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Transcranial Direct Current Stimulation Combined with Practical Blood Flow Restriction Training Enhances Efficiency in the Eccentric Phase of the Dumbbell Curl Movement, not the Concentric

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ABSTRACT

Objective: Transcranial direct current stimulation is a risk-free technique that stimulates the brain using a low-intensity current. Effectively increasing muscle thickness and maximal strength is possible with practical blood flow restriction training. The objective of this research endeavor was to examine the synergistic impacts of practical blood flow restriction training and transcranial direct current stimulation on the electrical activity and dynamic strength of the biceps brachii throughout concentric and eccentric phases of motion.

Methods and Materials: A total of twenty healthy participants were designated at random to either the sham-pBFR group (n=9) or the tDCS-pBFR group (n=11). The sham-pBFR group was administered sham-tDCS and pBFR, whereas the tDCS-pBFR group was administered pBFR and anodal tDCS over the M1 with an intensity of 1.5 (mA). The participants executed dumbbell curls for the biceps at 80% of their 1RM. Following initial assessments, a covariance analysis was performed.

Findings: The findings indicate that the combination of tDCS and pBFR training did not result in a synergistic effect on dynamic strength (p=0.251), concentric phase electrical activity (p=0.181), or the full range of biceps brachii dumbbell curl motions (p=0.165). However, a synergistic effect was observed during the eccentric phase of motion (p=0.049).

Conclusion: Our research shows that tDCS improves the efficiency and neuromuscular economy of muscle fiber recruitment during the eccentric phase of dumbbell curl movements when combined with pBFR training.

Keywords: *tDCS. pBFR Emg. biceps brachial, strength. movement phase*.

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1. Introduction

Human neuroscience research has extensively used transcranial direct current stimulation (tDCS), a non-invasive technique for brain stimulation, in the past decade. A weak direct current (up to 2 mA) is transmitted through the cranium via tDCS in order to generate a constant electric field in the brain. This field has the ability to alter the resting membrane potentials of neurons, thereby influencing their excitability(1). After stimulation, a single session of tDCS may elicit neurophysiological aftereffects that persist for over an hour. Repeated sessions can enhance the durability of tDCS effects (1). Consequently, this methodology enables us to examine the reversible neuroplasticity of the human brain (1) and its implications for alterations in motor performance and neural activity in clinical and healthy populations. Research has examined a novel form of strength training that functions similarly to conventional workouts, albeit with fewer limitations than high-intensity training. This approach, which is atypically executed at lower intensities (20–30% 1RM), accelerates the gains in muscle strength and volume (2). Blood flow restriction strength training (BFR) is the term applied to these methods of exercise. In this research, we utilised practical BFR (pBFR), which involves the use of sports elastic bands to restrict blood flow.

Strength training has been widely recognised for its ability to enhance muscular strength via neuronal and muscular adaptations (3). Research findings suggest that low-intensity BFR training induces restricted neural adaptations (4, 5); Consequently, it fails to enhance strength and neuromuscular adaptations in the same manner as conventional workouts (2, 6). Research has shown that low-intensity pBFR training effectively increases muscle thickness and maximal strength, but it does not appear to have the same impact on all strength-related parameters as high-intensity strength training (2, 6). Conversely, research has demonstrated that maximal strength can be increased through unilateral right limb strength training in conjunction with a single a-tDCS session (7). Furthermore, Hikosaka et al. (2021) provided empirical evidence that the induction of neuromodulation via tDCS could potentially enhance handgrip strength (8) This suggests that tDCS, in conjuction with pBFR training, could serve as an additional training tool to improve neuromuscular strength and efficiency.

Dynamic muscle contractions during resistance exercises are divided into concentric and eccentric phases. Concentric contraction happens when tension causes the muscle to shorten, whereas eccentric contraction occurs when tension causes the muscle to stretch out. Eccentric contractions occur when the external load surpasses the muscle's force production. According to the principle of specificity in strength training, distinct stimuli are elicited in the muscle during eccentric and concentric movements, resulting in unique adaptations (9, 10). Neural adaptation is affected by the manner in which resistance training involves muscle contractions. In contrast to isometric or concentric muscle contractions, the central nervous system controls skeletal muscles via a distinct neural strategy during eccentric contractions (11). This strategy involves the selective activation of fast-twitch motor units. Additionally, neuroimaging research has demonstrated that eccentric actions generate greater cortical activity than concentric actions. This may be due to the fact that eccentric movements necessitate the assistance of more complicated motor abilities or reflexes that regulate muscle lengthening (12). The increased cortical activity during eccentric exercises reinforces the distinct way in which the brain organizes eccentric and concentric movements (12). Additionally, research has demonstrated that eccentric activity induces a reverse in the recruitment pattern of motor units (starting with a larger motor unit) (13), accelerates neural adaptation subsequent to resistance training (14), and reduces EMG amplitude at comparable force levels (15). Measuring the electrical activity of the muscle can aid in assessing neuromuscular adaptations.

