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Comparison of Transcranial Direct Current Stimulation of the Primary Motor Cortex and Cerebellum on Static Balance in Older Adults

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Abstract

Background: Falling is a major problem in older adults. Transcranial direct current stimulation (tDCS) is a neuromodulation technique to improve balance in the elderly. The majority of previous studies have assessed the effects of cerebellar and primary motor cortex (M1) tDCS, while less attention has been paid to the comparison of the effects of tDCS in these two regions.
Objectives: The goal of this study was to compare the effectiveness of cerebellum and M1 tDCS on the balance in older adults.
Methods: In this double-blind sham-controlled crossover study, a total of 32 healthy older adults were randomly assigned to two groups of M1 and cerebellum tDCS. Each group received active and sham stimulation with a crossover design within a one-week interval. The intensity and duration of tDCS were 2 mA and 20 minutes, respectively. Before and after each session, the total path length (TPL) and mean velocity (MV) of the center of pressure were determined using a force plate in both mediolateral and anteroposterior directions under single-task and dual-task conditions.
Results: The results of mixed ANOVA test showed that the main effect of time on TPL and MV was significant in both mediolateral ($P < 0.01$) and anteroposterior ($P = 0.01$) directions. The interaction between time and stimulation was also significant on TPL and MV in both mediolateral ($P < 0.001$) and anteroposterior ($P < 0.001$) directions. The between-group analysis showed no significant difference in the efficacy of cerebellar and M1 tDCS in the mediolateral ($P = 0.79$) and anteroposterior ($P = 0.60$) directions.
Conclusions: Anodal tDCS of the cerebellum and M1 could improve the postural balance indices in healthy older adults. These two techniques exerted similar effects on static balance.

Keywords: Transcranial Direct Current Stimulation, Postural Balance, Older Adults, Cerebellum, Primary Motor Cortex

1. Background

Falling is a major problem in older adults, as it results in the loss of independence, injury, and death (1). Consequently, any intervention for increasing the balance of older adults can improve their quality of life and burden of falls on the healthcare system. Most previous studies have investigated the effect of musculoskeletal modification (i.e., exercise and training) on balance, while the effect of nervous system modulation on balance has been rarely studied (2).

Transcranial direct current stimulation (tDCS) is a neuromodulation technique, which can have positive effects on the balance in older adults (3, 4). Some studies have reported the effects of tDCS on supplementary motor area (5) and dorsolateral prefrontal cortex (6) on the balance of older adults. Most published studies used the cerebellum or primary motor cortex (M1) as the target areas for tDCS. They reported that 20 minutes of cerebellar tDCS in older adults could improve their stability indices in the anteroposterior (AP) (7, 8) and mediolateral (ML) directions (8). Craig and Doumas (7) also showed that M1 tDCS with an intensity of 2 mA could decrease the peak-to-peak sway amplitude in older adults.

The majority of studies regarding the effects of tDCS on balance have assessed young people, not older adults who are more prone to falling. On the other hand, tDCS proto-

cols in these studies vary in terms of intensity, electrode setup, and type of balance task (4). One of the differences between these protocols is the target area. In fact, introduction of a suitable target area for tDCS with the aim of improving balance in older adults can increase the quality and efficacy of tDCS interventions.

Most daily activates require concomitant motor and cognitive functions (9). It is suggested that integration of a cognitive task can have negative effects on balance and increase the risk of falling in older adults (10). Previous studies have assessed dual task balance only after dorsolateral prefrontal cortex stimulation (6), whereas in the current study, balance was measured in both single- and dual-task conditions after M1 and cerebellar stimulation.

2. Objectives

To the best of our knowledge, the present study is the first to compare the effects of cerebellar tDCS versus M1 tDCS on balance using identical electrode sizes. The aim of this study was to compare the effects of cerebellar tDCS versus M1 anodal tDCS (a-tDCS) on the balance of older adults under both single- and dual-task conditions. It was hypothesized that a-tDCS of both cerebellum and M1 can improve static balance in older adults and that cerebellar a-tDCS and M1 a-tDCS have similar effects on the balance of the elderly.

