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A Selected Balance Exercise Combined with Anodal tDCS Was Beneficial in Balance Performance but not in Working Memory in Healthy Older Adults

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ABSTRACT

Background: Transcranial direct current stimulation (tDCS) has recently drawn attention as an inexpensive, painless, safe, and effective technique to improve motor performance and cognitive function in older adults. This study examined the effects of a selected balance exercise combined with anodal tDCS on balance performance in older adults**. Methods**: Twenty-four healthy older adults (Mean ages= 69.79±5.50 years) participated in this study. The participants were randomly assigned into a real tDCS or sham tDCS groups. The participants in the real tDCS group received 2 mA anodal tDCS over the left primary motor cortex (M1) for 20 min while in the sham group they received a sham tDCS for the same duration. The participants performed a selected balance exercise program for 50 min following tDCS. Training was conducted 2 sessions per week for 8 weeks (16 sessions). Berg balance scale (BBS), timed up and go test (TUG) and working memory test (2-back task) were measured before (baseline), after 8 weeks of the training, and 4 weeks of follow-up. **Results:** Compared to sham tDCS group, BBS and TUG were significantly improved in real tDCS group after the training and 4 weeks of follow-up, however, this intervention could not affect working memory. **Conclusion**: In summary, these results indicate that the selected balance exercise program combined with anodal tDCS can improve balance performance but not working memory in older adults.

1. Introduction

Lower extremity functional ability involves basic tasks that are essential in carrying out daily activities and includes walking, lower extremity strength, balance, and postural control (Lusardi, Pellecchia, & Schulman, 2003). There exist several sets of evidence indicating that aging is associated with reduced lower extremity functional ability reflected in reduced muscle performance (Hunter, Weinsier, Bamman, & Larson, 1998), reduced strength (McNeil, Vandervoort, & Rice, 2007), loss of motor coordination (Seidler et al., 2010), and poor balance and walking (Rostami et al.,2020). In other words, deteriorated balance performance and lower extremity functions are among the issues related to lower quality of life for older adults which sometimes may even lead to falls or other motor problems (Kaminski et al., 2017; Modaberi, Saemi, Federolf, & van Andel, 2021).

In the process of aging, the brain's overall size naturally begins to shrink (Scahill, Leckman, Schultz, Katsovich, & Peterson, 2003). with age-related changes developing in different areas of the motor cortex. These changes are said to be associated with reduced motor control, impaired walking performance, and poor balance (Seidler et al., 2010). One area of the brain cortex that plays an essential role in proper activation of muscles and controlling voluntary movements (Radel, Tempest, Denis, Besson, & Zory, 2017) is the primary motor area (M1) (Mattay et al., 2002). Previous studies offered evidence suggesting that M1 importantly contributes to some aspects of lower extremity functions. Some have shown that during the gait cycle, M1 communicates with the subcortical region (responsible for gait control) (McCrimmon et al., 2017) as well as the supplementary motor area (SMA) that contributes to motor control (Wang et al., 2008). M1 also influences balance and gait control (Demain et al., 2014).and lower extremity strength (Oki et al., 2016).

Given the growing number of aging populations in developed as well as developing countries (Oki et al., 2016), it is essential to establish safe, inexpensive interventions and exercise methods to enhance lower extremity functional ability, balance performance,

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and cognitive performance among the older adults (Buch et al.,2017).

Transcranial direct current stimulation (tDCS) has recently drawn attention as an inexpensive, painless, safe, and effective technique in improving cognitive and motor performance (Buch et al.,2017; Ammann, Spampinato, & Márquez-Ruiz, 2016). tDCS is a neuromodulatory technique that results in cortical excitation without generating active potential. It can modulate the resting membrane potential, thereby modulating action potential of neurons (Buch et al.,2017). The technique involves using a weak electrical current applied on the scalp through two electrodes with the intention to manipulate certain regions of the brain. It works on ion homeostasis inside and outside the membrane, stimulating shifts in the resting membrane threshold (Fregni et al., 2005).

