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Effect of Transcranial Direct Current Stimulation on Walking Speed, Functional Strength, and Balance in Older Adults: A Randomized, Double-Blind Controlled Trial

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Data Interpretation D
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Background: The purpose of this study was to investigate the immediate effect of transcranial direct current stimulation (tDCS) on walking speed, functional strength of lower limbs, and balance in healthy older adults. Through this study, we intend to introduce a new method to improve the physical function of older adults.

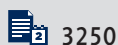
Material/Methods: This was a randomized, controlled, double-blind study in which participants and evaluators were blinded. Among 57 healthy adults (aged 65 years or older), 31 underwent tDCS, while 26 received sham stimulation. For the pre-test, participants performed a 10-meter walk test, functional strength test of lower limbs, and static and dynamic balance tests. Next, the primary motor cortex area was subjected to tDCS for 20 min. Tests were repeated as post-tests.

Results: There were significant differences in group-by-time interaction for 10-meter walk speed, functional strength of lower limbs, and static balance on the left side ($P < 0.05$). There was not a significant group-by-time interaction for dynamic and static balance on the right side ($P > 0.05$). There were significant differences in the main effect of time for 10-meter walk speed, functional strength of lower limbs, static balance on the right side, and dynamic balance ($P < 0.05$).

Conclusions: Results showed tDCS was effective in improving gait and functional strength of the lower limbs in older adults. We recommend tDCS as a safe and effective way to improve motor performance and increase physical function, including walking and functional strength of lower limbs, in older adults.

Keywords: **Accidental Falls • Frail Elderly • Physical Functional Performance • Transcranial Direct Current Stimulation**

Full-text PDF: <https://www.medscimonit.com/abstract/index/idArt/932623>



Background

During normal degeneration due to aging, physical deficits related to movement occur, such as in gait, strength, balance, and performance [1,2], leading to many problems in older adults, of which falling is the most common and important. Risk factors for falls include the use of antidepressants, fear of the environment, infectious diseases, joint and musculoskeletal disorders, decreased visual perception, biochemical problems, cardiovascular diseases, central and peripheral nervous system disorders, and cognitive impairment. The interaction of these factors increases the probability of falling [3].

Many researchers have implemented a variety of effective exercises based on fall risk factors to prevent and reduce the likelihood of falls among older adults. Existing fall prevention exercises include yoga, Pilates, tai chi, square stepping exercises, resistance, strength, and agility exercises, and static and dynamic balance exercises [4-6]. The decline in physical ability and motor learning in older adults impairs the efficiency of fall prevention exercises.

Transcranial direct current stimulation (tDCS) is noninvasive brain electrical stimulation that delivers a constant, low-intensity, direct current to a specific brain region through electrodes attached to the scalp [7,8]. It allows input of peripheral and central nerve information to improve synaptic plasticity and skill learning and increase motor performance [9,10]. The application of bipolar tDCS can increase cerebral cortex excitability and brain function and activate specific brain areas prior to and during the intervention to increase the positive learning effects of task-specific training and potential [7,10,11]. Recently, Dumel et al [7] applied the serial reaction time task for 5 sessions with tDCS or a sham stimulation for 20 min per day for 5 days to improve motor function and motor learning in 23 healthy older adults. They found that performance and motor learning ability in the tDCS group improved compared with that of the control group.

Treatment with tDCS is used as an effective approach for cognitive and motor functions in healthy older adults across a variety of tasks [12]. Existing tDCS equipment poses a disadvantage in terms of application to the general public owing to the requirement of operator expertise, high cost, and difficult portability [13]. This study was conducted using a portable tDCS device that is safe and easily operable by anyone through an application. The device is set up such that a weak current of less than 2 to 3 mA is used to excite the primary motor region through electrodes fixed on the scalp arranged in a form similar to that of a typical headset [9]. In addition, this equipment has been approved by the U.S. Food and Drug Administration and has been widely used in previous studies [13,14].

Research on tDCS and its effect on older adults and falls has been limited, and research on lower-limb function related to falls and tDCS is crucial. Thus, the purpose of this study was to investigate the immediate effects of tDCS on overall physical function, including walking, functional strength of lower limbs, and balance ability of older adults.

