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Original Article

The Effect of Cerebellar Transcranial Direct Current Stimulation (ctDCS) on Postural Control Strategies in Elderly Population

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Abstract: Loss of balance and postural control are the main reasons for falls among the elderly adults that are considered as serious elderly health challenges with high impacts on the quality of life. The cerebellum is involved in postural control as one of the key neural structures that receives many inputs from the sensory systems. Cerebellar transcranial direct current stimulation (ctDCS) is a popular noninvasive and safe method enabling the adjustment of cerebellar activity. Therefore, we investigated the effect of ctDCS on postural control variables among elderly population with a history of stroke. Thirty elderly individuals (60-75 years) participated in this study. After preliminary assessments of postural control strategies by post urography at six sensory conditions, they received five 20-min sessions of active ctDCS at 2mA (intervention, $n = 15$) or sham stimulation (control, $n = 15$) in a random manner. At the end of the stimulation process, postural control strategies were reassessed. After adjustment for pre-test values using the ANCOVA test, an improvement of the subjects' performance in the first four conditions was observed in the intervention group compared with the control group ($P < 0.05$). However, in the fifth ($P = 0.24$) and sixth ($P = 0.58$) conditions, there were no significant differences between the groups. The results of this study showed the significant effect of ctDCS on the postural control strategies. These improvements were reflected by normalization of strategy of postural control in elderly adults.

Keywords: Cerebellar Stimulation, Elderly, Stroke, Aging, Postural control strategies;

1. Introduction

Restoring postural control after stroke is the most important factor in gaining independence in movement in daily activities and preventing falls. Review studies on common interventions on postural control among stroke patients indicate the insufficient efficacy of routine methods for improving independence in movement suggesting the need for more effective methods to restore post-stroke balance (Zandvliet et al. 2018). Considering the role of cerebellum in updating motor commands and generating motor-error signals, increased cerebellar activity can positively affect the posture. Cerebellar transcranial direct current stimulation (ctDCS) is a safe non-invasive method with the capability of changing the output of cerebellar nuclei and subsequent cerebellar activity with no adverse effect. This method has reportedly been successful in the evaluation of human balance control and has therefore attracted the attention of many researchers in behavioral sciences, neurology, and rehabilitation (Hesse et al. 2007).

The brain electrical stimulation, motor control, and neural rehabilitation are experiencing a new phase with the emergence of ctDCS. Studies have shown that ctDCS can affect motor, cognitive, and emotional behaviors. This has provided an interesting opportunity to develop therapeutic approaches, especially for the elderly and patients suffering from ataxia (Leiner et al. 1994). It is possible to improve the plasticity of cerebellar cells by ctDCS since the cerebellum has a crucial role in cognition, function, balance, and posture among elderly population who are incapacitated with age-related issue. In fact, ctDCS can be introduced as one of the prophylactic and therapeutic interventions, especially in the field of rehabilitation, to achieve post-stroke proper balance, safe walking, and independence in movement (Daskalakis et al. 2004).

Despite the evidence for the positive effects of ctDCS on postural control, the exact mechanisms and the optimal ctDCS variables are not fully clear (Inukai et al. 2016). Therefore, with regards to the advantages of ctDCS on motor functions and the uncertainty about its effect on post-stroke postural control, the present study aimed to investigate the effect of ctDCS on the kinetic variables of postural control in the elderly after stroke by manipulating the sensory systems involved in postural control.

2. Methods

The study samples included 30 female and male subjects aged 60-75 years with a history of stroke who volunteered to participate in this study and were randomly assigned to the intervention and control groups. It should be noted that participants suffered from stroke at least 6 months prior to the study (Zandvliet et al. 2018). The tools used in this research were: 1) consent form 2) questionnaire for elderly health assessment to assess the indices required for safe and proper use of ctDCS, and computer dynamic cardiac posturography 3) short forms for cognitive status assessment to assess the cognitive disorders of the participants 4) dynamic computerized posturography (Equitest, NeuroCom, USA) which is one of the most advanced tools for evaluating kinetic variables and is applied for manipulating effective sensory systems in postural control. This device is a unique evaluation technique that provides quantitative data for postural control and seems suitable for analyzing age-associated oscillation mechanisms (Mason 2006). 5) The Electric Brain Stimulator (ActivaTek, Attenda Inc.) which induces 2mA uninterrupted direct current and is used for the anodal and cathodal stimulation of the studied area of the nervous system based on the International Electroencephalographic System 10-20 (Grecco et al. 2014).