Anodal current enhances cortical excitability and depolarizes cell membranes while cathodal current decreases cortical excitability and hyperpolarize cell membranes (Costa et al., 2020). Based on this, it is generally assumed that tDCS can enhance and preserve the effects of various physical and cognitive exercises on performance capacity in individuals (Ammann, Spampinato, & Márquez-Ruiz, 2016). These positive effects were first reported in the human motor cortex (Nitsche, & Paulus, 2000); however, later studies demonstrated the same positive effects on other cortical regions including the visual cortex (Antal, Nitsche, & Paulus, 2001), the sensorimotor cortex (Rogalewski, Breitenstein, Nitsche, Paulus, & Knecht, 2004), the prefrontal cortex (Fregni et al., 2005), and the cerebral cortex (Galea, & Celnik, 2009). For example, a session of anodal tDCS (a-tDCS) on M1 was reported to enhance upper extremity functional ability in the older adults (Zimerman, & Hummel, 2010). Similar findings were reported by other studies (Goodwill, Daly, & Kidgell, 2015; Hummel, Genow, & Landis, 2010; Parikh, & Cole, 2015). However, to the best of our knowledge, few studies have examined how a-tDCS on M1 can influence lower extremity functional ability in the healthy older adults. For example, researchers (Craig, & Doumas, 2017) examined how tDCS on the celebellum as well as M1 can influence postural control in adults and the older adults. Their findings indicated a minimal effect of tDCS on postural control in the eyes-open condition. In another study on the older adults, (Rostami et al.,2020) reported similar positive results. Therefore, a-tDCS seems to be a promising technique to enhance lower extremity functional ability.

In addition, aging leads to changes in all systems of the body. Moreover, morphological and biochemical changes in different areas of the brain, such as frontal and parietal cortices, reduce cognitive capacity while causing changes to appear in the musculoskeletal system (Coppin, et al., 2006). An investigation of neuroimaging indicates how working memory functions in the brain. The prefrontal region, particularly the dorsolateral prefrontal cortex, was cited as a major area involved in working memory processes and defects (Soltaninejad, Nejati, & Ekhtiari, 2019). Furthermore, a study of neuroimaging results has shown that the right inferior frontal gyrus is activated during inhibitory control activities (Soltaninejad, Nejati, & Ekhtiari, 2019). Thus, tDCS techniques that monitor and regulate activities of the dorsolateral prefrontal cortex (DLPFC) are capable of improving working memory as well as balance performance (Fregni et al., 2005).

Furthermore, many studies with promising results have examined effectiveness of noninvasive direct current stimulation of the brain (Nitsche et al.,2008). These effects may vary depending on electrode placement, their polarity, and current intensity. Studies about effects of electrical cortical stimulation on cognitive functions produced mixed results. For example, Andrews et al., (Andrews, Hoy, Enticott, Daskalakis, & Fitzgerald, 2011) examined the link between cognitive activity and anodal stimulation of the DLPFC to improve working memory in ten participants with the age of 20-51 years. Their findings indicated improved working memory function as a result of controlled stimulation combined with an n-back task.

However, while some studies reported favorable impact of this training technique on working memory as well as motor performance in children (Almeida, Barbosa, & Compte, 2015), adults (Karok, & Witney, 2013; Ke et al.,2019; Katagiri et al., 2021), and the older adults (Zandvliet, Meskers, Kwakkel, & van Wegen, 2018; Gomes et al., 2019), the results in this area are still inconsistent and others (Rabipour, Vidjen, Remaud, Davidson, & Tremblay, 2019; Kaminski et al., 2013; Steiner et al., 2016) failed to demonstrate positive effects of tDCS on cognitive and motor performance. For example, Kaminski et al. (2013) showed that a single session of anodal tDCS in the M1 region could not improve balance performance in the older adults. It seems, one possibility is that the degree of difficulty in postural balance control tasks leads to different results. Previous studies investigated tDCS effects on postural balance control during static standing with open or closed eyes, feet apart or feet together, and stable or movable platform (Katagiri et al., 2021; Zandvliet et al., 2018; Poortvliet, Hsieh, Cresswell, Au, & Meinzer, 2018; Steiner, K. M., Enders et al., 2016). Additionally, most studies have focused on the immediate effects of tDCS on postural balance control, but one paper reported that the 10 sessions of anodal tDCS (2 mA) over M1 and physical therapy training improve ankle control and balance in stroke patients (Ehsani, Mortezanejad, Yosephi, Daniali, & Jaberzadeh, 2022). Therefore, the repeated anodal tDCS over M1 and balance exercise program may improve balance performance (Ehsani et al., 2022; Hou, Nitsche, Yi, Kong, & Qi, 2022). However, to the best of our knowledge, no study has examined whether repeated anodal tDCS over M1 and balance exercise program improves balance performance and working memory in older adults. Therefore, the present study aimed to examine the effects of a 16-session balance exercise program combined with a-tDCS in M1 on motor and cognitive performance among the older adults. Accordingly, it is hypothesized that a 16-session balance exercise program combined with a-tDCS in M1, improves the balance performance of the older adults immediately after the exercise sessions and also one month after the end of the training. It is also hypothesized that how balance program and tDCS would improve working memory of the older adults.

