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Neuromodulación aplicada en la corteza prefrontal dorsolateral aumenta el rango de movimiento de la cadera: un estudio controlado aleatorizado

Neuromodulation applied in the dorsolateral prefrontal cortex increases hip range of motion: a randomized controlled study

Neuromodulação aplicada no córtex pré-frontal dorsolateral aumenta o alcance de movimento do quadril: Um estudo controlado randomizado

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RESUMEN

El estudio se centró en investigar el impacto de la estimulación transcraneal por corriente continua anódica (a-tDCS) en el rango de movimiento de la cadera (HROM) en hombres entrenados recreativamente. Secundariamente, se evaluó la percepción del dolor. 20 hombres (23.3 ± 5.2 años), y con un HROM izquierdo de 113.9° y derecho de 111.5°. Fueron divididos en dos grupos: a-tDCS y sham-tDCS. A lo largo de tres visitas, se evaluó: antropometría y evaluaciones pasivas de HROM. En las dos visitas siguientes, se aplicaron las respectivas estimulaciones y se midió el HROM antes y después de cada sesión. ANOVA mostró un incremento significativo en el HROM en el grupo a-tDCS tanto en la pierna izquierda (p = .01) como en la derecha (p = .014), mientras sham-tDCS no presentó cambios. La percepción del dolor fue máxima en todas las condiciones. La estimulación a-tDCS demostró mejorar el HROM en hombres entrenados recreativamente, sin embargo, la percepción del dolor no se alteró.

Palabras clave: flexibilidad, tDCS, rango de movimiento, corteza prefrontal dorsolateral.

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ABSTRACT

The study focused on investigating the impact of anodal transcranial direct current stimulation (a-tDCS) on hip range of motion (HROM) in recreationally trained men. Secondarily, pain perception was assessed. 20 men (23.3 ± 5.2 years), with a left HROM of 113.9° and a right HROM of 111.5°, were divided into two groups: a-tDCS and sham-tDCS. Over three visits, anthropometry and passive HROM assessments were assessed. At the following two visits, the respective stimulations were applied and HROM was measured before and after each session. ANOVA showed a significant increase in HROM in the a-tDCS group in both the left (p = .01) and right (p = .014) legs, while sham-tDCS showed no change. Pain perception was maximum in all conditions. a-tDCS stimulation was shown to improve HROM in recreationally trained men, however, pain perception was not altered.

Keywords: flexibility, tDCS, range of motion, dorsolateral prefrontal cortex.

RESUMO

O estudo se concentrou em investigar o impacto da estimulação transcraniana por corrente contínua anódica (a-tDCS) na amplitude de movimento do quadril (HROM) em homens treinados recreativamente. Secundariamente, foi avaliada a percepção da dor. 20 homens (23.3 ± 5.2 anos), com HROM esquerda de 113.9° e direita de 111.5°. Eles foram divididos em dois grupos: a-tDCS e sham-tDCS. Ao longo de três visitas, foram realizadas avaliações antropométricas e de amplitude de movimento passiva. Nas duas visitas seguintes, foram aplicadas as respectivas estimulações e a HROM foi medida antes e depois de cada sessão. A ANOVA mostrou um aumento significativo na HROM no grupo a-tDCS nas pernas esquerda (p = .01) e direita (p = .014), enquanto o grupo sham-tDCS não apresentou nenhuma alteração. A percepção da dor foi máxima em todas as condições. Foi demonstrado que a estimulação a-tDCS melhorou HROM em homens treinados recreacionalmente; no entanto, a percepção da dor não foi alterada.

Palavras chave: flexibilidade, tDCS, amplitude de movimento córtex pré-frontal dorsolateral

INTRODUCTION

tDCS is a non-invasive brain stimulation technique, where low-intensity electrical stimuli are applied to the scalp to stimulate certain areas of the cerebral cortex, leading to depolarization of the membrane resting potential (anodal stimulus, a-tDCS), or hyperpolarization of the membrane resting potential (cathodal stimulus, c-tDCS) (Antal et al., 2022; Nitsche & Paulus, 2000; Machado et al., 2019). Studies showed that tDCS has been seen as a potential resource to improve flexibility (Henriques et al., 2019; Lins et al., 2020; Mizuno & Aramaki, 2017; Rodrigues et al., 2022), c-tDCS applied to primary motor cortex (M1) increased ankle (Mizuno & Aramaki, 2017) and hip (Lins et al., 2020; Rodrigues et al., 2022) range of motion (ROM) in sedentary individuals, while other study demonstrated that a-tDCS applied to dorsolateral prefrontal cortex (DLPFC) also increased hip ROM (HROM) (Henriques et al., 2019).

