

The Immediate Effects of a Single 20-Minute Session of Transcranial Direct Current Stimulation (tDCS) on Muscle Strength in Older Adults

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Received: 8 April 2024, Revised: 4 May 2024, Accepted: 12 May 2024, Published: 20 September 2024

Abstract

The older population often experiences a gradual age-related decline in the primary motor cortex, leading to muscle weakness that can harm their physical performances. Exercise could improve physical performance and prevent falling in older adults. However, the decrease in motor function and motor skills in older adults reduces the efficiency of fall prevention. Transcranial Direct Current Stimulation (tDCS) is a non-invasive intervention aimed at improving muscle strength in various conditions by utilizing transcranial direct current stimulation applied to the primary motor cortex (M1). Pre- and post-studies were conducted to demonstrate the effects of a single 20-minute session of tDCS alone, as well as to assess any potential side effects. Sixteen older individuals, both male and female, aged 65 years or older, with or without underlying diseases, were assessed for leg and hand grip strength, followed by physical performance tests. Subsequently, they underwent stimulation of the primary motor cortex through the placement of anodal tDCS (a-tDCS) over the left M1 for 20 min. Immediate effects were evaluated within 24 h, and side effects were recorded for up to 2 weeks after the stimulation. The results demonstrated that a single session of tDCS led to a significant increase in leg strength by 13 kg (5.9 to 20.1 kg, $p < 0.01$). There was also a significant correlation observed with hand grip strength ($r = 0.68$, $p < 0.01$). All physical performance tests, except the fastest speed in the 10-meter walk test, showed statistically significant improvements ($p < 0.01$). Participants reported no serious side effects, and the intervention will now be incorporated into prospective clinical studies involving older populations to compare its effectiveness with other treatments.

Keywords: Transcranial Direct Current Stimulation (tDCS), Muscle strength, Older adults, Physical performance, Primary motor cortex, Health promotion

Introduction

The older population is growing worldwide, leading to increased dependence on daily assistance [1,2]. Muscle weakness is a significant issue in aging, primarily linked to the decline in the primary motor cortex's function [2,3]. This weakening of motor functions affects lower extremity strength, balance and walking ability [4-6], ultimately resulting in decreased physical performance and an elevated risk of falls among older adults [7-9].

Age-related changes in the primary motor cortex lead to muscle weakness via complex physiological mechanisms [10], including neuronal loss and degeneration, which reduce the neuron count in the region, impairing muscle signalling. Synaptic changes alter connections between motor cortex neurons and muscles, impacting signal transmission efficiency. Reduced excitability makes neurons less responsive to stimuli, resulting in weaker and less coordinated muscle contractions. Additionally, aging leads to a decrease in motor units, limiting the number of neurons available for muscle activation. These changes collectively contribute to age-related muscle weakness [10,11].

Transcranial Direct Current Stimulation (tDCS) is a neuromodulation technique that involves applying a low direct current to the scalp to influence primary motor cortex neuron activity, aiming to enhance cognitive and motor functions. tDCS can be used together with motor training or strengthening exercises [12]. Its mechanism involves altering the resting potential of neurons, making them slightly more excitable. This modulation can affect synaptic plasticity, strengthening connections between neurons and potentially slowing the decline in motor functions [13-16].

The primary goal of this study was to investigate the immediate effects of a single 20-minute session of anodal tDCS alone on the primary motor cortex in older individuals without neuromuscular diseases in a community-based setting. The hypothesis was that this stimulation would lead to improvements in leg and hand grip strength, correlating with enhanced performance in various physical tests. Additionally, the study aimed to report any adverse effects to ensure the safety of elder before recruiting a larger sample for a clinical randomized control trial.

Materials and methods

The present study used a pre-post-treatment design. Participants were recruited via health officers from community-dwelling elder adults in rural communities in Khon Kaen Province, Thailand between October and December 2022. The study was approved by the Research Ethics Committee of the Center for Ethics in Human Research, Khon Kaen University (Reference: HE612067) and informed consent was obtained from all subjects recruited for the study.