3. Methods

3.1. Participants

The inclusion criteria were age above 60 years and ability to stand on both feet for at least 90 seconds without assistive devices. On the other hand, the exclusion criteria were as follows: (1) having medical conditions, such as stroke, Parkinson's disease, Alzheimer's disease, brain surgery, brain tumor, peripheral neuropathy, and vestibular disorders; (2) history of intracranial metal implantation; and (3) using medications (psychoactive drugs) interfering with balance or resulting in unpredictable reactions to a-tDCS.

All participants signed written informed consents before the study. The study protocol was approved by the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences (registration number: IRCT20150923024151N7). All participants completed the intervention process. A total of 32 healthy elderly (16 females), with the mean age of 67.59 (6.29) years, participated in this study, based on the following sample size formula ($\alpha = 0.05$ and $\beta = 0.02$):

$$n = \frac{\left[z^{-1}\left(1-\frac{\alpha}{2}\right)+z^{-1}\left(1-\beta\right)\right]^2\sigma_m^2}{2\epsilon_R^2}$$

3.2. Procedure

Two parallel groups of older adults participated in this double-blinded, sham-controlled, crossover study. Demographic data, including age, gender, height, weight, history of falling, and fear of falling (11), were recorded in the first session. The participants were randomly assigned to the cerebellar or M1 tDCS group. Each group was exposed to two experimental conditions, including active a-tDCS and sham a-tDCS during a one-week washout period. The CONSORT diagram is presented in Figure 1. A trained physiotherapist (administrator) administrated the interventions, and a second researcher (assessor), unaware of the treatment groups (M1 and cerebellum) and stimulation conditions (active and sham), assessed balance before and after the interventions under both single- and dual-task conditions. The participants received a-tDCS in the sitting position and were masked to the stimulation condition.

3.3. Balance Assessment

Measurement of the center of pressure (CoP) movements and patterns is an accepted method for balance assessment (2, 12). The amplitude of ML CoP sways indicates the mediolateral stability, while the amplitude of AP sways indicates the anteroposterior stability, which can be used for the assessment of balance (13). In this study, balance was assessed using a portable force plate (Kistler Force Plate, 9260AA6, Kistler Instruments, Switzerland). The system recorded CoP trajectories over 90 seconds at a sampling frequency of 100 Hz.

The participants were asked to stand upright as still as possible with open eyes and arms by the body. The CoP excursion, path length, and velocity were measured in both AP and ML directions and collected using Qualisys Track Manager Software. Fifteen seconds from the beginning and 15 seconds from the end of 90-second recordings were cut. The filtering of data was carried out using a Butterworth filter at a cut-off frequency of 10 Hz (12, 14). Each participant was asked to stand on the force plate three times under the single-task (ST) condition and three times under the dual-task (DT) condition in a random order. Next, the average of three trials was calculated for each index (12). In addition, the participants were instructed to subtract three from a random number between 400 and 500 serially for the DT balance test (15).

3.4. Intervention

An ActivaDose II tDCS device (ActivaTeKTM Inc., Taiwan) was used to deliver tDCS, with large active (3×9 cm^2) and return electrodes (4×9 cm^2). The electrodes were covered