First, forms of health assessment for each volunteer were filled and assessed by the researcher by means of interview to collect the necessary data regarding the adverse effects of ctDCS and to control the health conditions of the participants. Also, through a 30-point questionnaire, a brief assessment of the cognitive status of areas responsible for attention and calculation, memory, language, the ability to perform simple commands, and temporal and spatial orientation were evaluated for any possible cognitive disorders (Folstein et al. 1975). Subjects were then selected from the participants. Finally, all subjects received a comprehensive verbal and written description of the research purposes and procedures and signed an informed consent form approved by the Ethics Committee of the Department of Sports Sciences.

According to the inclusion and exclusion criteria, the subjects were randomly divided into intervention (exposed to active 2mA ctDCS for 20 min, n = 15) and control (exposed to sham ctDCS for only 30 s, n = 15) groups. The intervention was performed for 5 days in two weeks and each session lasted for 20 minutes. An interval of 48 h between consecutive sessions was observed and all subjects were tested between 9 am and 4 pm. The protocol of current stimulation used in this study was the placement of an anode electrode 2 centimeters lower than the inion point and the cathode electrode in the segment associated with the right buccinator muscle (Choy et al. 2003).

In this double-blinded study, in the first day, at the beginning of the session and before the intervention, the sensory organization (SO) test was performed by a dynamic computerized posturography system and the results were subsequently recorded. In this test, standing posture control strategy were evaluated in six conditions of manipulating the sensory systems involved in the postural control as described by Bonan et al. (Bonan et al. 2004). The conditions consisted of: SO1) normal vision (open eyes) with fixed surrounding and supporting surface, SO2) eyes closed and fixed surrounding and supporting surface, SO3) sway-referenced vision and fixed supporting surface, SO4) eyes open and sway-referenced supporting surface, SO5) eyes closed and sway-referenced supporting surface and SO6) sway-referenced vision and supporting surface. The degree of ankle or hip movements in relation to the amount of shear force exerted was considered as a strategy score. A score of 100 meant solely ankle and no hip movements, whereas 0 indicated hip movement generating approximately 110 N shear force (Gupta et al. 1991).

In order to analyze the data, after completing the test, values of the strategy were analyzed in each six conditions of the sensory organization tests by NeuroCom software and the results were then stored in a notepad file. In the next step, for the final analysis of strategies scores, all data were transferred to the Excel file and finally the SPSS software. Descriptive statistics including mean and standard deviation (SD) were used to describe the data. Analysis of covariance (ANCOVA) test was used to analyze between-group differences at $p < 0.05$ level and pre-test value was considered as a covariate variable. Paired t-tests were also performed for within-group comparisons of data recorded at the baseline and after 5 weeks, and the amount of changes was calculated as the difference between these two values.

3. Results

Demographic characteristics including age, height, weight, and body mass index (BMI) of subjects in both intervention and control groups are illustrated in Table 1.

Table 1. Mean (SD) of descriptive characteristics of the groups

	Intervention (n=15: M=9, F=6)	**Control** (n=15: M=8, F=7)
Age (year)	68.61 (3.27)	64.90 (4.91)
Height (cm)	161.10 (7.07)	163.76 (10.18)
Weight (kg)	70.42 (13.87)	71.29 (9.35)
BMI (kg/m^2)	26.19 (4.43)	26.64 (2.88)

M: male; F: female; BMI: body mass index

Changes in the scores of all six sensory conditions from pre- to post-intervention are reported in Table 2. Paired t-tests showed that there was a significant increase in the scores of SO1 to SO4 in the intervention group. However, these changes were not observed in the control group. In comparison to pre-intervention, no difference was also found in the sensory conditions SO5 and SO6 in both groups.

Table 2. The results of paired t-tests, and mean (SD) strategy scores before and after the study period for the six sensory conditions studied in the intervention and control groups

	Intervention		t	p	**Control**		t	p
	Pre	post			pre	post		
SO1	63.80 (5.29)	70.06 (9.73)	-2.93	.011*	64.53 (4.95)	64.20 (6.54)	.34	.73
SO2	61.66 (4.96)	67.06 (6.91)	-4.25	.001**	61.33 (6.24)	61.66 (5.78)	-0.30	.76
SO3	44.66 (5.20)	53.00 (9.75)	-3.64	.003**	45.00 (4.94)	45.93 (5.04)	-0.62	.54
SO4	33.33 (4.08)	38.51 (5.69)	-3.39	.004**	32.86 (3.85)	33.06 (3.88)	-0.27	.79
SO5	13.06 (3.84)	13.53 (4.10)	-0.54	.59	12.80 (3.98)	12.20 (2.88)	.81	.42
SO6	10.46 (4.01)	10.73 (4.21)	-0.48	.63	12.13 (3.22)	12.06 (4.52)	.13	.89

SO1: eyes open, fixed supporting surface, SO2: eyes closed, fixed supporting surface, SO3: sway-referenced vision, fixed supporting surface, SO4: sway-referenced supporting surface, normal vision, SO5: eyes closed, sway-referenced supporting surface, SO6: sway-referenced vision and supporting surface.