Participants

The present study included participants from Khon Kaen Province who met specific criteria. The inclusion criteria involved participants being at least 65 years old and having a BMI ranging from 18.5 to 29.9 kg/m². The exclusion criteria were assessed through questionnaires and encompassed various factors. These exclusions included the inability to perform the test without assistive devices, the presence of acute inflammation accompanied by moderate or severe pain (visual analogue scale > 4 cm), a history of neuromuscular diseases (such as Parkinson's disease, stroke, and spinal cord injury), epilepsy, seizures, or mental disorders. Additionally, participants were excluded if they exhibited signs and symptoms such as dizziness, vestibular disorders, angina pain (indicating a potentially dangerous heart condition), uncontrolled hypertension, cognitive impairment, or metal inserted near the current stimulation site, defects in the skull bone, signs of depression, or sensory impairment.

The sample size was determined based on the isometric strength (N/kg) data reported in a prior study that employed tDCS to enhance maximal voluntary isometric contraction of the external rotators of the shoulder in handball players. Specifically, in the study by Hazime *et al.* [17], an effect size of 0.2 N/kg was reported, with a mean square error (σ) of 0.025. To achieve a study power of 80 % and a significance level of 0.05, accounting for a dropout rate of 10 %, a minimum of 16 participants was needed to be recruited for the present tDCS study.

Intervention

Older participants were instructed to sit in a comfortable chair for the tDCS session. Anodal tDCS was administered using a tDCS device (PortableTDCS, Khon Kaen, Thailand) (**Figure 1**), delivering the stimulation to the scalp through 2 large sponge electrodes ($7 \times 5 \text{ cm}^2$). The electrodes were secured in place using 2 elastic straps. The international 10 - 20 system was utilized to locate the primary motor cortex (M1) region on the scalp. A bipolar electrode montage consisting of 1 anode and 1 cathode was employed. The anode electrode was positioned over the left (dominant) M1, while the cathode electrode was placed over the right shoulder region. Due to the large size of the electrode, it covered the dominant M1 region for the hand, arm, trunk and leg areas. The current intensity was set at 2 mA for 20 min, with 10-second fade-in and 10-second fade-out intervals.

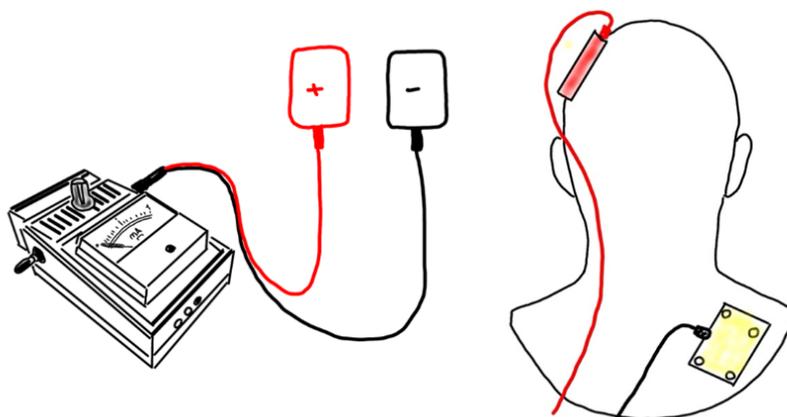


Figure 1 Setting tDCS, anode was represented by the red cable placed on the left primary motor cortex; Cathode was represented by the black cable placed on the right upper trapezius muscle.

Outcome measures

Measurement of muscle strength

Isometric leg strength was measured using back and leg dynamometers (TKK 5002; Takei Scientific Instruments Co., Ltd., Japan), which are commonly used instruments to assess the maximum isometric strength of the back and leg muscles. These dynamometers are known for their high validity and reliability [18]. During the measurement, participants were instructed to stand with their backs against a wall and their feet flat on the ground. The participant's knees were to be bent at a 90° , with their thighs parallel to the ground. Participants were directed to extend both knees maximally for 2 repetitions, resting for 30 s between each and selecting the highest value for analysis.