Mizuno and Aramaki (Mizuno & Aramaki, 2017) showed that c-tDCS over M1 at 2mA for 10 minutes resulted in an increase in ankle ROM in healthy men. Findings suggest that M1 is involved in joint flexibility as passive torque did not change and this may have affected neural factors such as joint angle perception. Also, in a randomized, double-blinded crossover design, studies found that c-tDCS applied to M1 bilaterally at 2 mA for 20 minutes increased HROM in sedentary healthy males (Lins et al., 2020) and in sedentary healthy women (Rodrigues et al., 2022). Within this context, literature suggests that the neuronal hyperpolarization promoted by c-tDCS (Nitsche & Paulus, 2000) can reduce muscle tone, and consequently, allows an increase in passive stretching (i.e., ROM) (Henriques et al., 2019; Lins et al., 2020).

With a different rationale, Henriques et al (Henriques et al., 2019), examined the effects of a-tDCS applied to DLPFC on HROM in sedentary healthy males and also found an increase in HROM. However, the mechanisms responsible for the relationship between muscle tone and ROM improvement associated to DLPFC is still unclear. Unlike M1, which is related to muscle tone, DLPFC, whose main function is the cognitive control of behavior,

seems to play an important role in processing internal and external cues related to the exercise performed (McMorris, 2021; Robertson & Marino, 2016). In addition, it exerts a top-down influence that can result in task interruption, with prolongation of motor output, delaying the end of the exercise or the shutdown of motor units (Robertson & Marino, 2016). Thus, exercise interruption will occur due to effort-based decision making that depends on motivation (e.g., the maximal effort or pain that a person is willing to exert or tolerate), perceived exertion, and previous experience associated with perceived exertion (intensity and duration) during exercise (McMorris, 2021; Pageaux, 2014). Therefore, application of a-tDCS to the DLPFC could strengthen this region's ability to disregard interoceptive cues (i.e., body signals), maintaining the volitional drive to M1, and thus delaying task interruption (i.e., the end of the exercise).

So, some points deserve to be highlighted: a) in practice, as flexibility is an important physical capacity, maintaining or increasing the range of movement is a required outcome in the context of health and performance; b) it appears that tDCS, in fact, can increase the range of motion, at least in untrained participants. However, we do not know the impact on individuals with higher levels of flexibility; c) Stimulating the DLPFC region is an area of interest in different studies and has shown promise as a target for tDCS, however, the study by Henriques et al., (2019) proposes a different understanding, which deserves investigation; d) The pain threshold may be a limiting factor on range of motion and in trained participants appears differently when compared to untrained participants. Studies suggest that changes in HROM after stretching may be caused by adjustments in pain sensations, in addition to changes in passive tension generated by joint components (Støve et al., 2021). Although studies on tDCS show an influence on pain perception (Lattari et al., 2016; Henriques et al., 2019), we do not know whether the same will occur in participants with recreational levels of training, which justifies investigation.

There are few studies that have analyzed the influence of a-tDCS on hip ROM, and no study has used recreationally trained participants. Therefore, intensive investigation into the subject is warranted. Thus, the aim of this study is to investigate the effect of a-tDCS on HROM in recreationally trained men, as well as its effects on pain perception. We hypothesized (H^1) that a-tDCS applied to DLPFC will improve HROM compared to sham-tDCS (placebo condition), and the perception of pain will be reduced (H^2).

METHODS

Design

The present study was carried out based on the guidelines for cross-sectional studies STROBE Statement (https://www.strobe-statement.org/checklists) (Malta et al., 2010). The study followed Resolution 466/2012 of the National Health Council and was approved by the Research Ethics Committee (CAAE: 26361819.6.0000.5083; nº 3.914.795). All participants were recruited by convenience, in a public call, or by verbal invitation by the researcher responsible for the study (P.A.), participants were recruited from a university gym, located in the central mesoregion of Brazil (central-west), between January and July 2022. Participants signed a consent form containing pertinent information about the experimental procedures, as well as the possible risks and discomforts involved in the study. This information was also explained verbally in detail. After selection, acceptance and understanding of the risks inherent to physical exercise, all participants signed the consent form. A double-blinded, randomized, within-subject design was used. Figure 4 presents the results of recruitment, entry, eligibility and exclusion of participants of experimental collection.

Participants

The sample size was calculated using G*Power software (version 3.1) based on the maximum HROM. For this analysis we used the following commands: Test family = t-tests, Statistical test = difference between two dependent means (matched pairs), α error probability = 0.001, and power (1-β error probability) = 0.95. Effect size was set with g=3.01. The climate during this period is characterized as mild and with little rainfall, therefore, with a moderate incidence of heat (approx. 25 to 27º). Seventeen healthy men, left-leg-dominant and recreationally trained were recruited (age = 23.3 ± 5.2 years, body mass = 61.9 ± 9.9 kg, height = 1.7 ± 0.1 cm, and left HROM = 118.9 ±

13.0◦ and right HROM = 116.2 ± 15.5◦). As an inclusion criterion, participants must have a minimum of 2 years of strength training experience, who performed exercises a minimum of three times a week and train flexibility at least twice a week, separately or in conjunction with strength training. It is important to highlight that we present our sample as recreationally trained, as they were not practitioners of sports with routines that require high physical capacity of flexibility. However, as the main inclusion criterion associated with the level of training required for inclusion in the sample, we determined a cutoff point of 100º of passive hip flexion (with the knee extended).