This investigation utilised the biceps dumbbell curl exercise, which comprises concentric and eccentric phases of muscle contraction. Multiple studies (16, 17) have reported different results about how tDCS works with other exercises. Because of this, we chose to look at the combined effect of these interventions separately during the concentric and eccentric phases of movement. As far as our knowledge goes, there is currently no research that has investigated the synergistic impact of pBFR and transcranial direct current stimulation on the electrical activity exhibited during the concentric and eccentric phases of the biceps dumbbell curl motion. With the knowledge that tDCS improves neural adaptations and pBFR training enhances muscle strength, the purpose of this study is to determine whether or not four weeks of combined tDCS and pBFR training can enhance muscle strength and electrical activity. We hypothesise that the combination of tDCS and pBFR training may elicit alterations in the electrical activity and strength of the biceps brachial muscle.

2. Methods and Materials

2.1 Study Design and Participants

A simple randomization study was performed. We enclosed random sequences generated using the SPSS version (SPSS Inc., USA) in illegible packets, numbered them, and sealed them. We randomly assigned twenty-two individuals to either the sham-pBFR (SP) group or the tDCS-pBFR (TP) group. Once it had been confirmed that every individual fulfilled the inclusion criteria, the envelopes were unsealed, and the participants were subsequently allocated to their respective groups.

Twenty-two young males in good health were enlisted from the University of Mazandaran. Nonetheless, personal obligations caused two of them to withdraw from the intervention sessions: tDCS-pBFR (n = 11) and shsm-pBFR (n = 9). (Figure 1). The following were the criteria for inclusion: 1) men 2) Lack of prior experience with tDCS and BFR or resistance training; 3) no upper body injuries 4) Good physical condition (using the PAR-Q to assess exercise-related risks). One week prior to the examination, each subject visited the health laboratory of the University of Mazandaran to familiarise themselves with biceps dumbbell curl movement, pBFR training, tDCS, EMG, and MVIC recording. The participants were furnished with explicit directives to adhere to a consistent daily regimen, abstain from supplement usage, and refrain from engaging in any additional exercise regimens throughout the duration of the study. Furthermore, they were directed to abstain from consuming caffeinated or alcoholic beverages and to cease all physical activity forty-eight hours before the testing sessions. All participants provided written informed consent, and the University of Mazandaran's research ethics committee granted approval for the study (IR.UMZ.REC.1403.001).