2. Materials and Methods

2.1. Subjects

Of the potential 42 participants, 24 older adults (22 men, 2 women; with the mean age±SD= 69.79±5.50) participated in the study. This sample size was selected according to the suggestion of previous studies in this field (Julious, 2005). We included individuals who were (1) 60 years of age or older; (2) physically unimpaired and of natural cognitive abilities (means they had not any disorder like the inner ear and vestibular apparatus disorder; locomotor disorders, orthopedic history); (3) capable of performing the tasks and the exercises without help; and (4) right-handed. We excluded individuals who (1) were not willing to continue taking part in the study; (2) did not actively and consistently attend the training sessions; or (3) dropped out for other unpredicted reasons (Figure 1). All participants gave their written informed consent before participating in the study.

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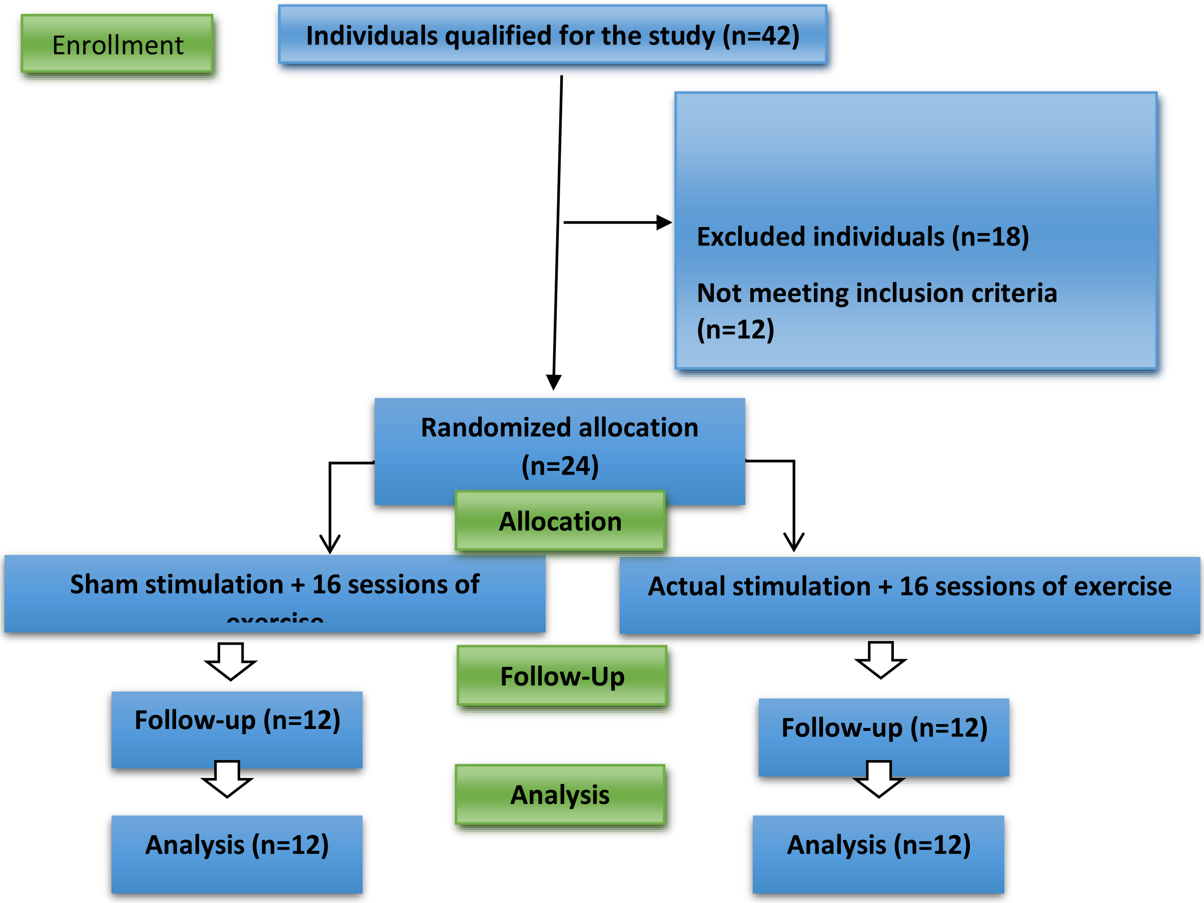