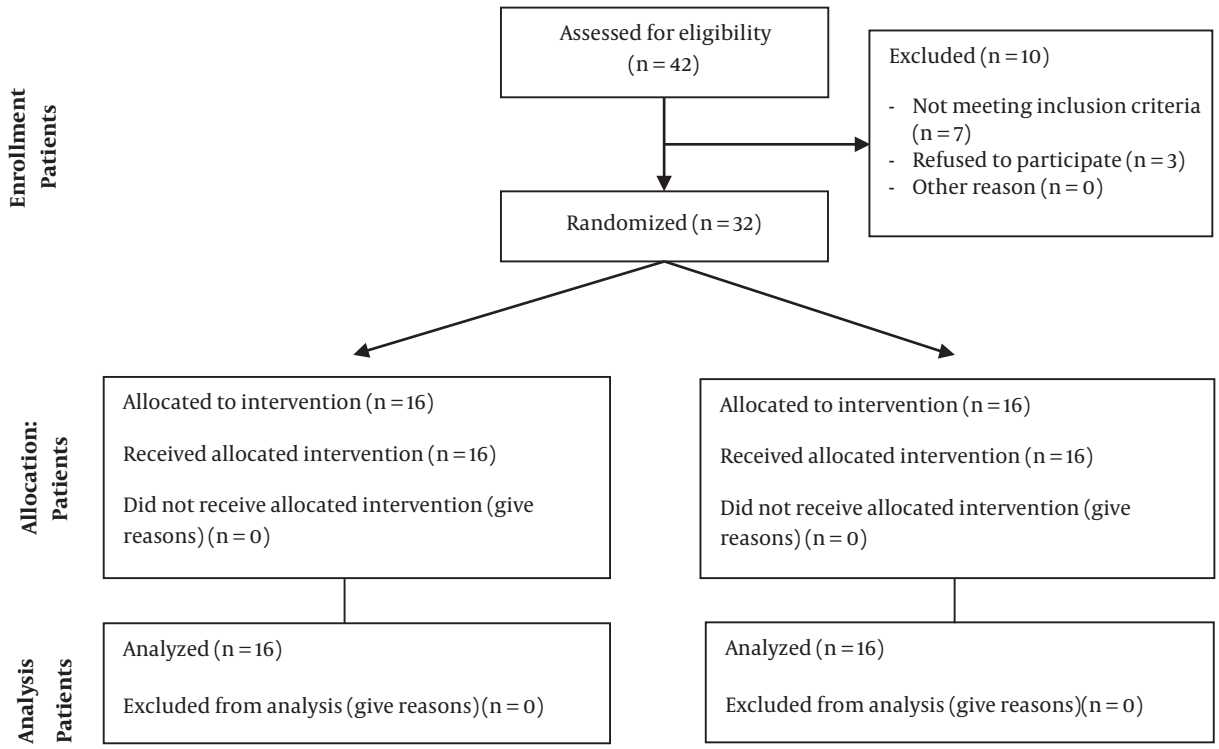

Figure 1. CONSORT flowchart diagram

by sponges soaked in saline solution. For active application of a-tDCS, the device was set at 2 mA for 20 minutes. The ramp-up and ramp-down time was 30 seconds with increments of 0.1 mA. In the M1 tDCS group, the anode was centered 1 cm behind the vertex, and the return electrode was placed on the forehead (Figure 2A). On the other hand, in the cerebellar tDCS group, the anode was centered 1 cm below the inion of the occipital bone, and the return electrode was fixed over the right shoulder (8) (Figure 2B). The electrode montage for sham stimulations was identical to that of active a-tDCS, while the maximum current (2 mA) was only present for 30 seconds (16).

3.5. Assessment of Side Effects

All participants were asked to answer the questions about the adverse effects or side effects of stimulation at the beginning, middle, and end of the stimulation. They rated the intensity of each item based on a numerical analogue scale, with 0 representing "no tingling" and 10 representing "the worst tingling imaginable". The items included numbness, itching, burning sensation, pain, fatigue, and headache.

3.6. Data Analysis

SPSS version 20 was used to statistically analyze the data. To compare the baseline values between the cerebellar and M1 groups, Independent-sample *t*-test was used. Paired *t*-test was also performed to compare the baseline values between active and sham stimulation in each group to rule out the carryover effect. To assess the interaction effects, mixed ANOVA ($2 \times 2 \times 2 \times 2$) test was performed for CoP displacement (CoPD), total path length (TPL), and velocity, with time (before and after), stimulation (active and sham), and balance task condition (single task and dual task) as within-subject factors and groups (cerebellum and M1) as the between-subject factor.

4. Results

4.1. Pre-Intervention Analysis

The demographic information of the participants in the cerebellar and M1 groups is presented in Table 1. There was no significant difference in terms of demographic characteristics between the two groups, and the number of male and female participants was equal in the groups (8 females and 8 males). Table 2 presents the mean values of CoPD, TPL, and velocity in the ML and AP directions. The