The exclusion criteria consisted of the presence of any injury (muscle or tendon), surgery on the joints involved in the study, use of supplements and anabolic steroids or any other drugs that could interfere with the outcome variables and HROM < 100º. Participants were also instructed not to consume caffeinated or alcoholic beverages 48 h before the experimental sessions. Therefore, if any of these instructions were not followed or if the exclusion criteria were met, participants would be excluded from the final sample.

Outcomes

As the primary outcome measure, the influence of tDCS on passive HROM was analyzed. Secondarily, pain perception was recorded and analyzed, as well as the reliability of the hip fleximetry measurement (intraclass correlation coefficient, typical measurement error and Bland-Altman).

Anthropometry

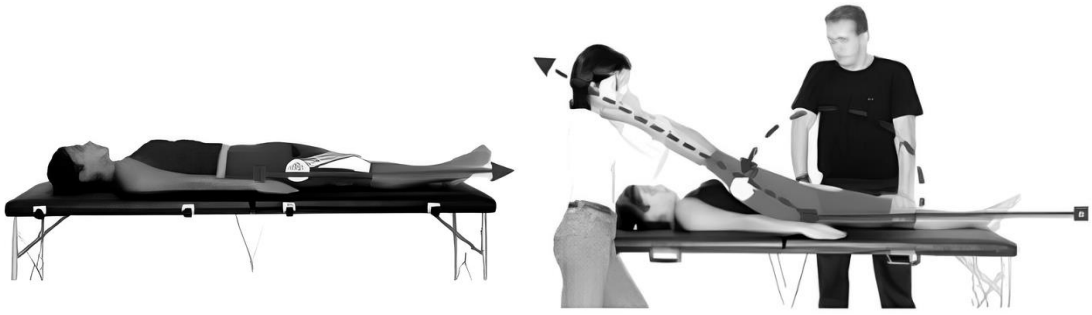
Participants' body mass and height were measured with a weighing scale and stadiometer (WELMY 110 CH, Brazil) (Martínez-Sanz et al., 2023), following the recommendations proposed by International Society for Advancement of Kinanthropometry (Stewart et al., 2011).

Fleximetry Measurement

A Sanny-FL6010 pendulum analog fleximeter was used with values expressed in degrees. The fleximeter was positioned as follows: participants were placed in supine position with their legs extended (i.e., with the hip at zero degrees of flexion, extension, adduction, abduction, and rotation) as proposed by the American College of Sports Medicine (Wilkins, 2017). They were instructed to stay relaxed throughout the whole assessment procedure. A researcher maintained the participant's contralateral leg fixed to the stretcher while passively raising the other leg to the highest level possible while keeping the knee extended and the foot in a neutral position in a single attempt. The second researcher performed the maximum passive HROM angle measurement reached in the hips side. The maximal degree of hip flexion was defined as the participant's highest angle in a single attempt. The same experienced researchers evaluated to minimize possible errors due to stretching speed and angular adjustments. The Figure 1 presents the HROM angular analysis procedure.

Figure 1

Angular analysis procedure tDCS Application.

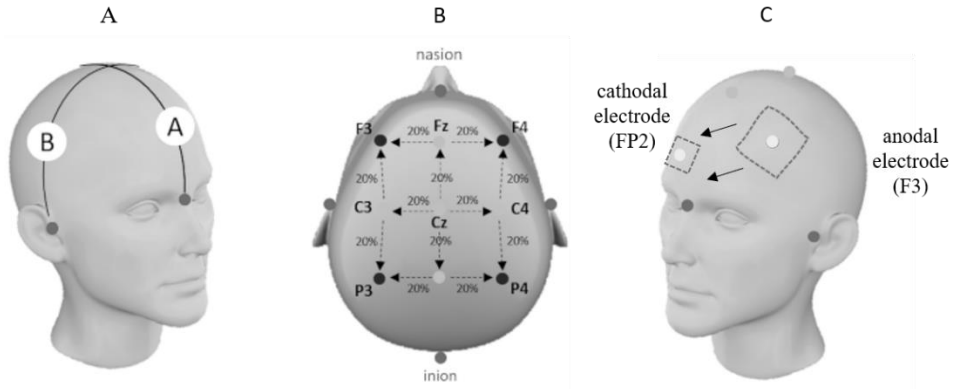


The participants remained seated comfortably in a chair located within the laboratory. The electrode montage was assembled according to the international EEG 10–20 system (Klem et al., 1999), with the anodal electrode placed over the left DLPFC and the cathodal electrode positioned over the right orbitofrontal cortex (OFC) in both conditions (Figure 2). First, the skull was divided into quadrants, based on the reference of nasion and inion (antero-posterior), and both meso-auricular regions (Figure 2A). Subsequently, based on the 10-20 EEG system, the adjacent anterior points F3 and F4 were measured and determined. Finally, FP2 was demarcated (Figure 2B). The electrodes were positioned diagonally, with the equipment wiring facing the posterior region of the subject (as visualized in Figure 2C).