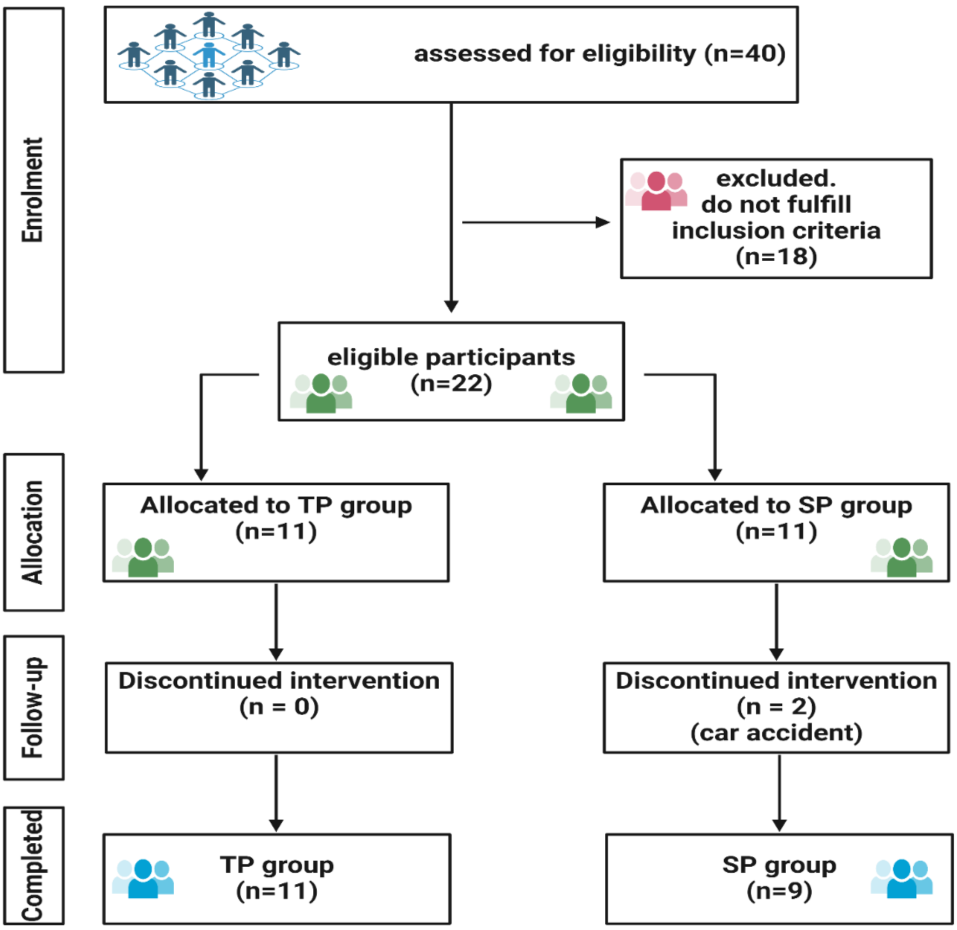

Figure 1. Study flow chart. Created with BioRender.com

2.2 Transcranial Direct Current Stimulation (tDCS)

The Neurostim 2 device (MedinaTeb, Iran) was used to apply transcranial direct current stimulation (tDCS). This device has a maximum output voltage of ±30 V and is capable of delivering direct currents ranging from 0.1 to 2 mA. The anode electrode was placed just above the C3 location, based on the international 10-20 system, in the primary motor cortex (18), The cathode electrode was set up above C4 on the opposite hemisphere. (8) An electric current of 1.5 milliamperes (mA) was applied to the scalp using a 5*5cm carbon pad that was soaked in conductive gel. The current was administered for a period of 15 minutes.

2.3 Practical Blood Flow Restriction (pBFR)

The research participants underwent blood flow restriction by utilising sports elastic bands to occlude blood flow. The bandage had dimensions of 5 x 94 cm, and perpendicular markings were made every 2 cm along the edge to assist patients in determining the suitable pressure for pBFR biceps dumbbell curl training. The wraps were applied to the proximal end of the upper limb (above the biceps, close to the deltoid muscle). Following that, the biceps curl training was conducted using dumbbells at a 30% intensity of the one-repetition maximum (1RM) weight. (2, 19) Which consisted of performing one set of 30 repetitions and three sets of 15 repetitions.

The wraps were placed before to the initiation of each training session and thereafter removed upon completion of the set. The use of elastic bands was employed to constrict blood flow, following the procedure outlined by Wilson et al. (20). Initially, the participants were introduced to the 0-10 pressure perception scale, where 0 signifies the absence of pressure, 7 out of 10 indicates moderate pressure without discomfort, and 10 out of 10 signifies intense pressure accompanied with pain. The participants were instructed that a perceived pressure rating of 7 out of 10 corresponded to the level of pressure exerted by the elastic band during all of the activities (20).

2.4 Electromyography

The electromyography data were collected using the MegaWin Muscle Tester ME 6000 (Mega Electronics Ltd., Finland). The biceps brachii muscle has been studied using a skintact surface electrode (Skintact, Innsbruck, Austria) to collect electromyographic data. To avoid noise interference, the electrodes were affixed using adhesive tape. The acquisition of EMG data was performed using Megawin software version 3.1, which has a sampling rate of 2000 Hz. The electrode site was selected and designated following the recommendations of Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM). The data underwent filtration using a high-pass and a low-pass filter with a frequency range of 10–500 Hz, as well as a notch filter at 50 Hz, in order to eliminate noise originating from electrical equipment. To minimise the impact of several factors, such as electrode positioning during the pre-test and post-test, on the data, the maximal voluntary isometric contraction (MVIC) was employed to normalise the RMS values.