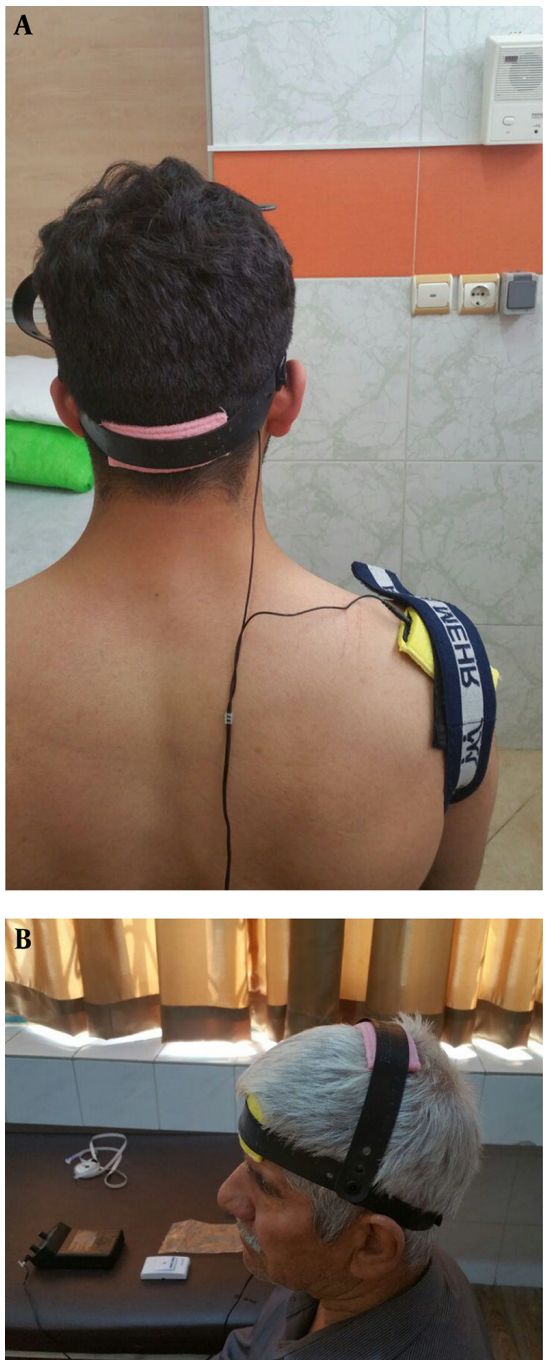

Figure 2. Electrode position; A, cerebellum, B, primary motor cortex

between-group analysis showed that there was no significant difference between the two groups in terms of balance indices before the stimulation. The results of Paired *t*-test revealed that the indices were not significantly different before sham and active stimulation; therefore, time and carryover effects were not influential. Moreover, two assumptions of mixed ANOVA, including normal distribution and equality of covariance matrices, were examined before analyzing the effect of tDCS on balance.

Table 1. Demographic Characteristics of Study Population[a]

	Cerebellum	M1
Age, y	67.81 (6.24)	67.38 (6.54)
Height, cm	163.31 (7.15)	168.75 (10.23)
Weight, kg	70.94 (8.47)	76.01 (13.50)
History of falling, number	0.62 (0.08)	0.83 (0.50)
Fear of falling, score	26.56 (9.87)	24.75 (8.27)

[a]Values are expressed as mean (SD).

4.2. Effect of tDCS on Balance

The main effect of time was significant for TPL and velocity in AP (Figure 3A and B) and ML (Figure 3C and D) directions, as well as the resultant CoP (Figure 3E and F). However, time had no significant effect on CoPD. There was a significant interaction between time and stimulation, which showed that active stimulation could improve the balance indices, whereas sham stimulation had no effect on the balance of older adults. These findings showed that 20 minutes of a-tDCS could have positive effects on balance in older adults.

4.3. Comparison of the Effects of M1 tDCS Versus Cerebellar tDCS on Balance

The results of MANOVA showed that there was no significant difference between the two groups (Table 3). These findings indicate that cerebellar and M1 stimulation had similar effects on balance in older adults.

4.4. Side Effects

Both active and sham tDCS were well-tolerated by all of the participants. Most of the participants reported no side effects during the interventions, while some reported itching and burning sensation. The side effects are presented in Table 4. No side effect was reported after the completion of stimulations for up to 24 hours.