The stimulation procedure had a duration of 20 min, with a 2-mA current intensity, and a ramp-up at the beginning, and a ramp-down at the end of one minute. In the sham condition, the stimulator was turned off after 30 s, acting as a placebo condition (Lins et al., 2020). Furthermore, independent researchers conducted the stimulation procedures and HROM assessments to ensure that researchers directly involved with the study were blinded to stimulation conditions. The stimuli were applied using a pair of pads soaked in saline solution (NaCl 140 mmol dissolved in Milli-Q water) comprising the two 5 × 5 cm2 electrodes, connected to a direct current stimulation device (TCT, Shanghai - China) and positioned using elastic bands. Additionally, impedance was verified and maintained under 5 k ohms (DaSilva et al., 2011).

Figure 2

tDCS electrodes.



Note: (A) demonstration of the marking process performed for tDCS; (B) demarcation of reference points; (C) Assembly of tDCS electrodes.

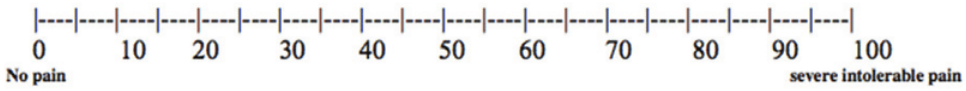
Pain Perception Scale

It is a Likert scale, with a total dimension of 100mm, where the starting point has a value of “zero” (0), representing “no pain” and the opposite side has a value of “one hundred” (100), representing “severe intolerable pain” (Dixon & Bird, 1981). The scale was positioned in front of the participant, and after initial explanations about the reading and stabilization of the contralateral limb, the evaluators conducted the extended limb to the maximum range of hip flexion movement, holding for 3 seconds (time necessary to obtain precision in observing the fleximeter). The evaluators were previously trained to extract the maximum ROM in the face of passive tension contrary to the procedure. In cases of need, a third evaluator participated in stabilizing the individual to that the maximum could be extracted. Participants were verbally encouraged to sustain the perception of pain, and as soon as the limb was passively extended (rest moment), they were asked to indicate a score on the pain scale. The

maximum HROM was defined by the maximum point of amplitude associated with maximum pain discomfort (severe intolerable pain). Figure 3 presents the visual pain scale.

Figure 3

Representation of the visual pain scale.



Procedures

The present study occurred in two separate experiments. The first experiment determined the reliability of the measurement between different days to determine the absolute and relative values of measurement and error behavior (n = 22). Each visit equally consisted of two passive hip flexion measurements (supine position), with 60 s interval between assessments, to determine the stability of the fleximetry measurement. Exact descriptions of the procedures are presented in the "Fleximetry Measurement" section.

In the main experiment, after a new public call, the participants were selected and randomly allocated to two experimental procedures (a-tDCS and sham-tDCS) and performed a total of three visits with a one-week interval between them (n = 22). On the first visit, they underwent anthropometric measurements and two measures of left- and right-side passive HROM assessments (baseline) and familiarization with the tDCS procedure. Familiarization was carried out following the assumptions of the sham session (control), progressively inducing a lower amperage throughout time (confounding factor for blinding maintenance). The individuals returned to the laboratory for the second experimental visit, where one of the tDCS procedures was offered (a-tDCS or sham-tDCS). At the last visit, participants underwent the remaining tDCS procedure (depending on the previous visit - a-tDCS or sham). Before and after experimental conditions (pre- and post-stimulation), without warm-up, participants performed a HROM measured (Figure 5) and the verification of pain responses (visual analogue scale). Furthermore, the responsible researchers trained to extract the maximum possible HROM (Cejudo et al., 2013).

All sessions were performed in the afternoon (i.e., 14:00–17:00 h a.m.) to avoid circadian effects on flexibility. The temperature was set between 21◦C and 23◦C, and relative humidity ranged from 55 to 70%. To avoid the influence of temperature, all participants upon arriving at the laboratory remained at rest for 15 minutes. Participants were also informed to maintain their regular food and hydration diet before performing the visits and were discouraged from consuming ergogenic beverages (e.g., coffee) or smoking. Two researchers conducted the HROM assessment, and another assistant researcher led the configuration of tDCS. These conditions were blinded to both researchers and participants.