Material and Methods

Participants

The participants of this study included healthy older adults who attended the P-Elderly Welfare Center located in Pocheon-si, South Korea. Adults aged 65 years or older who regularly participated in the senior center's programs were selected as participants. A sample size of 57 participants was required to verify significant intervention effects at a statistical power of 80%, a two-sided significance level of 0.05, and a presumed dropout rate of 10%. Healthy older adults were sufficiently motivated to perform the necessary tests and interventions; were able to walk independently; did not have orthopedic and neurological diseases; had no metal insertion near the current stimulation site; had no defects in the skull bone; had no history of epilepsy, seizures, or mental disorders; and had no signs of depression, sensory impairment, vestibular disease, or drug use that could interfere with the results of this study. The demographic data of the participants are shown in **Table 1**.

Procedures

After providing a detailed explanation of the study, we obtained written consent from all participants and recorded their characteristics. By using a random allocation software, 57 participants who met the selection criteria were randomly divided into a tDCS experimental group (n=31) and a control group (n=26).

The participants of both groups were subjected to a 10-meter walk test (10MWT), 5-repetition sit-to-stand test (5STST), one-leg standing test, and timed up and go (TUG) test before and after the intervention. After the pre-test, the participants in the experimental group underwent stimulation in the primary motor area for 20 min, and participants in the control group underwent a sham stimulation. Following this, a post-test was conducted. This study was conducted with the approval of the Research Ethics Committee of Sahmyook University. The experimental procedures of the study are shown in **Figure 1**.

Transcranial Direct Current Stimulation

In this study, the Halo Sport (Halo Neuroscience, San Francisco, CA, USA) was used as the tDCS device. The size of the electrodes

Table 1. Physical characteristics of the participants (n=57).

	Experimental group (n=31)	Control group (n=26)	t, χ^2 (p)
Age	78.13±4.76	78.77±4.80	-0.504 (0.616)
Gender (Male/Female)	10/21	9/17	0.185 (1.000)
Height (cm)	156.15±8.72	157.14±8.67	-0.431 (0.668)
Weight (kg)	62.17±8.34	61.53±8.63	0.283 (0.779)
BMI	25.54±3.17	24.83±2.38	0.894 (0.375)
10 MWT(s)	8.02±1.29	7.80±1.11	0.696 (0.489)
5 STST(s)	9.79±2.17	10.06±2.60	-0.434 (0.666)
OLSR(s)	12.98±1.41	13.31±1.84	-0.764 (0.448)
OLSL(s)	13.28±1.31	13.92±1.93	-1.498 (0.140)
TUG(s)	8.73±1.83	8.68±1.77	0.094 (0.926)

Mean±SD.

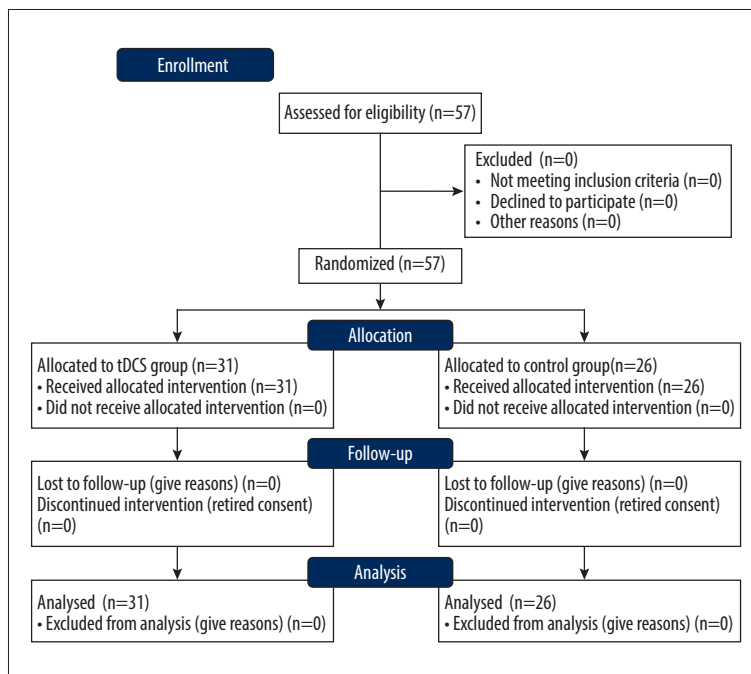


Figure 1. Flow diagram of the experimental procedures.

affixed to the scalp was 28 cm (6.4×4.4 cm). The device is composed of 3 studded foam electrodes termed primers (24 cm²/primer), which are wetted prior to use. It needs to be positioned on the midline central and ‘vertex’ top of the head. In this position, the primers lie across the top of the head, spanning from ear to ear, with the aim of stimulating both sides of the motor cortex.