2.5 1RM (dynamic strength)

The 1RM was determined using the Brzycki (1993) approach. Participants in this protocol are required to execute repetitions at an appropriate velocity and extent of movement until they reach the point of failure or lose correct posture. Following a preliminary warm-up, the participants chose a certain weight and performed ten repetitions in order to warm up. Subsequently, we increased the load to limit the individual to 4-6 repeats, concluded the examination at this juncture, and computed the one-repetition maximum (1RM) using Brzycki's formula (21).

2.6 Training Protocols and Groups

tDCS-pBFR group: In the tDCS-pBFR group, participants received transcranial direct current stimulation (tDCS) with an intensity of 1.5 mA for 15 minutes, then following a general and specific warm-up period of 5 minutes, participants completed pBFR exercises. The exercise was performed in four consecutive sets: the first set consisted of 30 repetitions, and the other three sets consisted of 15 repetitions each, with an intensity of 30% 1RM. A rest period of 45 seconds was allowed between each set. The exercises were performed in three sessions a week, with one day in between, over a period of four weeks, from 4 to 7 pm, at the health laboratory of the University of Mazandaran.

Sham-pBFR group: In the Sham-pBFR group, sham transcranial direct current stimulation was applied, and the current was discontinued after 30 seconds of stimulation. Following the sham stimulation, pBFR training proceeded in the same manner as in the tDCS-pBFR group. (Figure 2)

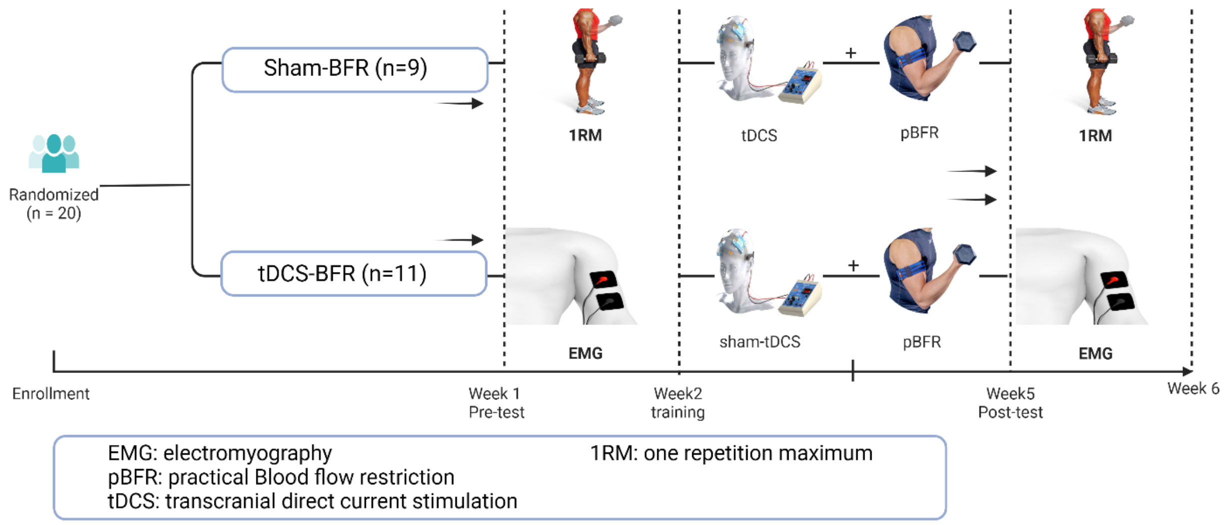

Figure 2. The timeline of the entire experimental interventions. three days per week, for a duration of four weeks. Created with BioRender.com

2.7 Pre-Test and Post-Test

During the pre-test session, individuals engaged in both a general warm-up and a particular warm-up. The one-repetition maximum (1-RM) was determined. The electromyographic (EMG) activity of their biceps during maximum voluntary isometric contraction (MVIC) was measured after a three-minute period of rest. Following a further three minutes of rest, the electromyography (EMG) activity of the biceps was measured while doing the dumbbell curl at 80% of their one-repetition maximum (1RM). The task was completed in three successive repeats, with a movement pace of 20 beats per minute, as determined by a metronome. We conducted the identical evaluations again during the post-test session, subsequent to a 48-hour time of rest.