Hand grip strength was measured using a hand grip dynamometer. Grip strength was determined by Grip strength (unit; kg) using an adjustable Smedley dynamometer (TKK 5401; Takei Scientific Instruments Co., Ltd., Niigata, Japan). This device is specifically designed to assess the grip strength of the dominant hand. Participants were seated upright on a height-adjustable chair with their feet supported. The arm being tested was positioned on a table, with the shoulders slightly abducted ($\sim 10^\circ$) and in a neutral rotation. The elbow was flexed at 90° , the forearm was maintained in a neutral position (between pronation and supination), and the wrist was in a resting neutral position [19]. Participants were instructed to hold the position and perform 3 repetitions of maximal grip strength with 30 s of rest between each analysis, and the highest value was selected for analysis.

Measurement of physical performance tests

10MWT

The 10-meter walk test (10MWT) was utilized to assess ambulatory status and walking speed over a brief period, specifically focusing on comfortable gait speed. During the 10MWT, participants performed the task with a “flying start”, meaning that the time recorded was for the middle 4 m of their 10-meter walk. Participants were instructed to walk at a comfortable speed for 3 trials [20]. The preferred speed was instructed the participants by an assessor subsequently, the average time was converted into gait speed, and measured in meters per second (m/s).

6MWT

The 6-minute walk test (6MWT) is employed to evaluate functional endurance. Participants were instructed to walk as far as they can around a rectangular walkway in 6 min. During the test, an assessor provided time updates every minute to inform participants about the time remaining. Although participants were allowed to rest, if necessary, the timer continued without any interruption. Furthermore, participants received verbal encouragement at the 1-, 1- and 5-minute marks during the test. The distance covered within the 6-minute timeframe was recorded in meters (m).

TUG

The timed up-and-go (TUG) test is a commonly employed method to evaluate balance ability [21]. To perform the test, participants were instructed to sit on a standard chair with an armrest, where the seat height was set at 43 cm while keeping their back against the backrest. They were then instructed to stand up from the chair without using their hands, walk 3 m at a fast but safe speed, navigate around a traffic cone, and return to sit down on the chair. The time taken from the command “go” until the subject’s back touches the backrest was recorded. The average time from 3 trials was calculated and reported in seconds (s).

FTSST

The five-times sit-to-stand (FTSST) test is used to evaluate the strength of the lower limb muscle [22]. During the test, participants sit on a standard armless chair set at a height of 43 cm, with their arms resting beside their trunks. They were then instructed to stand up, fully extending their hip and knee joints, and subsequently sit back down again. This process was repeated 5 times, to complete the movements as quickly as possible without utilizing their arms for support. The time taken to complete the test is measured in seconds, starting from the moment the command “go” was given until the subject’s back made contact with the backrest on the 5th repetition. The average time of 3 trials was recorded for analysis.

Adverse effects

Any negative impacts were noted promptly after the tDCS treatment and continued to be observed for up to 2 weeks.

Procedure

The researchers directly contacted health officers to assist them in announcing their study within a rural community and informing older individuals about the project. The older people willingness to participate underwent a screening process using a screening form, were interviewed to evaluate their health status and determine if they met the inclusion and exclusion criteria. To ensure consistency, all

older participants were instructed to refrain from engaging in heavy physical activity for 1 week prior to the start of the trial. The following tests were conducted for the participants in a random order: Baseline measurements, including isometric leg and hand grip muscle strength, and physical performance tests. The next day, after the 20-minute tDCS treatment, a post-tests of muscle strength and physical performance was performed.