Figure 1: Flow diagram of the progress through the intervention

2.2. Apparatus and Task

2.2.1. Selected balance exercise program

It includes a set of physical exercises that were designed with the aim of improving balance and with emphasis on practicing and repeating static and dynamic balance movements in a progressive manner. Exercises were performed for 50 minutes, twice a week for 8 weeks and a total of 16 sessions. The duration and the repetitions of the exercise program in each session are all defined based on and in agreement with previous studies to improve the balance of the older adults (Campbell et al., 1997; Gardner, Buchner, Robertson, & Campbell, 2001). The exercise program included warm-up (10 minutes), main balance exercises (30 minutes) and cooling down (10 minutes). The structure of the warm-up consisted of stretching and low intensity exercises to increase the heart rate. Also, the cooling phase ends with a group of stretching movements. The exercises program was in accordance with the task-oriented approach emphasizing the improvement of balance skills. This balance program was performed first in the closed environment, and then with the advancement of the exercise program, was moving towards becoming more complex and in the open environment (Adams, 1999). In order to increase the willingness and motivation of the older adults to exercise, challenging but enjoyable movement activities were chosen. The intervention included maintaining balance on one leg, maintaining balance while walking, and a subset of exercises related to strengthening balance while standing and walking. These exercises were designed with the aim of increasing the participation of the senses involved in balance. The participants performed all exercises with their eyes open and received help from the instructor when needed (Table 1).

2.2.2. tDCS

Brain stimulation signals were applied using Neuristim tDCS device with two separate channels manufactured by Medina Teb Gostar (Iran). The instrument was formerly used by other studies in this area (Kamali et al., 2019). Each channel can be independently adjusted in terms of current, duration, and frequency for applying different types of stimulation. The output current can be set at 0.1 to 2 mA, up to a wave frequency of 200 Hz for maximum stimulation duration of 45 minutes. In the present study, tDCS was given over the left M1 for all participants using two saline-soaked sponge-electrodes (AD electrode measuring 50 cm^2 in area, and reference electrode measuring 25 cm^2 in area) for 20 minutes by applying a 2mA current.

Table 1.

Selected exercise program for improving balance in the elderly.

Exercise	Duration and number of repetitions per session
Warm up	10 minutes
Head turn	From 5 repetitions in the first session to 10 repetitions in the sixteenth session
Neck rotation and bend	
Backward stretch	
Upper body rotation	
Ankle flexion	
Knee extension	From 5 repetitions in the first session to 10 repetitions in the sixteenth session
Knee flexion	
Side leg raise	
Heel raise	
Toe raise	
Knee bends	
Backward walking	10 steps per session
Walk and turn	From 1 set of repetition in the first session to 3 sets in the sixteenth session
Sideways walk	10 steps per session
Heel-to-toe stand	10 repetitions per session
Heel-to-toe walk	10 steps per session
One-leg stand	10 repetitions per session
Heel walking	10 steps per session
Toe walking	10 steps per session
Tightrope walk	10 steps per session
Sit to stand	From 5 repetitions in the first session to 10 repetitions in the sixteenth session
Stair step up/down	From 1 repetition in the first session to 12 repetitions in the sixteenth session
Cool down	10 minutes

2.2.3. Balance tests

2.2.3.1. Berge Balance Scale (BBS)

BBS was used to measure dynamic and static balance. To this end, the participants first received general information about the scale. BBS was originally designed to measure balance in patients with imbalance (Blum, & Korner-Bitensky, 2008). The scale consists of 14 items (generally associated with routine daily activities). Each item is scored on a 5-point scale from 0 to 4. The tools used in BBS include a ruler, two chairs (one with armrest, one without, i.e., step stool), a stopwatch, and a 5-m even flat space for walking. The test takes approximately 10 to 15 minutes to complete. The scale scoring ranges from 0 to 56.