Comparisons of the effect of active and sham ctDCS on the postural control scores in both intervention and control groups are shown in Table 3. ANCOVA analysis was used to compare the pre- to post-test differences of the postural control strategies between two groups. After adjustment for pre-test values, the results showed that ctDCS leads to the improvement of the subjects' performance in the first four conditions. However, in the fifth and sixth conditions, there were no significant differences between the groups.

Table 3. The results of ANCOVA test to examine the differences between the intervention and control groups regarding the six sensory conditions

	Mean Square	F	p	η^2
SO1	326.63	7.63	.010*	.22
SO2	197.29	9.52	.005**	.26
SO3	394.88	7.37	.011*	.21
SO4	185.59	9.98	.004**	.27
SO5	10.32	1.39	.24	.04
SO6	1.33	.30	.58	.01

SO1: eyes open, fixed supporting surface, SO2: eyes closed, fixed supporting surface, SO3: sway-referenced vision, fixed supporting surface, SO4: sway-referenced supporting surface, normal vision, SO5: eyes closed, sway-referenced supporting surface, SO6: sway-referenced vision and supporting surface.

4. Discussion

The overall aim of this study was to investigate the effect of ctDCS on the postural control strategies in stroke patients by comparing its active and sham effects in different conditions of manipulating sensory systems involved in postural control.

The results of the present study are similar with Knotkova et al. (Knotkova et al. 2013), Dumont et al. (Dumont et al. 2015), Massetti et al. (Massetti et al. 2017), Galéa et al. (Galea et al. 2011), and Parazzini et al. (Parazzini et al. 2014), it can be said that elderly patients with stroke have shown similar patterns in comparison with adults with regards to joints movement and changes in CoP during balancing and postural control. The proper interaction between the CoP and the center of body mass has been able to efficiently control the postural control system (Miranda et al. 2006). ctDCS has facilitated the stimulus-response process required for postural control in elderly due to their inability to use the optimum continuous control process for postural control by making positive changes in the rate of conformance of the locomotor and correction of bodily deviations.

Preserving vertical position is a complicated task that requires the integration of visual information, vestibular, and motor-sensory inputs to assess the spatial body position and force generation for postural control (Woollacott and Shumway-Cook 1990). The degree of participation of these systems in postural control is a function of age-related decline. Under normal circumstances, mature nervous system considers the information from deep receptors more important than visual data for balancing. However, when the function of deep receptors diminishes with aging and changes the performance of musculoskeletal system, vision is crucial for maintaining balance, and healthy elderly individuals use visual information rather than the information from deep sensing system to maintain a postural position (Brandt et al. 1986). In this study, the ctDCS with positive changes in the postural function of the visual system allowed subjects to selecting the correct strategy to restore CoP to the point of relative balancing (King et al. 2012).

The ability of balance control is influenced by the interaction of biomechanical, skeletal, sensory, muscular, and central nervous systems. The quality of this ability can be assessed by the way these devices' function. With the advent of age-related diminishing changes in the performance of biomechanical, sensory, skeletal, and muscular systems, in the form of reduction in mass, strength, and distribution of muscle fibers, the importance of making incremental and stimulating changes in the central nervous system increases. The ctDCS can be efficiently used for postural control since cerebellum is considered as the "trainer" and "comparator" of the body and it is involved in autonomous movements through processing information obtained from the environment and comparing them with the commands issued from the motor cortex (Toppila 2000).

The ctDCS causes quicker adaptation to visual-motor disturbances measured by a rapid reduction in motor errors. Galea et al. (Galea et al. 2011) showed that cerebellar changes are major contributors to faster compliance, and the elderly patients can benefit from this fast adaptation. This stimulation dramatically reduces the long delay in tensile reactions by increasing the inhibitory effect of cerebellar cortex on the cerebellar nuclei.

On the other hand, the strategic analysis of walking in elderly showed that the acquired values of the strategy after active ctDCS are moving away from the limitations of sustainability. Moreover, subjects used a higher percentage of the wrist strategy rather than the pelvic strategy for the correction of the center of gravity and hence their postural control in response to the induced instabilities.