Statistical analysis

The data analysis was conducted using the Statistical Package for the Social Sciences SPSS version 28 by International Business Machines Corporation (IBM Thailand Co., Ltd., Thailand). To check the normality of the outcome measures, the Shapiro-Wilk test was used. A paired t-test was performed to compare the baseline and post-treatment results. The statistical significance level was set at $p < 0.05$. The figure was created using R software (R Core Team (2020), Vienna, Austria. URL <https://www.R-project.org/>).

Results and discussion

Demographic data

Initially, 55 older participants were screened, out of which 16 participants (10 females and 6 males) were found to be eligible for participation. Their average age was 72.3 years, and their body mass index (BMI) was 23.6 kg/m². Among them, 11 participants reported underlying health conditions, including 7 cases of diabetes mellitus, 10 with hypertension, 2 with chronic kidney disease, 2 with dyslipidemia and 1 with heart disease.

Primary outcomes

The findings of the study are summarized in **Table 1** and **Figure 2**. The results show that tDCS alone had a significant positive effect on isometric leg strength, increasing to 13 kg (95 % CI [20.10 to 5.91 kg], $p < 0.001$). However, there was no statistically significant change on-hand grip strength ($p > 0.05$).

The study found that there was a strong and significant positive correlation ($r = 0.68$, $p < 0.01$) between the change in isometric leg strength and the change in hand grip strength. However, there were some correlations observed between the change in physical performance, but they were not statistically significant (**Figure 3**).

Secondary outcomes

The study results showed significant improvements in various physical performance tests after the intervention. The preferred speed-10-meter walk test increased by 0.20 m/s (95 % confidence interval [0.29 to 0.11 m/s], p -value < 0.001). The distance covered in the 6-minute walk test increased by 52.5 meters (95 % confidence interval [85.8 to 19.2 m], p -value < 0.01). The time taken to complete the Timed Up and Go (TUG) test decreased by 2.1 s (95 % confidence interval [-1.6 to -2.57 s], p -value < 0.001). Similarly, the time taken to complete the Five-Times Sit-to-Stand (FTSST) test decreased by 1.61 s (95 % confidence interval [-0.72 to -2.51 s], p -value < 0.01).

Table 1 The immediate effects (within 24 h) of 20 min of tDCS on physical performances.

Outcomes	Baseline Mean (SD)	Post-treatment Mean (SD)	Mean difference compared with baseline, (95 % CI) with <i>p</i> -values
Primary outcomes			
Leg strength (kg)	54.8 (20.5)	67.8 (20.7)	13 (20.1 to 5.9)* <i>p</i> = 0.001
Hand grip strength (kg)	24.4 (5.8)	25.2 (5.6)	0.8 (1.7 to -0.1) <i>p</i> = 0.072
Secondary outcomes			
Prefer speed-10MWT (m/s)	1.1 (0.1)	1.3 (0.2)	0.2 (0.3 to 0.1)* <i>p</i> = 0.001
Fastest speed-10MWT (m/s)	1.4 (0.3)	1.4 (0.2)	0.1 (0.1 to -0.1) <i>p</i> = 0.631
6MWT (m)	312.2 (59.3)	364.7 (87.5)	52.5 (85.8 to 19.2)* <i>p</i> = 0.004
TUG (s)	11.0 (2.4)	8.9 (2.1)	-2.1 (-1.6 to -2.6)* <i>p</i> = 0.001
FTSST (s)	13.2 (2.5)	11.6 (2.0)	-1.6 (-0.7 to -2.5)* <i>p</i> = 0.002

Note: Data are mean with SD; 10MWT, 10-meter walk test; 6MWT, 6-minute walk test; TUG, time up-and-go test; FTSST, five-times sit-to-stand test; (*), significant *p*-value < 0.05.

