltered (subjects 1, 5, and 8) for VAS pain. For sham-tDCS condition, occurred a small increase in three subjects (1, 3, and 7; 1 A.U. for each one), a decrease in three subjects (2, 5, and 8; −1 A.U. for each one), and two remained unaltered (subjects 4 and 6) for VAS pain (Fig. 5).

4. Discussion

The aim of this study was to examine whether the effects of tDCS enhance hip ROM, and pain perception in comparison to a-tDCS and sham-tDCS in a sedentary male. According to our initial hypothesis, results showed that c-tDCS condition improved hip ROM, and decreased VAS pain in comparison to a-tDCS and sham-tDCS. Our findings showed that c-tDCS over the SM1 bilaterally significantly increased hip ROM and reduced VAS pain, while a-tDCS over SM1 bilaterally led to a decrease in hip ROM, and sham-tDCS had no effect.

Just one study analyzed the effects of c-tDCS on flexibility. Mizuno et al. [13] showed that 2 mA c-tDCS applied to SM1 10 minutes, significantly increased ankle ROM, whereas a-tDCS and sham-tDCS had no effect. Our results were similar by Mizuno et al. [13], despite the different joint assessed. Corroborating our findings, all subjects demonstrated an increase in ROM following c-tDCS (our results, range: 7.1–22.1%; Mizuno et al.'s results [13], range: 1.0–26.2%).

After c-tDCS application, hip ROM was likely because of decreased pain perception, considering that the individuals do not stopped hip flexion at the same level of perceived discomfort during the pre- and post-tDCS tests. However, we did not find a positive association between the increase in hip ROM and a reduction in pain perception. A possible explanation is that changes in pain perception could cause a decrease in SM1 excitability after c-tDCS. Many fMRI studies have substantiated the involvement of SM1 in pain perception [30–34]. Peyron et al. [32] revealed that significant SM1 activation after painful stimulation and specific nociceptive neurons are known to exist in SM1 [35]. Furthermore, Antal et al. [36] showed that c-tDCS over the SM1 decreased laser-stimulated subjective pain perception of the hand, whereas anodal and sham-tDCS had no effect. These findings suggest that c-tDCS over the SM1 decreased subjective pain perception. Previous results also indicate that the increase in hip ROM observed in our study may be based on decreased pain perception secondary to decreased brain excitability, which was caused by c-tDCS over the SM1 [19].

In addition, pain perception decreased in all subjects. In fact, SM1 seems to be involved with the perception of pain, according to some studies [37]. Our findings are similar to several studies that applied c-tDCS to SM1 in healthy adults, observing a decrease in pain thresholds [20,33–36,38,39]. fMRI studies have shown that experience of pain coincides with hyperactivity of SM1 [33–36,38,39]. The rationale for the reduction of pain by c-tDCS over SM1 is corroborated by some studies [40,41]. c-tDCS when applied to M1 and S1 in healthy individuals [42–45], decreases brain excitability [46,47] and increases pain threshold perception in healthy individuals [44,45].

However, new evidence suggests that inhibitory effects of c-tDCS may shift to excitatory effects by modulation of c-tDCS parameters such as current intensity and duration [48], site of stimulation [49], and repetition [50]. This same argument could be used for a-tDCS and could explain our result, i.e., no increase in pain perception. Thus, tDCS intensity does not essentially increase efficacy of stimulation, however, may also modify the direction of excitability alterations [48–50]. This should be taken into account for applications of tDCS using different intensities and durations in order to achieve stronger or longer lasting after-effects.

Some methodological limitations were presented in the study. First, the number of subjects was small, although the effect size calculation was performed. Second, it is possible that the site of the stimulated area has been large, due to

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the size of the electrode (35 cm^2). Third, the flexion of the hip was performed with knee extended, limiting our interpretation on biarticular muscles involved in this movement.

5. Conclusion

This study suggests that c-tDCS applied to SM1 may promote increased in ROM of the hip and decreased and perception of pain. tDCS has been stepping out of the laboratory into the community at large, including the sports and fitness fields. Although its effects are variable between individuals and within individuals, it is not unreasonable to claim that tDCS has great potential as ''ergogenic resource'' for improving human physical performance, e.g. flexibility and pain perception. In an increasingly success-oriented society with less effort and improved performance, tDCS seems to be a useful tool for use in sports and fitness, as well as safe with regard to its tolerance and adverse effects, relatively inexpensive and readily available.

Disclosure of interest

The authors declare that they have no competing interest.

Uncited reference

[51].

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