2.8 Data Analysis

To evaluate the normality of the data, the Shapiro-Wilk test was used to investigate the study hypotheses. The results, which did not show statistical significance ($P<0.05$), indicated that the data followed a normal distribution. The homogeneity of variances was assessed using Levene's test, which revealed that the group variances were not equal ($P<0.05$). After doing these preliminary assessments, a covariance analysis was carried out. The data analysis was performed using SPSS 27. significance level of 0.05 was established.

3. Results

Table 1 presents the descriptive features of the 20 individuals who successfully completed the whole 4-week course. Prior to the intervention, the two groups were similar in terms of age ($p = 0.364$), height ($p = 0.121$), weight ($p = 0.197$), and body mass index ($p = 0.562$), with no significant differences seen. Table 2 presents the analysis of the study parameters using covariance.

Table 1. Descriptive characteristics of the participants

Items	TP (n=11)	SP (n=9)	p-value
Age (years)	1.1±20	1.2±20.3	0.364
Height (cm)	5.5±178	7±173.6	0.121
Weight (kg)	7.6±75	12.9±67	0.197
BMI (kg/m2)	2.2±23.7	3.2±22.1	0.562

Table 2. Analysis of the research parameters using covariance

Observed Power	Effect size	p-value	SP	TP	Groups
0.99	0.454	0.251	14.1± 2.2	15.3 ± 1.6	1RM (Kg)
0.84	0.292	0.165	62.5±26.6	54.4±16.5	Full range of motion (%MVIC)
0.55	0.124	0.181	76.8±39.6	68.3±23.7	Concentric phase (%MVIC)
0.509	0.167	0.049*	48.3±15.3	40.4±10.5	eccentric phase (%MVIC)

The parameters tested demonstrated significant effects or interactions. The data is presented as Mean ± Sd; * indicates a significant group difference at P<0.05. TP tDCS-pBFR, SP sham-pBFR. 1RM one repetition maximum. MVIC maximum voluntary isometric contraction.

3.1 Electrical Activity of full range of motion*

After 4 weeks, Although a decrease in the electrical activity of TP group has been seen, there were no significant difference in the normalized root mean square of biceps brachii between groups, as shown in Figure 3a. (P=0.165).

3.2 Concentric phase

After 4 weeks, as shown in Figure 3b, although a decrease in the electrical activity of TP group has been seen, no significant difference in the normalized root mean square of the biceps brachii was observed in group TP compared to group SP (P=0.181).

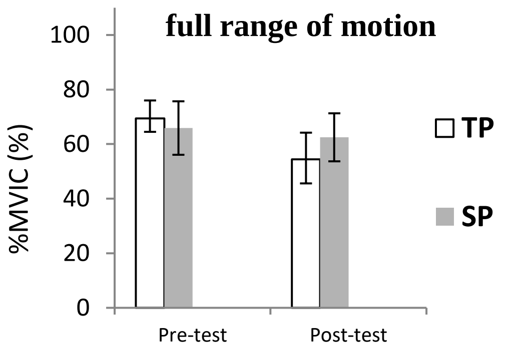

Figure 3a. pre and post, trial group scores for biceps normalized RMS in full range of motion.no significant difference observed. p=0.165.

3.3 Eccentric phase

After 4 weeks of interventions, the difference in electrical activity in the pre-test and post-test is shown in Figure 3c. There was a significant decrease in the normalized root mean square of the biceps brachii muscle in the TP group compared to the SP group (P < 0.05).

3.4 Muscle strength

One repetition maximum (1RM) strength results for the biceps brachii muscle are shown in Figure 3d. Statistical analysis showed that there is no significant difference in muscle strength (p =0.251).

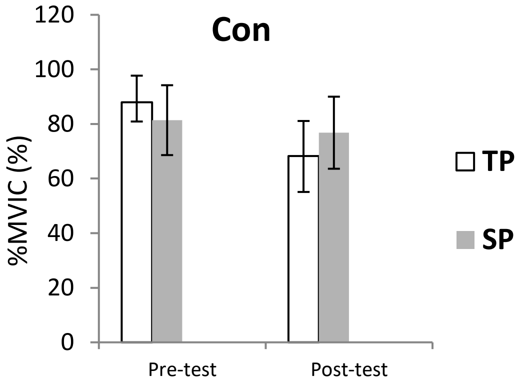

Figure 3b. pre and post, trial group scores for concentric phase of dumbbell curl movement. no significant difference observed. p=0.181.