Blinding and Data Analysis and Treatment

To avoid possible analysis biases, the data was collected by two different researchers associated with the project and the research group (P.A. and P.D). A third evaluator was responsible for blindly programming the tDCS equipment. The equipment was positioned at a safe distance from the subject, so that neither the participant nor the evaluators could see the configuration made. The researcher responsible for data analysis remained blind throughout the entire data collection process (group leader A.S.).

Randomization and Allocation Process

Simple randomization was applied. The randomization process was done manually by depositing papers with procedure designations in an opaque paper bag. For the randomization process, one of the evaluators organized two numbers on paper, referring to the two experimental sessions (a-tDCS and Sham-tDCS), and a third evaluator, not directly involved in data collection, sequentially removed the numbers, being assigned the experimental sessions in which each participant would be conditioned. Participant allocation was concealed from the two main assessors (P.A and P.D).

Statistical Analysis

Descriptive statistics were performed using mean (M) and standard deviation (SD) values in the following variables obtained at baseline: age, body mass, height, and HROM degrees. The Shapiro-Wilk's test was used to verify the normality of data. A one-way ANOVA was used to determine parity of baseline measurements. The intraclass correlation coefficient (ICC), together with the typical measurement error (TME), were used to determine the reliability of the HROM measurement. A two-way repeated-measures analysis of variance (ANOVA) was used to evaluate the effect of conditions (a-tDCS and sham) and time (pre-condition and post-condition) on HROM levels. Post-hoc comparisons were performed using the Tuckey's test, adopting a significance level with $p < 0.05$ (Statistical Package for the Social Sciences 23.0 - SPSS). Effect size analysis was conducted to report the magnitude of differences into a-tDCS and sham-tDCS conditions for HROM. Effect sizes were computed using the equation proposed by Cohen. 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) (Rosenthal, 1996). The graphical representations of data were performed using the software GraphPad Prism (v.8, Boston, USA).

RESULTS

The sample eligibility results, as well as the participant entry and exclusion flow, are presented in Figure 5, respectively. All data were expressed as mean, standard deviation (SD) and 95% confidence interval (95% CI).

The reliability of the HROM measurement was previously established (n=22) and showed an excellent ICC for both limbs evaluated, in addition to low TME and ES (Table 1). From this data, it is possible to infer whether the results resulting from the intervention are within the variations of the HROM measurement or, in fact, were greater than the measurement error. The graphical representations of passive angular measurement errors expressed by the Bland-Altman plot model are shown in Figures 5.

Table 1

Reliability measure of the hip flexion fleximetry technique (n = 22).

	Inter-day	
	Right	Left
ICC	0.90	0.92
p valor	0.001	0.001
TME (Absolute)	4.7º	5.1º
TME (Relative)	4.2%	4.5%
ES	0.01	0.02
Qualification	Trivial	Trivial

Note: ICC: intraclass correlation coefficient; TME: typical measurement error; ES: effect size.

Figure 4

Sample eligibility, entry and exclusion of participants.