2.2.3.2. Timed up-and-go test (TUG)

TUG static and dynamic balance test was developed by Mathias in 1986. It is rated on a scale from 1 to 5; TUG also has a very good reliability and validity (Pourmahmoudian, Noraste, Daneshmandi, & Atrkar Roshan, 2018). The test involves a participant sitting comfortably in correct position on a chair, leaning against the backrest to easily identify a line 3 meters away. On the command “Go”, the participant stands up without using his hands and starts to walk safely at the maximum pace for 3 meters, turns around, and walks back to the chair and sits down while his/her time is being recorded. The test will be repeated if the participant fails to walk the line. The test is given to each participant 3 times on each round and the participant’s best time is recorded.

2.2.4. N-back task

Working memory can be assessed using many tests including the well-known n-back task (Jaeggi, Buschkuehl, Perrig, & Meier, 2010). The n-back task is a cognitive task originally developed by Kirchner to assess visuospatial memory (Jaeggi et al., 2010). In a general n-back task, the participant is given a sequence of (visual or auditory) stimuli in a number of steps. The participant is required to identify whether or not the stimulus in the present step matches those presented in n steps ago. The task is carried out for different values of n, with greater n values denoting a more difficult task. We used n=2 in the present study. The stimuli included the numbers 1 to 9 presented in a sequence over a period of 1 second. The participant was instructed to start the comparison from the third stimulus on to compare the third stimulus with the first one (2 steps ago) and press the “Yes” or “No” button depending on whether or not a match was found. The process continued with comparing the fourth stimulus with the second one, and the fifth with the third one. The program output for each individual consists of the number of false responses, success rate, and mean response time (Hoshyari, Saemi, & Doustan, 2022).

2.3. Procedure

Before the start of this study, informed consent was obtained from all participants. This study was approved by the Shahid Chamran University Ethics Committee (EE/1400.2.24.32886/scu.ac.ir; 26/10/2021). All methods were carried out in accordance with relevant guidelines and regulations.

The present study was a randomized sham-controlled trial and conducted over four phases of pretest, intervention, posttest, and follow-up (Figure 1). After giving the initial information to the participants about the test, the participants were assessed through balance tests (BBS, TUG) as well as the n-back task to measure and record their balance and working memory scores. Next, the participants were randomly assigned to either the experimental (intervention) or the sham group. During the intervention phase, all participants attended sixteen exercise sessions (8 weeks, 2 sessions per week and each session was included 20 min tDCS + 50 min exercise). The participants in the intervention group received a 20-

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minute tDCS over the left M1 in the beginning of each session. The participants in the sham group received a sham tDCS for the same duration. To mimic tingling related to current change during sham condition, participants received 30 s of current at the start and the end of the 20 min. This small stimulation (a traditional method of ramping up/down) in sham group does not change the cortical excitability and only causes an itching and tingling sensation in the person (Thair, Holloway, Newport, & Smith, 2017). In each session, the participants attended a selected balance exercise program for 50 minutes immediately following the tDCS. In the posttest phase immediately following the 16-session intervention, both groups completed balance and working memory tests to identify immediate effects of the interventions. The participants also took a follow-up test one month after the intervention finished to have their balance performance and working memory variables re-assessed.

2.4. Data Analysis

The data in this study were descriptively analyzed using the statistical indices mean and standard deviation. In addition, inferential analysis and hypothesis testing were conducted using mixed analysis of variance, one-way analysis of covariance (ANCOVA), and the student t-test. The level of significance for all tests was set at 0.05 while Bonferroni post hoc test was used to make comparisons and examine differences. Statistical analyses were performed using IBM SPSS 24.0 (IBM Corp., Armonk, NY, USA).

3. Results

Table 2 presents the results for analysis the demographic data as well as the study variables in the initial stage (pretest). As seen in this table, the sham and the intervention (tDCS) groups had similar results on all demographic indices and test variables except for BBS. All participants successfully completed training for 8 weeks. There were no reports of adverse events due to the training or tDCS.