* Concentric + Eccentric

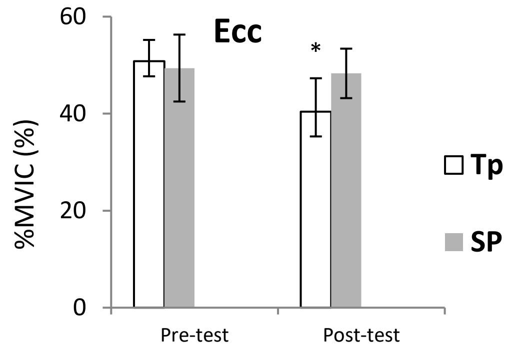

Figure 3c. pre and post, trial group scores for eccentric phase of dumbbell curl movement. "*" represents signigicant difference between groups. p<0.05

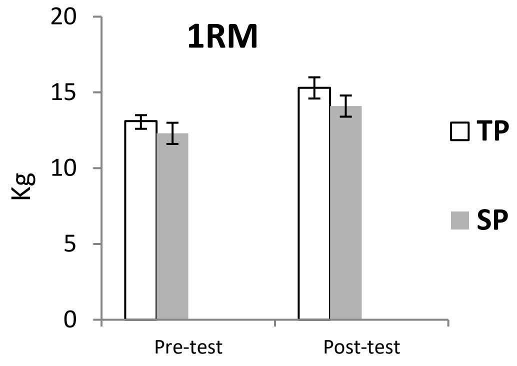

Figure 3d. pre and post trial group scores for biceps 1RM. 1RM one-repetition maximum. no significant difference observed. p=0.251.

Figure 3. Data expressed as Mean ± S.E. according to Bonferronie. T tDCS, C control, Con concentric phase. Ecc eccentric phase. MVIC maximum voluntary isometric contraction. 1RM one repetition maximum.

4. Discussion and Conclusion

The objective of this study was to execute a biceps dumbbell curl with a weight equivalent to 80% of the one-repetition maximum (1RM) during both the pre-test and post-test periods. The evaluation of the modifications caused by transcranial direct current stimulation (tDCS) and practical blood flow restriction (pBFR) was performed by measuring electromyographic activity and 1RM.

The results of our study indicate that the electrical activity of the concentric phase and the full range of motion, as depicted in Figure 3a and b, in the TP group compared to the SP group was not statistically significant, suggesting that tDCS and pBFR did not have a synergistic effect. However, in the eccentric phase of the dumbbell curl movement, it was significantly lower in the TP group compared to the SP group (P<0.05) (Figure 3c). This suggests that the TP group's muscles were able to recruit muscle fibres more efficiently and economically when subjected to the same load, and tDCS of the M1 may be the main factor contributing to the changes observed in the TP group. This finding is consistent with the results reported by Cadore et al. (2010), who found that a period of strength training reduced muscle activity (22). These data suggest that tDCS may enhance the economy of neuromuscular activity by improving the recruitment of motor units during a particular load. Neuromuscular economy refers to the occurrence of changes in electrical activity that show the minimal level of muscle activation required to accomplish a certain job (22, 23). At an equivalent weight, the researchers proposed that individuals need a lower number of motor units, specifically fast-twitch muscle fibres. As a result, the amplitude of electromyography decreases, as seen in Figure 3c. This finding is significant as neural processes play a greater role during the eccentric phase of movement, and it highlights the limited efficacy of blood flow restriction (BFR) workouts in enhancing neural adaptations and tDCS has demonstrated its ability to provide a complimentary and synergistic impact when used in conjunction with pBFR training.