5. Discussion

5.1. Effect of tDCS on Balance

The main hypothesis of this study was that tDCS could improve balance in older adults. The results approved this hypothesis and showed that anodal stimulation of the cerebellum or M1 could influence TPL and velocity of

Table 2. Changes in CoP Values in Both Groups Before and After Anodal or Sham Stimulation[a]

	Cerebellar Group				M1 Group			
	Anodal Stimulation		Sham Stimulation		Anodal Stimulation		Sham Stimulation	
	Before	After	Before	After	Before	After	Before	After
CoPD ML, mm								
ST	29.25 (6.75)	29.45 (13.26)	28.23 (7.10)	31.88 (5.76)	36.92 (13.71)	31.82 (8.60)	35.24 (14.25)	37.15 (8.7)
DT	38.81 (14.11)	37.28 (12.88)	35.43 (8.61)	42.38 (11.07)	49.05 (19.38)	46.41 (19.79)	44.80 (17.21)	52.52 (17.24)
CoPD AP, mm								
ST	19.03 (8.28)	15.71 (8.77)	20.80 (12.48)	23.23 (12.44)	28.83 (17.09)	20.06 (8.07)	27.53 (20.98)	27.36 (24.18)
DT	38.75 (27.98)	28.43 (18.46)	35.42 (38.86)	42.62 (28.25)	60.15 (56.47)	50.26 (48.22)	56.85 (53.67)	53.70 (24.78)
CoPD R, mm								
ST	27.31 (8.79)	26.87 (10.81)	28.04 (10.22)	29.51 (7.29)	35.32 (14.70)	29.01 (7.82)	34.60 (16.06)	35.12 (13.15)
DT	40.63 (18.60)	33.60 (13.10)	35.49 (15.51)	43.55 (16.66)	50.57 (26.53)	46.85 (27.41)	46.60 (24.83)	53.14 (27.13)
TPL ML, mm								
ST	1034.36 (425.70)	860.28 (392.30)	1056.19 (571.91)	1029.44 (539.70)	1003.09 (352.62)	807.81 (286.33)	861.84 (356.54)	985.73 (433.47)
DT	1219.39 (423.93)	1032.83 (326.10)	1269.75 (623.97)	1184.11 (536.06)	1317.13 (428.29)	1095.59 (287.59)	1200.59 (446.92)	1162.03 (382.81)
TPL AP, mm								
ST	900.39 (265.55)	775.24 (222.12)	856.45 (255.64)	910.88 (274.64)	894.08 (429.06)	725.22 (290.09)	695.61 (313.80)	807.50 (310.80)
DT	1180.85 (375.10)	967.70 (309.50)	1060.24 (388.12)	1051.43 (327.83)	1160.87 (529.04)	1003.74 (409.74)	1043.15 (482.01)	963.49 (349.75)
TPL R, mm								
ST	1056.39 (394.88	863.61 (345.09)	1044.87 (535.91)	1024.89 (502.73)	984.84 (391.42)	791.36 (284.41)	833.32 (354.78)	961.70 (412.59)
DT	1268.73 (399.60)	1035.58 (311.80)	1261.08 (603.16)	1204.98 (516.67)	1295.58 (482.75)	1080.59 (353.98)	1198.23 (464.96)	1147.08 (334.52)
MV ML, mm/s								
ST	17.24 (7.09)	14.34 (6.53)	17.61 (9.53)	17.15 (8.99)	16.71 (5.87)	13.46 (4.77)	14.36 (5.94)	16.42 (7.22)
DT	20.32 (7.06)	17.20 (5.43)	21.15 (10.39)	19.73 (8.93)	21.95 (7.13)	18.25 (4.79)	20.01 (7.44)	19.36 (6.38)
MV AP, mm/s								
ST	15.01 (4.42)	12.92 (3.70)	14.27 (4.2)	15.18 (4.57)	14.90 (7.15)	12.08 (4.83)	11.59 (5.23)	13.45 (5.18)
DT	19.67 (6.25)	16.12 (5.15)	17.67 (6.46)	17.52 (5.46)	19.34 (8.81)	16.72 (6.82)	17.38 (8.03)	16.05 (5.82)
MV R, mm/s								
ST	17.60 (6.58)	14.39 (5.75)	17.41 (8.93)	17.07 (8.37)	16.41 (6.52)	13.18 (4.74)	13.88 (5.91)	16.02 (6.87)
DT	21.14 (6.66)	17.25 (5.19)	21.01 (10.05)	20.08 (8.61)	21.59 (8.04)	18.01 (5.89)	19.96 (7.74)	19.11 (5.57)

Abbreviations: AP, anterioposterior; CoPD, center of pressure displacement; ML, mediolateral; MV, mean velocity; R, resultant; TPL, total path length.
[a] Values are expressed as mean (SD).