After the pre-test, the experimental group underwent tDCS for 20 min, and then the post-test was performed. As the “leg, core & arms” mode was performed 20 s before and after the neuropriming period during brain activation, ramping up and ramping down to 2.0 mA were performed for 30 s each. The

current of the tDCS was set at 1.98 mA. These parameters were consistent with the literature on motor cortex stimulation [15] and were conducted to stop the operation of the tDCS device when the electrical stimulus was discontinued. The equipment was checked after it was switched off. The electrode of the tDCS device needed to be sufficiently wet so that it adhered to the scalp. The participants were asked to inform the test operator immediately if any problems occurred during the test. Furthermore, we monitored for unintended flow of electric current in the participants during the test. In the control group, a device similar to that used in the experimental group was employed; however, no electrical stimulation was provided. The experiment was conducted in a quiet place so

that the participants had minimal distractions from the surrounding environment. The pre-test and post-test were performed in the same environment.

Outcome Measurements

To assess walking ability, the 10MWT was conducted. To exclude the acceleration and deceleration periods, walking distance was measured by placing markers at 2-meter intervals on a path with a length of 14 meters, before and after the 10-meter markings. The participants were instructed to walk as fast as possible, beginning at the “start” signal. The time taken to walk from the 2-meter marking to the 12-meter marking was measured twice, and the average value was recorded for each participant. The 10MWT has been shown to have excellent test-retest reliability, with intraclass correlation coefficient (ICC) values ranging from 0.96 to 0.98 [16].

The 5STST was used to measure the functional strength of the lower limbs. A chair with a height of 46 cm was used, and participants were asked to sit comfortably with their back resting against the back of the chair. The seated participants were asked to move forward on the chair until their feet were placed flat on the floor and to fold their upper limbs across their chest. The participants were then instructed to stand up and sit down once without moving their upper limbs. The time from the command “go” until the participant’s buttocks touched the chair on the fifth repetition was recorded once, in seconds, using a stopwatch. The test-retest reliability (ICC range, 0.89-0.96) of the 5STST has been established in healthy older adults [17].

The one-leg stand test was performed to measure static balance. Participants were allowed to place their arms in a slightly open position for balance. While looking forward, the participants were asked to lift either the right or left foot after the “start” signal and were asked to maintain that position for as long as possible. If the participants took support of a wall or any surrounding structure with their hand, touched the ground with the leg that was lifted, held the position for more than 60 s, or shifted their center of gravity, the measurement was stopped and the time was recorded [16]. A total of 2 measurements were obtained using a stopwatch, and the average value was recorded. To prevent any falls during the measurement, the measurer secured the participant from behind. Inter-rater reliability of the test has demonstrated an ICC of 0.994 [18].

The TUG test was performed to measure dynamic balance. The participants were asked to sit on a standard armchair, having a height of 46 cm and an arm height of 67 cm, with their back against the chair and arms resting on the chair’s arms. They were then instructed to stand up, walk to a line on the floor 3 meters away, turn, walk back to the chair, and sit down again at a comfortable and safe speed. The TUG time was measured

in seconds. High intratester and intertester reliability have been reported in older adults, with an ICC of 0.99 [19].

Statistical Analyses

SPSS version 21.0 for Windows 10 (IBM, Inc., Armonk, NY, USA) was used to analyze the data. Data were summarized using the mean and standard deviation. The normality of the continuous variables was examined using the Kolmogorov-Smirnov test. The participants’ general characteristics were analyzed using the chi-squared test and independent *t* test. To determine the effect of group on outcome measures, 2×2 (group-by-time) repeated measures ANOVAs were performed with time (pre-test and post-test) as the repeated factor and group (tDCS group and control group) as the between-participants factor. Significant main or interaction effects were followed by appropriate post hoc analyses with the Bonferroni test. Statistical significance was set at $\alpha=0.05$.

Results

10-Meter Walk Test

The changes in 10MWT of the participants in the experimental and control groups after the intervention are shown in **Table 2**. There were significant differences in the group-by-time interaction for 10MWT ($F[1, 55]=6.18, P=0.016$). There were significant differences in the main effect of time for 10-meter walking speed ($P<0.05$).