Enoka et al.'s research demonstrates that the instructions issued by the nervous system to control eccentric activity differ from those for other types of contractions, such as concentric or isometric contractions. This phenomenon involves a shift in motor unit recruitment, beginning with larger motor units, which subsequently leads to a decrease in muscle activity during eccentric contractions. This alternative strategy modulates the network of neurons that control the muscle in order to optimise performance and preserve the well-being of motor units (11). According to Fang et al.'s (2001) analysis of muscle EMG signals and cerebral cortex EEG, there is less electrical activity observed in the eccentric phase of the movement compared to the concentric phase in the muscle. However, they observed greater cortical activity in the eccentric phase. It demonstrates that the brain has a greater role in eccentric behaviour. The activation of stretching reflexes in the muscle may result in increased cerebral activity during eccentric movements. The cortical processes related to planning eccentric movements are not only more pronounced, but the neurons also begin their activities earlier for eccentric movements (12). The present research demonstrates that tDCS significantly decreases muscle activity during the eccentric phase in the TP group compared to the SP group. We achieve this by regulating and enhancing the neural processes in the primary motor cortex, in conjunction with pBFR workouts. Bruce et al. (2020) showed that the combination of a-tDCS and strength training can enhance muscle activation following six weeks of training (24). This aligns with our research findings on the impact of tDCS on muscle activity and its ability to enhance motor performance. To our knowledge, no research has explored the combined impact of tDCS and pBFR on distinct motor phases. Therefore, we are unable to make comparisons between our findings and other studies in this particular area. The result is remarkable and demonstrates the potential benefits of applying these methods. However, further research is required to fully comprehend these systems and their implications for physical exercise and rehabilitation.

Figure 3d shows that the dynamic strength (1RM) increased in both the TP and SP groups after 4 weeks. However, there were no statistically significant differences between the groups. The results indicate that the concurrent use of tDCS and pBFR did not provide a synergistic impact on strength. The ceiling effect, which occurs when an intervention reaches its maximum potential and no further progress is observable, could possibly explain the null finding. This is potentially true for the TP group, which had both tDCS and pBFR training. An individual's baseline level may influence the impact of tDCS on their performance, and it's possible that the TP group has already achieved their maximum degree of brain enhancement through the combination of tDCS and strength training. Consequently, they were unable to enhance their strength above a specific threshold. This may be comparable to the contrast between those who are highly skilled or experienced (elites) and those who are just starting out (beginners), since they tend to have distinct reactions to the same intervention. For instance, Furuyama and his colleagues conducted a study where they showed that the application of anodal transcranial direct current stimulation (a-tDCS) across the primary motor cortex (M1) led to enhanced motor control in individuals who did not have any musical training. Nevertheless, this intervention resulted in a decrease in performance among experienced pianists. (25). Rosen et al. discovered that applying anodal tDCS to the right dorsolateral prefrontal cortex had a positive impact on the improvisation skills of less experienced jazz pianists, but it had a negative effect on individuals with higher proficiency (26). However, our findings align with several studies that did not detect the combined impact of tDCS and exercise training. Jung et al. (2023) examined the impact of combining tDCS with physical training on the physical performance of a group of healthy individuals. The researchers discovered that only physical exercise, and not tDCS, enhanced maximal isometric muscular strength (MIMS). (17). In a study conducted by Beaulieu et al. (2019), the researchers evaluated the efficacy of several sessions of tDCS combined with an upper limb resistance training programme. The findings revealed that tDCS did not result in further improvements in sensorimotor function compared to a sham-tDCS condition. (27). The results of these studies are consistent with our own, despite the use of different protocols.

This study is the first, as far as we know, to present experimental proof of the combined effects of tDCS and practical BFR training on the synergistic adaptation and enhancement of neuromuscular efficiency during the eccentric phase of the dumbbell curl movement. Furthermore, our findings indicate that the use of tDCS did not provide a combined impact with pBFR training on dynamic strength, electrical activity during the concentric phase, and the full range of motion in the biceps brachii dumbbell curl movement. Nevertheless, given the study's limited duration and the small number of participants, it is important to use caution when interpreting the data. In order to clarify the neural changes that take place in response to tDCS, additional research is required.

Authors' Contributions

This research was carried out collaboratively by all authors. The study design and execution of experimental tests were handled by Z. Fallahmohamadi and B. Taheri. Meanwhile, the coordination of the study, statistical evaluation, and assistance in manuscript preparation were undertaken by authors KH. Irandoost and S. Namdar. The final manuscript received the approval and endorsement of all authors.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All the procedures of the ethics committee in human research were considered. all participants provided written informed consent, and the study was approved by the research ethics committees of University of Mazandaran (IR.UMZ.REC.1403.001).

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