Table 2:

Characteristics of the participants

Personal characteristics	**Groups (M±SD)**		**Sig**
	tDCS	**Sham**	
n	12	12	-
Gender	(11 males, 1 female)	(11 males, 1 female)	-
Age (year)	70.50 ± 5.76	69.08 ± 5.38	0.54
Height (cm)	169.08 ± 8.07	163.33 ± 7.66	0.08
Weight (kg)	79.33 ± 21.63	68.16 ± 15.28	0.15
BMI (kg/m^2)	27.43 ± 5.49	25.47 ± 5.23	0.38
Balance (BBS score)	50.00 ± 4.88	41.75 ± 8.65	0.009*
Balance (TUG; sec)	12.28 ± 5.46	14.13 ± 3.99	0.35
WM (False responses ;No)	42.00 ± 17.41	39.58 ± 17.81	0.74
WM (Success rate ;%)	51.75 ± 19.18	43.08 ± 19.26	0.28
WM (Mean *r*esponse time ;sec)	565.16 ± 205.80	634.50 ± 268.38	0.48

Note: * Significant at p<0.05, WM= Working memory, BMI= Body mass index

3.1. Berg Balance Scale

Given the initial difference between the sham group and the tDCS group in terms of BBS scores, so for controlling pretest of BBS scores, a one-way analysis of covariance (ANCOVA) was used to compare the scores attained by these two groups during posttest and follow-up (Figure 1). ANCOVA results for posttest indicated a significant difference between the tDCS group (54.91±2.15) and the sham group (44.50 ± 9.07) in the posttest, with the tDCS group outperforming the sham group in BBS scores ($F_{(1,29)}$ =4.99, adjusted P= 0.036, partial η^2=0.19; R^2= 0.82, adjusted R^2=0.80). Similarly, the tDCS group (54.66±2.14) maintained its better performance over the sham group (44.41±9.05) in the follow-up ($F_{(1,29)}$ =4.59, adjusted P =0.044, partial η^2=0.18; R^2= 0.82, adjusted R2=0.80).

3.2. Timed up-and-go test

Given the significant statistics found in Mauchly's test of sphericity, the results from the 2 (groups; sham and tDCS)×3 (test phases; pretest/posttest/follow-up) mixed ANOVA over the time data as a measure of balance based on Greenhouse-Geisser correction indicated that all two main effects and one interaction effects, namely stage ($F_{(1.30,\ 28.65)}$=6.03, P =0.014, partial η^2=0.21), intergroup main effect ($F_{(1,\ 22)}$=6.22, p=0.021, partial η^2=0.22), and interaction effect ($F_{(1.30,\ 28.65)}$=6.06, P =0.014, partial η^2=0.21), were significant. In other words, these findings suggested that the tDCS group during posttest (7.59±2.17) and follow-up (8.88 ± 3.36) outperformed the sham group during posttest (13.64 ± 5.60) and follow-up (15.55±8.36).

3.3. Working Memory

3.3.1. False responses

The results from the 2 (groups; sham and tDCS)× 3 (phases; pretest, posttest, follow-up) mixed ANOVA over the number of false responses as a measure of working memory indicated that none of the main effects, namely stage ($F_{(2,\ 44)}$ =2.4, P=0.1, partial η^2=0.09), group ($F_{(1,\ 22)}$ =0.82, P =0.37, partial η^2=0.03), and interaction ($F_{(2,\ 44)}$ =0.61, P =0.54, partial η^2=0.02), were significant. Therefore, the results of the follow-up tests for this measure were not reported.

3.3.2. Success rate

The results from the 2 (groups; sham and tDCS)× 3 (phases; pretest/posttest/follow-up) mixed ANOVA over the success rate data as a measure of working memory indicated that only the main effect of test stage was significant ($F_{(2,\ 44)}$ = 20.12, P =0.0001, partial η^2= 0.47). Other main effects, *i.e.* group ($F_{(1,\ 22)}$ =0.82, P =0.37, partial η^2= 0.03), and interaction ($F_{(2,\ 44)}$ = 0.62, P=0.54, partial η^2=0.01), were not reported to be significant.

3.3.3. Mean response time

The results from the 2 (groups; sham and tDCS)× 3 (phases; pretest, posttest, follow-up) mixed ANOVA over the mean response time data as a measure of working memory indicated that none of the main effects, namely stage ($F_{(2,\ 44)}$ =2.28, P =0.11, partial η^2=0.09), group ($F_{(1,\ 22)}$ = 0.11, P =0.74, partial η^2=0.005), and

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interaction ($F_{(2, 44)} = 0.41$, $P=0.65$, partial $\eta^2=0.01$), were significant. Therefore, the results of the follow-up tests for this measure were not reported.