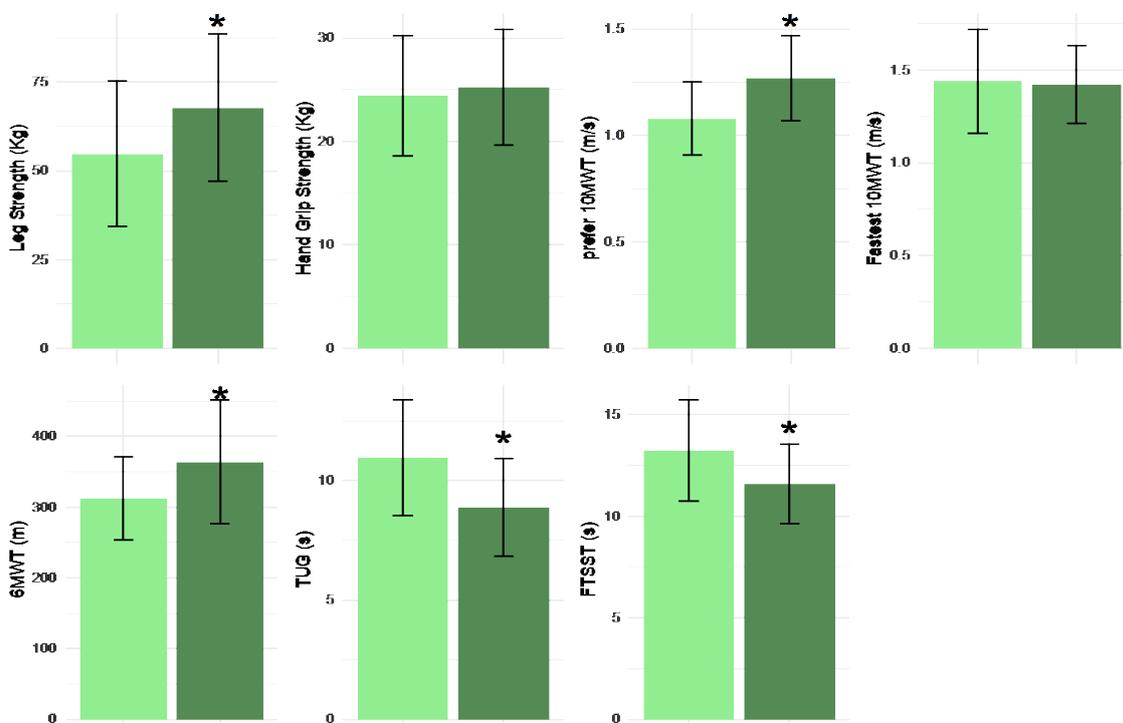


Figure 2 Compared between baseline (light green bar graph) and immediate post-treatment (Dark green bar graph) within 24 h of 20 min of tDCS on muscle strength which contains leg and hand grip strength, and physical performances which contain 10MWT, 10-meter walk test; 6MWT, 6-minute walk test; TUG, time up-and-go test; FTSST, five-times sit-to-stand test; (*), significant *p*-value < 0.05.