Table 3. The Results of MANOVA Analysis for Balance Measurements

	Main Effect of Time			Interaction of Time and Stimulation			Between Group Analysis		
	F	P	η^2	F	P	η^2	F	P	η^2
CoPD ML	2.35	0.13	0.07	12.99	0.001	0.30	1.35	0.23	0.03
CoPD AP	7.71	0.009	0.20	14.64	0.001	0.32	1.98	0.16	0.06
CoPD R	0.01	0.91	0.00	14.96	0.001	0.33	3.13	0.08	0.09
TPL ML	9.64	0.004	0.24	17.11	< 0.001	0.36	0.07	0.79	0.00
TPL AP	7.01	0.01	0.18	24.72	< 0.001	0.45	0.26	0.60	0.01
TPL R	11.20	0.002	0.27	25.60	< 0.001	0.46	0.24	0.62	0.01
MV ML	9.64	0.004	0.24	17.11	< 0.001	0.36	0.07	0.79	0.00
MV AP	7.01	0.01	0.19	24.72	< 0.001	0.45	0.26	0.61	0.01
MV R	11.20	0.002	0.27	25.60	< 0.001	0.46	0.24	0.62	0.01

Abbreviations: AP, anterioposterior; CoPD, center of pressure displacement; ML, mediolateral; MV, mean velocity; R, resultant; TPL, total path length.

CoP movements, indicating the potential benefits of tDCS on the balance of older adults. A recent review study by Yadolahi et al. (4) showed that tDCS could be a promising intervention to improve static balance in older adults.

5.2. Effect of Cerebellar tDCS on Balance

In line with the present findings regarding the effects of cerebellar stimulation on balance, other studies showed that a-tDCS of the cerebellum could improve stability parameters in AP and ML directions (8), peak-to-peak sway amplitude, and mean power frequency of sways (7) in older adults. Some motor and cognitive disorders in older adults are associated with age-related changes in the cerebellum (17). The cerebellum receives and processes inputs from the vestibular, somatosensory, visual, and auditory systems and controls the muscles involved in balance (18, 19). The