4. Discussion and conclusion

Several studies have examined effects of tDCS as a noninvasive technique on balance and postural control in the older adults (Mehrdadian, Saemi, Doustan, & Yamaguchi, 2022). Since these effects vary depending on a number of factors including where stimulation is applied in the brain (Dieckhöfer et al., 2006). number of training sessions (Monte-Silva et al., 2013), and intensity of the current applied (Batsikadze, Moliadze, Paulus, Kuo, & Nitsche, 2013), it is difficult to make a general conclusion about the extent to which tDCS can influence balance and postural control, and thus further studies are needed in this area.

To extend the previous studies and shed more light on their findings, the present study examined the effects of balance exercise combined with tDCS on balance performance and working memory in the older adults. We hypothesized that participation in balance exercise + tDCS sessions can positively influence working memory and balance performance in the older adults compared to a sham group. Our findings showed that 16 sessions of balance exercise combined with anodal tDCS on M1 in the left hemisphere of the brain of the physically unimpaired older adults can improve balance performance immediately following the intervention and even one month after the intervention is finished. However, the findings failed to demonstrate positive effects of tDCS + balance exercise on working memory in the older adults.

Since the intervention group outperformed the sham group in terms of balance performance, our findings are largely consistent with major previous studies in this area (Rostami et al.,2020; Costa et al., 2020; Karok, & Witney, 2013; Ke et al.,2019; Zandvliet, Meskers, et al., 2018; Gomes et al., 2019; Ehsani, Samaei, Zoghi, Hedayati, & Jaberzadeh, 2017; Fujiyama et al., 2017). For example, Costa et al., 2020 showed that an exercise program combined with tDCS can positively influence performance capacity of the older adults' participants 24 hours following the intervention or even 30 days after the intervention is complete. In another study, Fujiyama et al. (2017) observed significant improvements in motor skills associated with the upper limbs in the older adults who carried out isometric strength training and received tDCS compared to the control group.

In the present study, we examined balance using two common methods: Berg Balance Scale (BBS) and timed up-and-go test (TUG). Similar results were reported in the literature using BBS. For example, Ehsani et al. (2017) showed that a tDCS-based training session applied to the cerebral cortex can improve balance performance in the older adults. A major difference between our study and Ehsani et al. (2017) consist in the stimulated region in addition to the number of sessions. Here, we examined how 16 tDCS sessions combined with balance exercise influenced balance while Ehsani et al 2017 only used one session. Therefore, our findings present a set of more reliable results.

Anodal tDCS-based training can cause shifts in neurotransmitters of this region by increasing local concentration of glutamate and glutamine where tDCS is applied, thereby enhancing brain activity which, in turn, can eventually improve motor performance (Hunter et al., 1998). In addition, experimental evidence has shown that anodal tDCS can improve motor performance and learning by increasing excitability of the motor cortex, leading to amplified stimulation and engaging a greater number of motor units (Fertonani, & Miniussi, 2017).

In other words, when excitability of M1 region in the primary motor cortex is increased through tDCS interventions, it is possible that supraspinal fatigue is delayed due to increased M1 output and downward shifts, and this in turn could enhance motor performance (Nitsche, & Paulus, 2000). Furthermore, tDCS can influence the activity of the insular cortex, thereby reducing rate of perceived exertion (RPE) in participants. This can also improve motor performance in individuals (Okano et al., 2015). Moreover, anodal tDCS can also amplify active muscle outputs by increasing M1 excitability, facilitating supraspinal stimulation, and reducing inhibitory feedback in M1 (Angius et al., 2016; Cogiamanian, Marceglia, Ardolino, Barbieri, & Priori, 2007). Although we did not measure the motor cortex excitability in the current research, it can be said presumably that following 16 sessions of balance exercise combined with 20 minutes of unilateral a-tDCS on M1, the participants in the present study experienced higher motor excitability and engaged in a greater number of motor units in balance tests to outperform the sham group. This improved balance performance may also be caused by reduced number of inhibitory feedbacks in M1. Based on the studies described above, improved balance performance in the tDCS group can be attributed to increased activity of the insular cortex and lower levels of perceived exertion during training sessions. However, one limitation of our study that future studies should address is that we did not record this perceived exertion using standard checklists during training sessions. Another limitation of the current research was the use of clinical tests such as the Berg balance test to measure balance performance. Some researchers have shown that Berg balance test is not a suitable test for predicting falls in the older adults (Cogiamanian et al., 2007; Lima, Ricci, Nogueira, & Perracini, 2018). Therefore, it is suggested that future researches use more accurate and reliable tools such as the force plate to measure balance performance.