Functional Strength

The changes in the functional strength of the participants in the experimental group and control group after the intervention are shown in **Table 2**. There were significant differences in group-by-time interaction for functional strength ($F[1, 55]=7.02, P=0.011$). There were also significant differences in the main effect of time for the functional strength of lower limbs ($P<0.05$).

Static Balance

The changes in static balance of the participants in the experimental group and control group after the intervention are shown in **Table 3**. The participants in the experimental group exhibited a significant difference in group-by-time interaction for static balance only on the left side after the intervention ($F[1, 55]=6.043, P=0.017$). However, there was no significant difference in group-by-time interaction for static balance on the right side ($F[1, 55]=0.403, P=0.528$). There were significant differences in the main effect of time on static balance on the right side ($P<0.05$).

Table 2. Results of 10-meter walk test and functional strength before and after treatment (n=57).

	Group	Pre	Post	Time main effect		Interaction (group×time)	
				F	p	F	p
10MWT(s)	tDCSG	8.02±1.29	7.56±1.02	18.639	.000	6.180	.016
	CG	7.80±1.11	7.68±1.11				
5STST(s)	tDCSG	9.79±2.17	8.64±1.69	23.607	.000	7.020	.011
	CG	10.06±2.60	9.73±2.47				

Mean±SD. 10MWT – 10 meter walk test; 5STST – 5-repetition sit-to-stand test; tDCSG – tDCS group; CG – control group. The significance levels were evaluated using the repeated ANOVA.

Table 3. Results of balance test before and after treatment (n=57).

	Group	Pre	Post	Time main effect		Interaction (group×time)	
				F	p	F	p
OLSR(s)	tDCSG	12.98±1.41	13.85±1.87	7.363	.009	0.403	.528
	CG	13.31±1.84	13.86±2.47				
OLSL(s)	tDCSG	13.28±1.31	14.32±2.36	2.141	.149	6.043	.017
	CG	13.92±1.93	13.66±2.22				
TUG(s)	tDCSG	8.73±1.83	8.18±1.39	25.947	.000	0.654	.422
	CG	8.68±1.77	8.28±1.74				

Mean±SD. OLSR – one-leg standing right; OLSL – one-leg standing left, TUG – timed up and go test; tDCSG – tDCS group; CG – control group. The significance levels were evaluated using the repeated ANOVA.

Dynamic Balance

The changes in dynamic balance of the participants in the experimental and control groups after the intervention are shown in **Table 3**. There was no significant difference in group-by-time interaction on dynamic balance ($F[1, 55]=0.654, P=0.422$). There were significant differences in the main effect of time on dynamic balance ($P<0.05$).

Discussion

This study aimed to investigate the effects of tDCS on 10MWT, functional strength of lower limbs, and balance of older adults. The results clearly demonstrated that the 10MWT and functional strength of lower limbs significantly improved after the immediate application of tDCS.

In the present study, the participants in the tDCS group took a significantly shorter time to complete the 10MWT. Zhou et al [20] performed tDCS on the extrafrontal lobe of younger adults for 20 min in addition to gait and posture maintenance and a cognitive subtraction test to evaluate dual function performance. The researchers found that walking speed increased in the tDCS group. These results were consistent with those of the present study.

Thus, the application of tDCS to the primary motor area of older adults increased their walking speed, which resulted in improved motor performance. Such improvement in motor performance can be attributed to an improvement in synaptic plasticity of the cerebral cortex due to cerebral cortical depolarization, which activates the primary motor region and increases the excitability of the cortical spinal cord to increase voluntary muscle activity [10,21].

In the present study, the participants in the tDCS group exhibited a statistically significant increase in functional strength of the lower limbs after the intervention, as assessed by the 5STST. In a previous study, Tanaka et al [22] conducted a knee extension test of the lower paretic extremity in stroke participants before and after the application of tDCS and reported a 13.2% improvement in muscle strength, compared with that in the control group. Kim [23] reported that the application of tDCS in participants with hemiplegic stroke led to a significant improvement in overall muscle strength and mean maximum muscle strength of the knee muscle after stimulation. Moreover, in a study of 60 participants with stroke, Andrade et al [24] found that tDCS stimulation of the primary motor area was effective in improving lower-limb function, including walking ability and muscle strength.