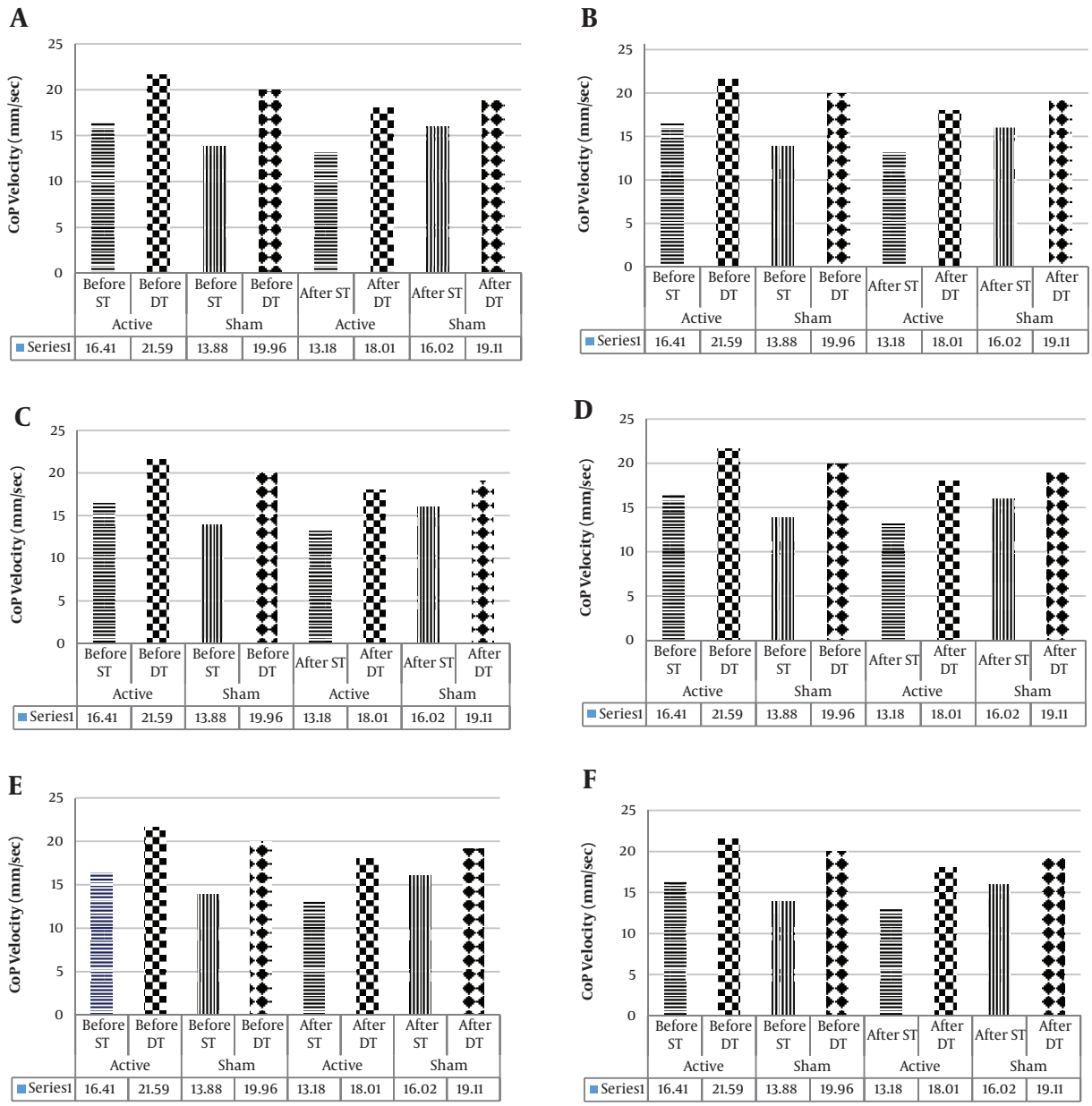

Figure 3. The charts of center of pressure mean velocity before and after stimulation. A, anterioposterior direction in cerebellar group; B, anterioposterior direction in M1 group; C, mediolateral direction in cerebellar group; D, mediolateral direction in M1 group; E, center of pressure resultant in cerebellar group; F, center of pressure resultant in M1 group. ST, single task; DT, dual task.

cerebellar white matter tracts connect the cerebellum to other brain regions, and the vermis plays a key role in balance (20, 21).

Cerebellar tDCS has potential benefits for cognitive and motor tasks and improves locomotor adaptations (22, 23). Evidence suggests that a-tDCS can increase postural control by affecting rich connections between the cerebellum and motor cortex and influencing the function of the vermis (24). Moreover, tDCS can increase Purkinje cell activation and have positive effects on the function of vermis and white matter tracts (24). Purkinje cells exert inhibitory effects on deep cerebellar nucleus neurons, which control the motor output and decrease unwanted activities (24). On the other hand, in some studies on young individuals,

Table 4. Reported Side Effects by Numeric Sensation Score[a]

	Real tDCS		Sham tDCS	
	Anode Electrode	Return Electrode	Anode Electrode	Return Electrode
Itching				
Beginning	3.73 (0.65)	1.06 (0.31)	1.33 (0.78)	0.8 (0.02)
Middle	2.46 (0.76)	0.2 (0.4)	0.1 (0.02)	0.06 (0.00)
End	1.93 (0.32)	0.1 (0.02)	-	-
Burning sensation				
Beginning	1.66 (0.98)	1.06 (0.54)	-	-
Middle	0.6 (0.08)	0.6 (0.06)	-	-
End	0.4 (0.02)	0.3 (0.04)	-	-

[a]Values are expressed as mean (SD).

a-tDCS of the cerebellum had no significant effects on balance (25-27). These controversial findings show that age is a factor, which may affect the outcomes of brain stimulation techniques (7, 28, 29).

5.3. Effect of M1 tDCS on Balance

The present findings also showed that a-tDCS of M1 could improve balance in older adults. Similarly, Craig and Doumas (7) found that M1 stimulation had positive effects on the sway amplitude of older adults. In line with studies on older adults, it was reported that M1 facilitation could improve balance in young adults (7, 30, 31) and patients with Parkinson's disease (32), chronic low back pain (33), and stroke (34).