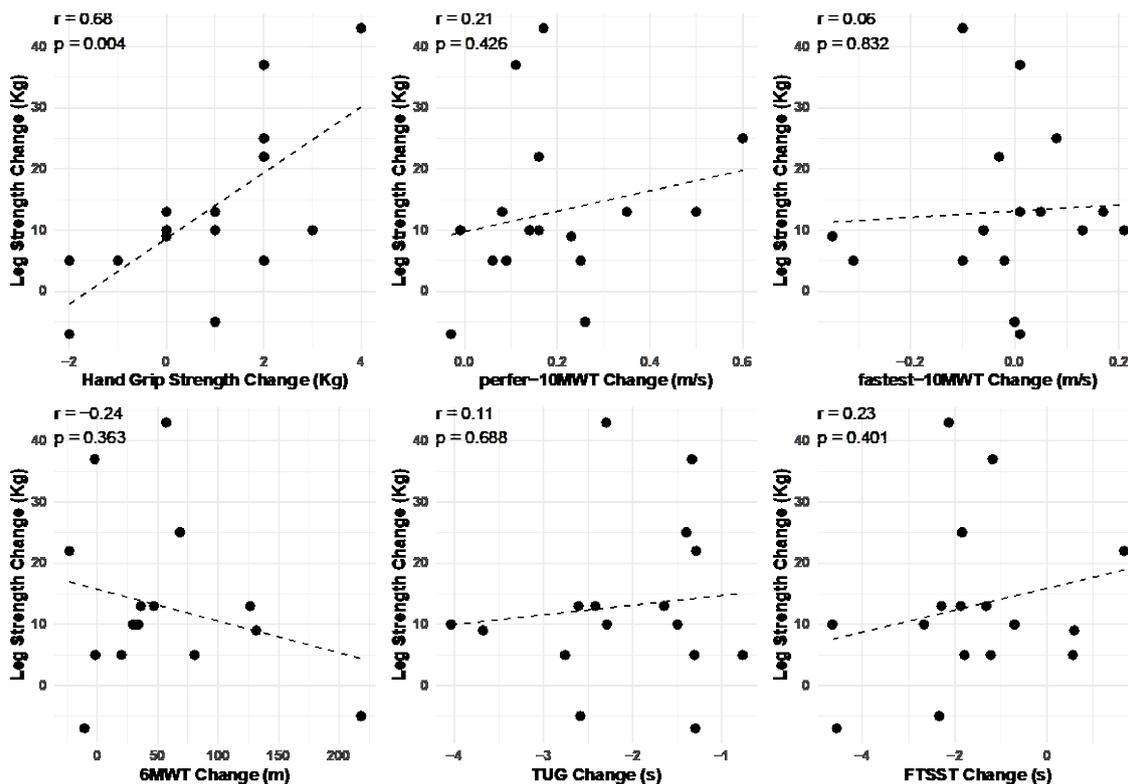


Figure 3 Pearson's correlations were calculated from the changed value between baseline and post-treatment by presenting the correlations between leg strength and each physical performance test which contains a 10-meter walk test (10MWT), 6-minute walk test (6MWT), time up-and-go test (TUG), five-times sit-to-stand test (FTSST) and hand grip strength.

In this study, we have investigated the effects of a single 20-minute tDCS session on older adults within a community setting. The results indicated that this intervention had positive effects on isometric leg strength and various physical performances. These improvements encompassed an increase in the preferred speed for the 10MWT and 6MWT, as well as a decrease in the durations of the TUG test and FTSST. Interestingly, while isometric leg strength saw an increase, it did not exhibit a significant correlation with the enhancements observed in physical performance. Our findings offer reassurance regarding the safety of this treatment approach for older adults within a community environment.

Our findings showed the efficacy of a single 20-minute session of tDCS alone on isometric leg strength but no improvement in hand grip strength in older adults, which was similarly reported in previous studies [15]. Tanaka *et al.* [15] reported increased knee extensor strength but no change in handgrip strength compared to sham stimulation. Moreover, the strength of the lower limbs showed significant differences after tDCS application on the primary motor cortex in older adults [23]. The possible mechanism behind these effects can be explained by cortical and corticospinal excitability. Anodal tDCS can increase motor unit recruitment by depolarizing the resting membrane potentials of motor cortex neurons. This leads to improved muscle recruitment and, consequently, increased muscle strength. This enhancement of corticomotor excitability is supported by Liu *et al.* [13], who demonstrated in a rat model that the motor evoked potential significantly increased immediately after anodal tDCS at both 0.1 and 0.8 mA, and this enhancement persisted for 30 min. Additionally, the common physical connection mechanism theory [24] describes how anodal tDCS might augment the strength of common corticospinal drive to spinal motor neurons. This, in turn, could increase the extent of motor unit

synchronization [25]. This theory is supported by Dutta *et al.* [26], who demonstrated that the application of tDCS can alter motor unit firing patterns and muscle recruitment strategies.