After the application of tDCS to the primary motor area, the ability to control voluntary muscle function improved momentarily, such that the muscles were more activated and the efficiency of the activated muscles also improved in terms of receiving signals to perform a particular action from the primary motor area [25]. Therefore, in the present study, tDCS in the primary motor area significantly improved walking ability and functional strength of the lower limbs of the healthy older adults, which in turn improved their physical function and motor performance.

In this study, compared with that of the control group, the change in static balance ability of the participants in the experimental group was significant only in the one-leg standing test on the left foot. According to previous studies, there is leg dominance difference in postural control [26]. In general, the ability to adjust the balance of the right dominant foot is better than that of the left non-dominant foot because people have mainly used the right dominant foot in various activities, such as balance and physical activity [27]. Since the intervention in the present study occurred once, there can be no significant change unless the single-time effect was large. Rather, for the non-dominant foot (left), which was not normally used, even though the intervention method itself was administered once, the ability to adjust the balance was lower than that of the dominant foot. As a result, motor learning was more effective with the dominant foot. In the case of dominant feet, there seems to be no difference between before and after the application of the intervention due to the ceiling effect. The dynamic balance ability of the participants in both the experimental and control groups in the present study was not significant. According to Yosephi et al [28], who compared the effects of tDCS on the primary motor area and the cerebellum during 2 weeks of postural training in adults aged 65 years and older, the effect of tDCS was greater when applied to the cerebellum than when applied to the primary motor area. Kaminski et al [29] examined whether dynamic balance ability on a balance plate improved after the application of tDCS to a lower extremity region of the primary motor area in older adults and observed no significant difference between the experimental and control groups. Zandvliet et al [10] reported that the application of tDCS to the opposite cerebellum led to improvement in balance ability when participants were standing for a short time.

The lack of improvement in balance ability in the present study may be attributed to the placement of the electrodes at the primary motor region and not at the cerebellum, unlike in previous studies that reported the cerebellum plays an important role in controlling human body movements, including coordinated movement of the limbs, postural control and balance, gait, and other specific body movements [30]. The primary motor area also accelerates signal transmission to muscles to

improve motor performance. However, the difference in balance ability is more pronounced when the tDCS was applied to the cerebellum [31]. In addition, the most important factor in maintaining postural balance is the interaction between vision, perceptual sensation (proprioception), and vestibular organs [29,32]. In the present study, improved muscle strength may have led to an improvement in proprioception, which affected the balance ability of the participants in the experimental group [33]. To improve balance, it is necessary to further determine the brain location according to function for the application of stimulation.

A previous study and the present study have shown that the application of tDCS, combined with exercise, improves motor performance [7]. In addition, tDCS can be recommended to older adults as a potential approach for improving physical function, including walking and functional strength of the lower limbs. According to the results of the present study, tDCS applied for a short time led to significant improvements in the walking ability and functional strength of the lower limbs of older adults. tDCS can be used to safely and effectively stimulate the brain and can function as an assistive device for older adults who either cannot exercise or find it difficult to exercise in their environment. In addition, in the future, it can be used as an assistive approach to further improve physical function and prevent falls in older adults who can exercise.

To validate the outcomes of this study, it may be worthwhile to repeat this intervention several times in a long-term study [34]. Long-lasting effects are also important to consider. Single-dose tDCS intervention has a relatively short effect. Multiple stimulation sessions are required to induce significant changes in synaptic efficacy [35]. Therefore, repeated sessions of tDCS may have cumulative effects on the magnitude and duration of intervention. It will also be important to apply tDCS to the cerebellum to confirm its efficacy in terms of balance ability. Also, the collection of additional participant data, including learning of the tests, cognitive status, educational level, and physical fitness level, which can influence the results of study, should be considered in a future study. Furthermore, more studies with varying participant criteria and methods of intervention could also be beneficial.

Conclusions

In this study, we aimed to improve synaptic plasticity and activate neurotransmitter secretion to enhance motor performance of older adults through tDCS. In addition, the effects of tDCS alone on walking ability, functional strength of the lower limbs, and static balance of older adults were examined. Our results showed that the application of tDCS significantly improved the gait and functional strength of the lower

limbs of adults aged 65 years or older. These results showed that tDCS has good clinical potential to safely and effectively improve motor performance and increase physical function, including walking and functional strength of the lower limbs, in older adults.

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Conflicts of Interest

None.

Declaration of Figures Authenticity

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