Generally, M1 is part of the cortico-basal ganglia network, which plays an important role in balance control (18). Several studies showed that tDCS could influence the cerebral cortical activity (35) and corticospinal tract and increase the spinal network excitability (36). In this regard, Debarnot et al. (37) showed that a-tDCS of M1 could increase implicit learning. In another study, it was found that a-tDCS enhanced neuronal excitability in the cortical network and that balance tasks increased synaptic activities, resulting in improved balance indices (38).

On the other hand, reduction of lower extremity strength is one of the causes of falling in older adults. Also, some effects of tDCS on balance may be attributed to the increased muscle strength. M1 tDCS may increase the excitability of leg muscles in patients with stroke (39), toe pinch force in lower extremities (40), and knee extension performance in bodybuilders (41). In contrast, Kaminski et al. (28) showed that M1 tDCS did not affect balance learning in the elderly. Differences in the findings can be related to differences in the type of outcome, which was dynamic balance in the study by Kaminski et al. (28) and static balance in the current study. In another study, Zhou et al. (42) reported that a-tDCS could not change the duration of Timed Up and Go (TUG) test in older adults. They believed that TUG was not enough challenging to represent the effects of tDCS and that the findings were impressed by the floor effect.

5.4. Comparison of the Effects of M1 tDCS Versus Cerebellar tDCS on Balance

To the best of our knowledge, this is the first study designed to compare the immediate effects of cerebellar and M1 tDCS on balance in older adults. The between-group analysis indicated that cerebellar and M1 stimulation had similar effects on balance in older adults. In line with the current study, Craig and Doumas (7) showed that both cerebellar and M1 stimulation could improve balance in young and older adults. However, they did not compare the effects of cerebellar versus M1 stimulation. In contrast, in a study by Yosephi et al. (43), cerebellar tDCS had stronger effects than M1 tDCS. This discrepancy in the results may arise from differences in the tDCS protocols, as in the current study, both M1 and cerebellum were stimulated bilaterally, whereas in their study, unilateral stimulation was used for M1 tDCS and bilateral stimulation for the cerebellum.

5.5. Limitations and Suggestions for Future Research

The strengths of this study were the implementation of the same protocol for stimulating different areas of the brain and considering the effects of different balance tasks on the outcomes of the intervention. On the other hand, one of the shortcomings of this study was that the participants included healthy older adults, and the effect of tDCS was not assessed with regard to the severity of balance deficiency. Therefore, future studies need to assess the effects of tDCS in two groups of faller and non-faller older adults

or in patients with diseases associated with falling, such as Parkinson's disease, stroke, or multiple sclerosis. It should be noted that static balance was the only outcome measure in this study; therefore, assessment of dynamic balance can increase our knowledge about the effects of tDCS on balance.

5.6. Conclusions

The findings showed that a-tDCS is a safe and promising intervention for balance improvement in older adults. Both cerebellar and M1 stimulation exerted similar effects on static balance.

Footnotes

Authors' Contribution: Study concept and design: Hamzeh Baharlouei, Ebrahim Sadeghi-demneh, Mohammad Jafar Shaterzadeh Yazdi, and Shapour Jaberzadeh; acquisition of data: Hamzeh Baharlouei, Ebrahim Sadeghi-demneh, and Parisa Manzari; analysis and interpretation of data: Hamzeh Baharlouei, Ebrahim Sadeghi-demneh, Mohammad Mehravar, Mohammad Jafar Shaterzadeh Yazdi, and Parisa Manzari; drafting of the manuscript: Mohammad Jafar Shaterzadeh Yazdi, Hamzeh Baharlouei, Ebrahim Sadeghi-demneh, and Shapour Jaberzadeh; critical revision of the manuscript for important intellectual content: Mohammad Jafar Shaterzadeh Yazdi, Ebrahim Sadeghi-demneh, and Shapour Jaberzadeh; statistical analysis: Mohammad Mehravar, Mohammad Jafar Shaterzadeh Yazdi, and Hamzeh Baharlouei; administrative, technical, and material support: Ebrahim Sadeghi-demneh and Parisa Manzari; study supervision: Mohammad Jafar Shaterzadeh Yazdi and Shapour Jaberzadeh.

Clinical Trial Registration Code: IRCT20150923024151N7.

Conflict of Interests: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical Approval: IR.AJUMS.REC.1397.507.

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Patient Consent: All participants signed the written informed consent prior this study which was approved by Ahvaz Jundishapur University of Medical Sciences Ethics Committee.

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