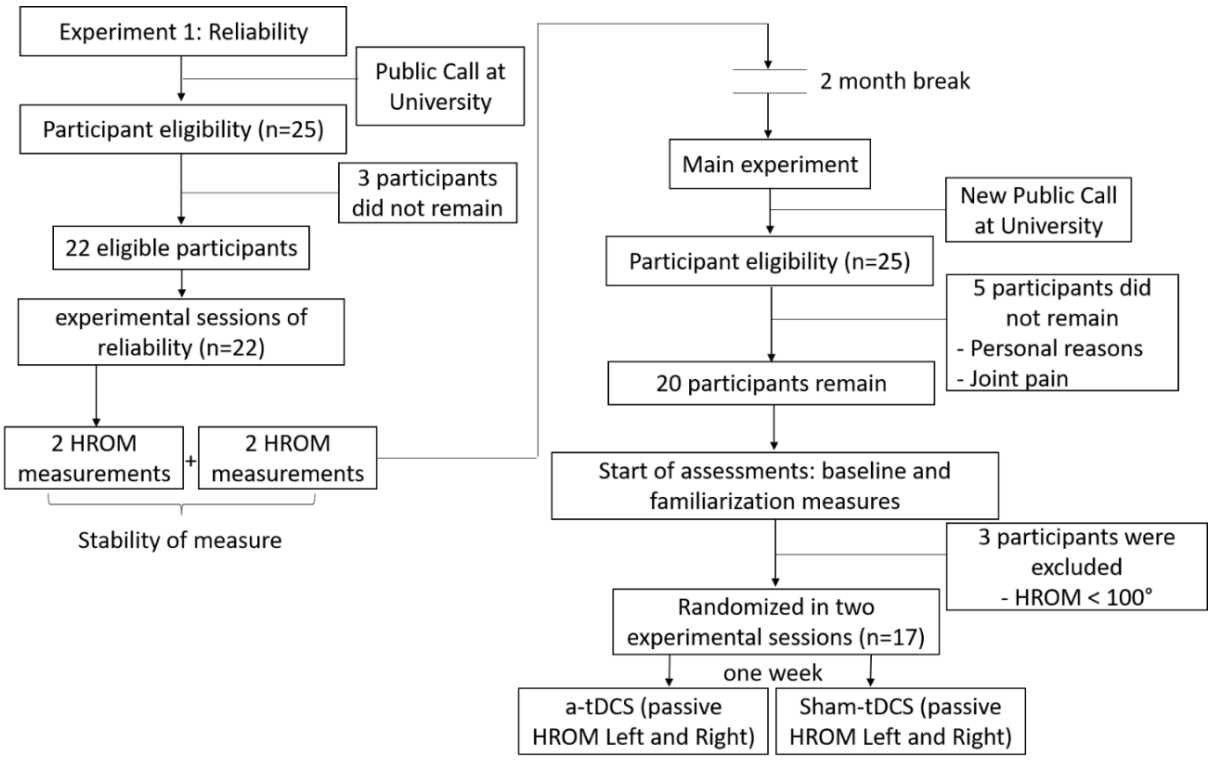
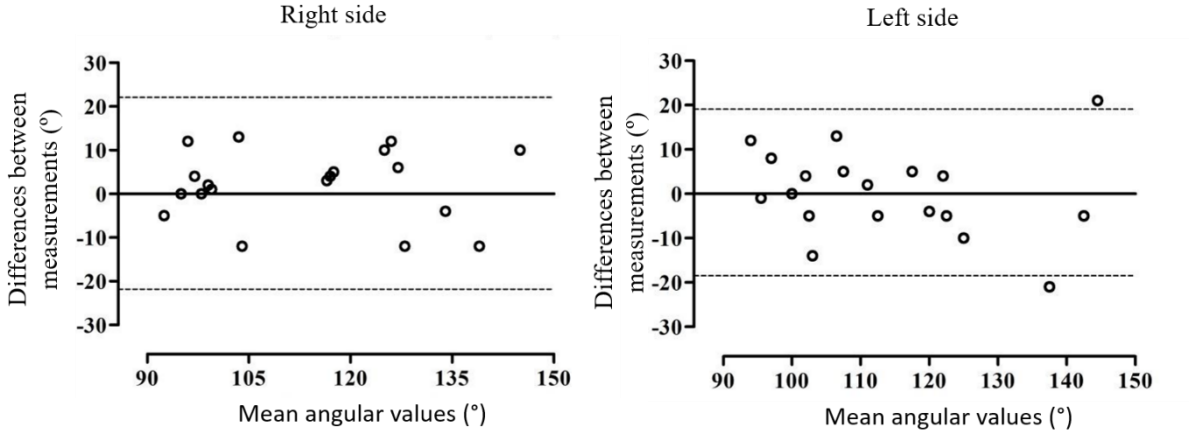


Figure 5

Representation of measurement error behavior - Bland Altman plot.



After analyzing the statistical assumptions, all dependent variables were normal ($p > 0.05$). The homogeneity of variance based on the mean determined by Levene's test was preserved for all base variables (HROM left limb: $p = 0.984$; HROM right limb: $p = 0.876$). One-way ANOVA compared the pre-exercise HROM means (baseline x pre a-tDCS; baseline x Sham-tDCS), showing no significant differences for HROM in the left leg [$F(2,48) = 0.057$; $p = 0.945$] - left limb: pre a-tDCS vs. baseline ($p = 0.954$) and pre sham-tDCS vs. Baseline ($p = 0.955$). The same

occurred for HROM in the right limb [F(2,48) = 0.049; p = 0.952] - pre a-tDCS vs. baseline (p = 0.981) and pre sham-tDCS vs. baseline (p = 0.992).

The repeated measures ANOVA showed no violation of homogeneity, based on Levene's test (p = 0.987 and p = 0.740, respectively for the left and right HROM measure) and equality of covariance between groups (p = 0.925). ANOVA showed main effects for time factor [F(1, 32) = 38.141; p = 0.000] as well as in the group x time interaction [F(1, 32) = 28.869; p = 0.000] for measurement on the left limb. The same occurred for the HROM of the right limb, time factor [F(1,32) = 19.907; p = 0.000] and the group x time interaction [F(1,32) = 20.781; p = 0.000].

We found an increase in HROM in the post-condition compared to the pre-condition in the left limb, as well as in the right limb (p = 0.000; p = 0.000, respectively for a-tDCS group). In addition, sham-tDCS did not show significant results (p > 0.05). The post hoc showed differences between groups both for HROM of the left limb (p = 0.028) and right limb (p = 0.047). Effect sizes (ES) showed moderate clinical effects for the experimental group, according to the Cohen index. Table 2 presents the main outcomes of the study. Figure 6 presents a graphic representation of responders and non-responders to the tDCS technique.