Anodal tDCS applied to the primary motor cortex alone can demonstrate efficacy in improving physical performance measures (such as 10MWT, 6MWT, TUG and FTSST). However, the change in isometric leg strength only shows a positive correlation with hand grip strength, with no correlation observed between the changes in these physical performance measures. This discrepancy may be explained by various factors that influence independent daily living abilities, including muscle strength, walking speed, endurance and balance ability [27]. While muscle strength is a key factor in achieving daily activities independently, other factors also hold significance. Our findings indicate a significant improvement in physical performance measures following a single session of anodal tDCS treatment alone. This slight difference from previous studies may be attributed due to limitations in the study design, which will be elaborated on the next paragraph. Most previous studies suggest that significant improvements in physical performance are observed when tDCS is combined with other active exercises. Supporting this notion, Zimerman *et al.* [28] combined 20 min of anodal tDCS with a motor learning task, resulting in improvements in both motor and cognitive functions in older individuals. Rodrigues *et al.* [29] confirmed significantly improved strength when tDCS was combined with physical training. Furthermore, Yamaguchi *et al.* [30] proposed that combining attentional focus with tDCS could be an effective strategy for enhancing rehabilitation training in patients with stroke and neurodegenerative disorders. Therefore, we recommend further studies that explore combining tDCS with active exercises or physical training in older populations, could potentially enhance the efficacy of physical performance improvements.

This study has some limitations that might have influenced its results. Firstly, we did not include a control group, which made challenging to establish a direct cause-and-effect relationship between the intervention and the outcomes we observed. It is possible that other factors, such as natural variability, learning effects, or placebo responses, could have contributed to the observed changes. Secondly, the potential for placebo and expectancy effects needs to be considered. Participants may have anticipated positive effects due to their awareness of receiving an intervention, which could have led to placebo effects and influenced their reported outcomes. Thirdly, the issue of selection bias arises. Participants who willingly agreed to take part in the study might not be fully representative of the entire population, could introduce bias, potentially affect the generalizability of the findings. Lastly, the study design lacked a follow-up assessment to determine if the observed effects was sustainable beyond the immediate post-intervention period. Future studies with longer follow-up durations are recommended to provide a more comprehensive understanding of the lasting impact of the intervention.

A key strength of the current study is that it included older individuals, the majority of whom had limited engagement in regular exercise. The average age of older participants was 72.3 years, and none of them relied on assistive devices for their daily activities. This selection process ensured that we included individuals with minimal impact on their physical performances, which required the ability to function normally. We excluded individuals who were severely disabled and dependent on assistive devices. Additionally, this present study confirmed that the only minor adverse effects of tDCS presented in older adults included skin irritation under the electrodes. In future studies, we recommend ensuring safety through proper electrode placement and safety guidelines [31,32].

Adverse effects

During stimulation, 2 older adults (12 %) reported minor adverse effects of itchy skin under anodal tDCS. No severe adverse effects were reported within 2 weeks after treatment, aligning with findings

from a previous study on subacute stroke patients [33]. This suggests that tDCS is generally safe and well-tolerated in older adults, with a very low risk of severe complications.

Conclusions

The findings of this present study suggest that potential a 20-minute tDCS session has the potential to improve isometric leg strength and various physical performance measures in older adults in a community setting. Furthermore, the tDCS does not lead to any serious adverse effects and could be considered an effective treatment for older adults. We recommend combining tDCS with active exercises to enhance its efficacy in a clinical randomized controlled trial.

Acknowledgements

The authors would like to thank older adults who participated in the current study. Additionally, the authors wish to express their gratitude to physiotherapist Mr. Wiraphong Sucharit for his assistance in carrying out the study. This work was supported by the Research Program, at Khon Kaen University, Thailand [Grant Number RP66-3-002].

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