In a gaiting strategy, the subject adjusts the reliance level for rapid changes center of gravity using a suitable strategy, and acquired scores can be placed under the combined conditions of the hip and ankle strategies, while when corrective adjustments of posture can be done by creating a small torque in the ankle joint to reset the center of gravity, limitations of stability are lower and ankle strategy is the most appropriate strategy. Whereas, the use of hip strategies to create larger torques in the hip for changing the location of the center of gravity indicates the limitations of individual stability. Small values of strategy indicate that the subject relies on hip strategy for postural control and large values reflect the person's optimal use of ankle strategy (Wallmann 2001). Craig et al. (Craig and Doumas 2017) compared the effect of ctDCS on youth and the elderly and found a significant interaction in the strategies used by the elderly compared to the youth. They pointed out that this significance was higher in terms of visual acuity. Jayaram et al. (Jayaram et al. 2012) also found the effect of ctDCS on the walking pattern of 40 healthy adult subjects on treadmill, psychosis, foot motion symmetry, and better use of walking strategy patterns. They recognized the role of the cerebellum in improving the sensory redistribution of the pacemaker patterns. Dilda et al. (Dilda et al. 2014) also found the cerebellar role in improving the sensory reproduction of walking patterns using cerebellar galvanic stimulation in 10 adult subjects.

The field of ctDCS and neural rehabilitation is experiencing a new phase with the advent of ctDCS. Studies have shown that ctDCS can affect motor behaviors. This has provided an interesting opportunity to improve the health of the elderly suffering from stroke and the development of therapeutic approaches for elderly people with balancing disorders. This new knowledge can be useful for understanding the interaction between the cerebral cortex and the deep cortical nuclei. However, the effectiveness of ctDCS and the way it works best on motor behavior of the elderly suffering from stroke should be more investigated.

5. Conclusion

The improvement in standing balance performance after anodal contralesional cerebellar ctDCS shows promise for the application in stroke rehabilitation. Future studies should elucidate the full mechanism of ctDCS, the optimal stimulus parameters and its effect on cerebellar physiology and, of course, its safety. Qualitative outcome parameters that can capture the subtle effects of ctDCS can be used to explore the optimal dose and should be related to clinically meaningful improvements. It is proposed to make the electric field more effective by optimizing the stimulating parameters such as the use of a new multi-channel ctDCS technique as well as increasing the intensity and density of the current. The increase in the number of stimulation sessions and number of subjects, the separation of male and female, the use of subjects with a weaker balance, and the use of self-declaration of subjects at meetings can improve the results. High-quality randomized controlled trials in the early phase after stroke are needed to establish the role of ctDCS in the critical time window of recovery after stroke and its potential to enhance clinical outcome in rehabilitation practice

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Conflicts of Interest: The authors declare that they have no competing interest.

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فصلنامه رویکرد انسانی در مطالعات ورزشی

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تأثیر تحریک جریان مستقیم جمجمه ای مخچه (ctDCS) بر راهبردهای کنترل وضعیتی در افراد سالمند

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چکیده: از دست دادن تعادل و کنترل وضعیتی از دلایل اصلی زمین خوردن در میان سالمندان است که به عنوان چالش های جدی سلامت سالمندان با تأثیرات زیادی بر کیفیت زندگی در نظر گرفته می شود. مخچه به عنوان یکی از ساختارهای عصبی کلیدی که ورودی های زیادی را از سیستم های حسی دریافت می کند، در کنترل وضعیتی نقش دارد. تحریک جریان مستقیم ترانس کرانیال مخچه (ctDCS) یک روش غیرتهاجمی و سالم پرطرفداری است که امکان تنظیم فعالیت مخچه را فراهم می کند. بنابراین، تأثیر ctDCS بر متغیرهای کنترل وضعیتی در میان سالمندان با سابقه سکته را بررسی شد. ۳۰ فرد سالمند (٦۰ تا ۷۵ سال) در این مطالعه شرکت کردند. پس از ارزیابی اولیه استراتژی‌های کنترل پاسچر توسط پوسچروگرافی در شش شرایط حسی، آزمودنی ها پنج جلسه ۲۰ دقیقه‌ای ctDCS فعال در ۲ میلی آمپر (مداخله، n=۱۵) یا تحریک ساختگی (کنترل، n=۱۵) را به صورت تصادفی دریافت کردند. در پایان فرآیند تحریک، راهبردهای کنترل وضعیتی مجدد مورد ارزیابی قرار گرفت. پس از تعدیل مقادیر پیش آزمون با استفاده از آزمون ANCOVA، بهبود عملکرد آزمودنی ها در چهار شرایط اول در گروه مداخله نسبت به گروه کنترل مشاهده شد ($P \leq ۰/۰۵$). اما در شرایط پنجم ($P = ۰/۲٤$) و ششم ($P = ۰/۵۸$) تفاوت معنی‌داری بین گروه‌ها وجود نداشت. نتایج این مطالعه تأثیر معنادار ctDCS بر راهبردهای کنترل پاسچر را نشان داد. این پیشرفت عادی سازی استراتژی کنترل وضعیتی در سالمندان را نشان می دهد.

واژه‌های کلیدی: تحریک مخچه، سالمندان، سکته مغزی، پیری، راهبردهای کنترل وضعیتی؛

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