Table 2

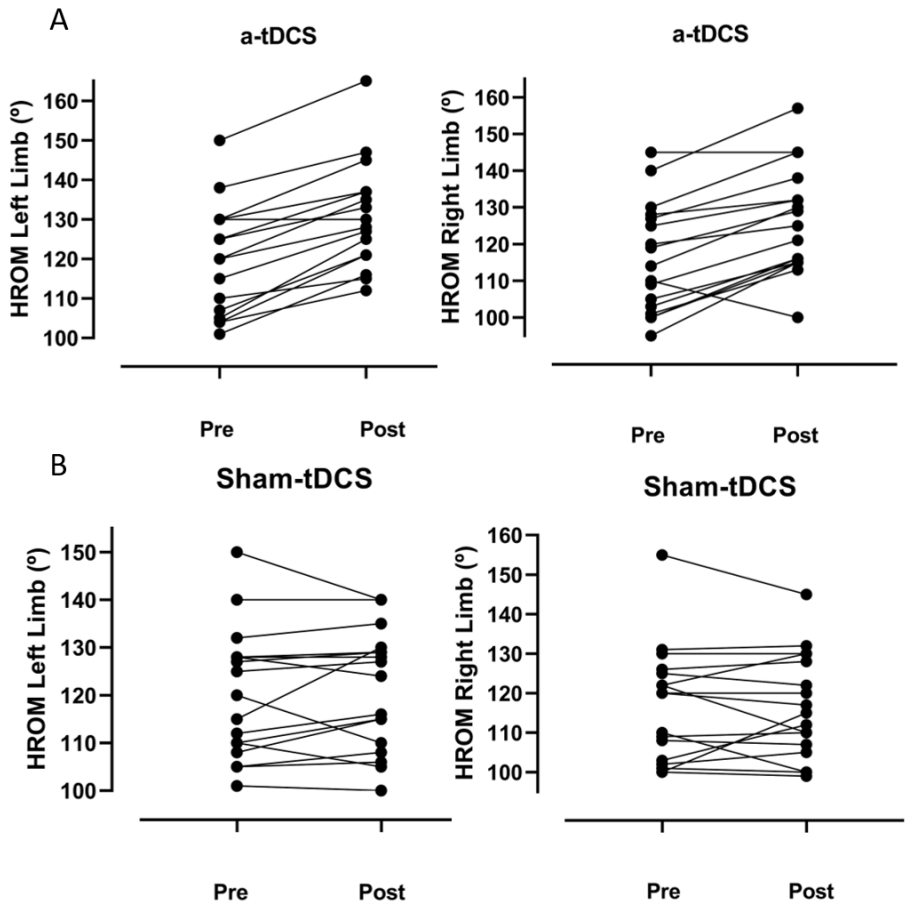
Outcomes of experimental procedures

Measures		Mean	SD	(CI95%)	ES	Δ%
Baseline	Left	118.9	13.0	(112.2-125.5)	-	-
	Right	116.2	15.5	(108.2-124.2)		
a-tDCS Left limb	Pre	120.2	13.8	(113.1-127.3)	0.80	9.2%
	Post	131.2*¥	13.3	(124.3-138.0)		
a-tDCS Right limb	Pre	115.9	14.9	(107.7-123.2)	0.68	9.0%
	Post	126.1*¥	14.5	(118.9-134.0)		
Sham-tDCS Left limb	Pre	120.2	13.6	(113.2-127.2)	0.06	0.7%
	Post	121.0	12.6	(114.5-127.4)		
Sham-tDCS Right limb	Pre	116.7	14.7	(109.1-124.2)	0.01	0.1%
	Post	116.6	13.2	(109.8-123.3)		

SD = standard deviation; ES = effect size; Δ% = pre and post intervention variation; * = significant differences between pre and post intervention conditions; ¥ = significant differences between groups.

Figure 6

Responders and non-responders to tDCS experimental procedures in the two conditions investigated.



Pain Perception Responses

According to methodological assumptions, the HROM stimulus was developed for maximum range associated with severe pain perception. Therefore, it was not possible to perform statistical calculations, since pain perception was reported to be maximum in all conditions (100,0 ± 0,0).

Unintended outcomes of tDCS

No moderate or severe adverse effects were observed or reported. Local redness in the electrode region was found in all participants during interventions involving a-tDCS. A tolerable tingling sensation was reported by 90% of participants (n = 15) during a-tDCS. Only one of the participants had significant difficulty tolerating it, and the procedure was paused for a short moment. No effects were reported for sham-tDCS. No other adverse effects were reported during the development of the study.