In line with some previous research (Murphy et al., 2020). our findings failed to indicate tDCS effects on working memory, although there are reports of these effects in the existing literature. For example, Berryhill, & Jones (2012) showed that three a-tDCS training sessions on the left and right premotor cortices (F3 and F4) can improve working memory in the older adults with higher levels of academic educations although they found no improvement in the older adults with lower education levels. Ineffectiveness of tDCS in improving our participants' working memory may be associated with the fact that they had low levels of academic education.

On the other hand, studies that demonstrated positive effects of tDCS on working memory (Andrews et al., 2011; Boggio et al., 2006) assumed that tDCS enhances excitability in the outer anterior prefrontal cortex, probably due to increased levels of glutamate, an amino acid associated with working memory, recognition, and learning how to respond to a stimulus (Robbins, & Murphy, 2006). Another probable reason behind ineffectiveness of tDCS in improving working memory of our participants is the fact that the outer anterior prefrontal cortex was not stimulated here. Thus, future studies can re-examine these effects by including the factors noted above.

In our study, the active electrode was placed on M1 in the left hemisphere of the brain to examine effects of unilateral tDCS. The technique was similar to those reported in the literature (Alix-Fages et al., 2019; Friehs, Güldenpenning, Frings, & Weigelt, 2020) The left hemisphere appears to play a more important role in motor control and balance performance (Veldema, Engelhardt, & Jansen, 2022). However, it is recommended that future studies should examine the other hemisphere as well or examine how bilateral tDCS influences balance performance and working memory. We applied 2mA anodal tDCS, but since the outcome may vary depending on current and type of stimulation (anodal vs. cathodal) (Mehrdadian et al., 2022), future studies may examine tDCS effects by manipulating these two variables. Of the different cognitive functions associated with motor performance, we only examined working memory using the n-back task. Therefore, we recommend future studies to assess working memory using other available

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standard tests while noting other cognitive functions such as selective attention and cognitive flexibility. As we only examined the older adults, our findings cannot be generalized to other age groups including adults, children, or the middle-aged. Thus, further studies can be conducted to examine the effects of unilateral a-tDCS in M1 on balance performance and other cognitive functions in adults, children, or the middle-aged. Nevertheless, our findings indicated that the effect of the within-group was significant, especially in the indicator of success rate, therefore, it can be partially concluded that sixteen sessions of balance exercises, regardless of the presence or absence of tDCS, had a positive effect on improving of the success rate as an indicator of the working memory. These results partially are in line with the findings in this field that have shown physical exercise, especially balance practice improve older adults's working memory (Azhdar et al., 2022; Zhidong, Wang, Yin, Song, & Chen, 2021). For example, Azhdar et al., (2022) showed that a balance exercises intervention can increase cognitive performance and especially working memory in the older adults. In the present research, both the intervention and sham groups were able to increase the working memory of the older adults, since the balance exercise was applied to the same extent in both groups, so it can be concluded that the balance exercises has been able to improve the cognitive function and especially the working memory of the older adults. Of course, since in the current study, we did not have the control group (one with only balance exercise and one with only *tDCS*), so this conclusion should be used with caution and it is suggested that future studies add these control groups to the research for more clarification. In addition, the present study used balance exercises, where the authors suppressed a single sensory pathway, such as the visual. However, a specific balance program should mix multiple sensory pathways such as the visual, vestibular, and somatosensory systems. Further studies are warranted to investigate which type of balance training is most effective to improve balance when combined with anodal tDCS.

In summary, our findings indicated that physically unimpaired older adults can improve their balance performance compared to a sham group by attending 16 sessions of balance exercise based on unilateral a-tDCS applied to M1. Although the intervention group did not outperform the sham group in terms of working memory, it seems that tDCS can be used as a safe, useful, noninvasive technique to enhance balance and assist the older adults to walk better and reduce their falls. Therefore, it is recommended that trainers and coaches working with senior citizens should use this safe, inexpensive, and effective technique more frequently.

Authors' contributions

Conceptualization, M. M and E.S; methodology, E.S software, ES; validation, M. M, E.S and M.D.; formal analysis, M.M; investigation, E.S.; resources, M.M; data curation, M. M, E.S and M.D; writing—original draft preparation, E.S, G.B and T. Y; writing—review and editing, M. M and E.S. visualization, E.S and T. Y; supervision, M.M and E. S; project administration. All authors have read and agreed to the published version of the manuscript.

Conflict of interests

The authors declare that there is no conflict of interest

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