DISCUSSION

The present study aimed to analyze the effects of a-tDCS on HROM in recreationally trained individuals. According to our hypothesis, results show that the assembly with the a-tDCS over the DLPFC was efficient in improving HROM. As far as we know, this was the first study to investigate the effects of a-tDCS on ROM of recreationally trained individuals, supporting a-tDCS applied to DLPFC as an ergogenic resource to acutely increase ROM. Our main hypothesis was accepted, indicate that the HROM was higher in post-condition compared to pre-condition in a-tDCS group, but not in sham-tDCS. However, the same cannot be positioned for the secondary hypothesis (H^2), since the perception of pain was not affected.

The literature is scarce on findings associated with the effects of tDCS on DLPFC and flexibility, with just one study published (Henriques et al., 2019). This study applied a-tDCS over DLPFC and observed an increase in HROM in sedentary healthy males. The average difference found from a-tDCS was 9.2°, while sham-tDCS represented a reduction of 0.13°. In our study, we found a mean variation in degrees by 10.1° in the left limb and 11.3° in the right limb. These findings are similar to those of the study by Henriques et al., (2019). It is worth noting that the electrode assembly in the study by Henriques et al., (2019) was performed differently from our study, supporting the idea that in participants with a higher level of training, different mechanisms would be related. The DLPFC is responsible for internal and external cues involved in exercise performed, with a top-down influence on exercise interruption due to motor mechanisms, such as the shutdown of motor units (McMorris, 2021; Pageaux, 2014). Behind our findings, we suggest that the increase in cortical excitability in DLPFC caused by a-tDCS is the mechanism responsible for the increase in ROM. This fact is due to the increase in cortical excitability, with a decision made by the DLPFC that the execution of the exercise should continue, through volitional impulses to M1, reducing muscle tone, thus allowing the increase in HROM. Despite our findings, the relationship between muscle tone and ROM after using a-tDCS applied to DLPFC is unclear regarding the mechanisms involved in this process. We speculate that a-tDCS strengthened the ability of the DLPFC to disregard interoceptive information during exercise, allowing the maintenance of M1 functioning, thus delaying the end of the exercise. On the other hand, the use of a-tDCS to increase HROM in recreationally trained participants does not appear to have different effectiveness due to the increases observed in the present study when compared to the study by Henriques et al., (2019), in sedentary participants.

Additionally, our secondary hypothesis was not accepted, differing from the main study observed in the literature (Henriques et al., 2019). It is clear that the effects of tDCS on pain modulation are controversial. Henriques et al., (2019), assert that DLPFC was able to modulate this region promoting a significant decrease in pain levels. In our study, we did not observe changes in pain responses, but we also see improvements over HROM. We know that untrained participants commonly report inadequate perceptions of pain or effort in the face of minor discomforts, which results in underestimated outcomes or inadequate responses. It doesn't seem to have been the case. Therefore, the most likely explanation for the outcomes that occurred in both studies was the change in the pain threshold. Boggio et al. (2008), showed that anodal stimulation of the DLPFC increased pain threshold ($p = 0.046$) by approximately 10%. In participants with a greater level of training, as observed in our study, the increase in threshold may have provided greater tolerance to the demands of the task performed and to pain, which would allow greater use of force by the evaluators and changes in HROM, maintaining maximum task characteristics.

The limitations of the present study can be duly pointed out. First, the sample size can be questioned. In our study, the literature was considered as the basis for determining the N of the sample and, in our perspective, there was significant statistical power for the representativeness of an effect of the experimental model used. In addition, secondarily, the individuals participating in the sample did not practice sports in which there is a great need for physical flexibility, only individuals with routine training for the development of different physical valences, including flexibility, therefore classifying them as recreational. Lastly, the size of the 5 x 5 cm electrode also does not allow for the idea that a specific area was stimulated, but multiple adjacent areas may also have been influenced concomitantly, which in the end could generate acute responses that are difficult to explain. Despite this, our responses were quite similar to those observed in the literature (Henriques et al., 2019), suggesting that there was

no interference. Another limitation was the use of a fleximeter to assess ROM, which is not the gold standard. However, even though there are more relevant methods to assess ROM (Wilkins, 2017), the fleximeter is a validated and reliable method, with easy and practical applicability (Florêncio et al., 2010).

CONCLUSION

The present study concludes that a-tDCS in the DLPFC significantly acutely improved the HROM of recreationally trained participants. However, pain perception did not reduce after tDCS intervention.

PRACTICAL APPLICATIONS

The tDCS has moved out of the laboratory into the wider community, including the fields of sports and fitness. Although its effects are variable between individuals and within individuals, it is reasonable to state that tDCS has great potential as an "ergogenic resource" to improve flexibility performance. In an increasingly success-oriented society, with less effort and better performance, tDCS appears to be a useful tool for use in sports and fitness, as well as safe with regard to tolerance and adverse effects, relatively inexpensive and readily available.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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