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Original Article

Effect of a single session of transcranial direct-current stimulation combined with virtual reality training on the balance of children with cerebral palsy: a randomized, controlled, double-blind trial

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Abstract. [Purpose] The aim of the present study was to investigate the effects of a single session of transcranial direct current stimulation combined with virtual reality training on the balance of children with cerebral palsy. [Subjetcs and Methods] Children with cerebral palsy between four and 12 years of age were randomly allocated to two groups: an experimental group which performed a single session of mobility training with virtual reality combined with active transcranial direct current stimulation; and a control group which performed a single session of mobility training with virtual reality combined with placebo transcranial direct current stimulation. The children were evaluated before and after the training protocols. Static balance (sway area, displacement, velocity and frequency of oscillations of the center of pressure on the anteroposterior and mediolateral axes) was evaluated using a force plate under four conditions (30-second measurements for each condition): feet on the force plate with the eyes open, and with the eyes closed; feet on a foam mat with the eyes open, and with the eyes closed. [Results] An increase in sway velocity was the only significant difference found. [Conclusion] A single session of anodal transcranial direct current stimulation combined with mobility training elicited to lead to an increase in the body sway velocity of children with cerebral palsy.

Key words: Cerebral palsy, Electrical stimulation, Static balance

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INTRODUCTION

The term cerebral palsy (CP) refers to permanent, mutable motor development disorders stemming from a primary brain lesion that causes secondary musculoskeletal disorders which limitations regarding activities of daily living[1)]. The prevalence of CP ranges from 1.5 to 2.5 among every 1,000 live births, with little or no difference among western countries[2)]. Motor impairment is the main manifestation of this condition and causes difficulties for CP subjects with in the biomechanics of the body[3, 4)]. Thus, functional mobility (how an individual moves in the surrounding environment in interactions with society)[5)] is an important physiotherapeutic goal for children with CP, as walking with or without assistance favors physical development and allows such children with CP to participate in activities[6)].

Approximately 90% of children with CP have compromised gait performance due to excessive muscle weakness, altered joint kinematics and reduced postural reactions[7)]. Consequently, such children have a reduced capacity to participate in games and sports with sufficient intensity to develop adequate cardiorespiratory fitness[8, 9)]. Indeed, exercise programs that include aerobic and muscle strengthening components have often been contraindicated for individuals with CP, as greater exertion was believed to result in an increase in muscle tone and reductions in the both the gamut of movements and overall function[10, 11)]. While there is current evidence of the physiological benefits of aerobic exercise for children with CP, the influence of these benefits on functional capacity remains unkown[11)].

Continual, intensive physical therapy is considered the gold standard in the treatment of individuals with CP, but achieves varying results. Different approaches have been employed to favor selective motor control, coordinated muscle action during gait[7, 12)] and physical fitness[10, 11)]. Recent such approaches that are currently being studied are

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gait training on a treadmill as and as mobility and balance training using a virtual reality system.

Postural control involves coordinating balance (stability and orientation of the body) among different body segments[13], and requiries interactions between motor control and the visual, vestibular and somatosensory systems[14]. The maintenance of postural control without alteration of the support base is determined by the ability to maintain the center of body mass within the limits of stabilty[15]. Many patients with neurological disorders have considerable difficulty maintaining the visual, vestibular and somatosensory systems in harmony for adequate postural stability[16]. A body is in equilibrium when at rest (static balance) or during stable movements (dynamic balance). In a stable system, movements do not significantly deviate from the desired trajectory even when submitted to perturbations[17]. Motor impairment in children with CP exerts a negative impact on their performance of activities of daily living, which is more evident in the standing position due to their greater demand for postural control[18, 19].

The development of novel therapeutic modalities for use in combination with conventional physical rehabilitation is important for the optimization of functional capacity[20]. In this context, noninvasive brain stimulation become a topic of the interest among researchers. Indeed, significant improvements have been reported following short periods of cerebral stimulation in individuals with brain lesions[20, 21]. Transcranial direct current stimulation (tDCS) is a promising low-cost technique, that is easy to administer and well tolerated, which has minimal adverse effects[22]. When used in combination with physical therapy, tCDS may potentiate neuroplasticity[20]. It is therefore important to determine the effects of novel techniques, such as tDCS and virtual reality, on the static and dynamic balance of patients with neurological disorders.

The aim of the present study was to investigate the effects of a single session of tDCS over the primary motor cortex combined with virtual reality training on the balance of children with CP.

SUBJECTS AND METHODS

A cross-sectional, randomized, placebo-controlled, double-blind clinical trial was carried out. This study received approval from the Human Research Ethics Committee of University Nove de Julho (Brazil) under process number 69803/2012 and was conducted in accordance with the ethical principles established by the Declaration of Helsinki. The study is registered with the Brazilian Registry of Clinical Trials under process number RBR-9B5DH7. All parents or guardians agreed to the participation of their children by signing a statement of informed consent.

The study took place at the Movement Analysis Lab, University Nove de Julho, Sao Paulo, Brazil, from March 2013 to July 2014. Twenty children with CP were recruited from specialized outpatient clinics and the physical therapy clinics of the university. The following were the inclusion criteria: levels I, II or III of the Gross Motor Function Classification System (GMFCS); independent gait for at least 12 months; age between four and twelve years; and degree of comprehension compatible with the execution of the procedures. The following were the exclusion criteria: history of surgery or neurolytic block in the previous 12 months; orthopedic deformities; epilepsy; metal implants in the skull or hearing aids. All children who met the eligibility criteria (n = 12) were submitted to an initial evaluation and randomly allocated to an experimental group (virtual reality training combined with active tDCS) and control group (virtual reality training combined with placebo tDCS). Block randomization was used and stratified based on GMFCS level (levels I–II or level III). Numbered opaque envelopes were employed to ensure the concealment of the allocation. Each envelop contained a card stipulating to which group the child was allocated.

Stabilometric analysis was performed for the evaluation of static balance. For this, a force plate (Kistler model 9286BA) was used. This force plate, which allows the recording of oscillations in the center of pressure (COP). The acquisition frequency was 100 Hz, captured by four piezoelectric sensors positioned at the extremities of the force plate, at a sampling frequency of 100 Hz; the force plate's size is 400 × 600 mm. The data were recorded using the SWAY software program (BTS Engineering) and integrated and synchronized by the SMART-D 140® system. The children were instructed to remain in a stand barefoot position on the force plate, with their arms alongside the body, with an unrestricted foot base, heels aligned, and to look at fixed on a point marked at a distance of one meter at the height of the glabellum (adjusted for each child). Children classified on level III of the GMFCS used their normal gait-assistance device, which was positioned off the force plate. A foam mat[23] measuring 40 × 60 × 5 cm was used as a proprioceptive stimulus.

Measurements were taken under four conditions: feet on the force plate with the eyes open; feet on the force plate with the eyes closed; feet on the foam mat with the eyes open; and feet on the foam mat with the eyes closed. Three 45-second measurements were taken under each condition, and the mean was used in the analysis. The order of the different conditions was randomized to avoid the possible effects of motor learning. Between measurements, the participants were given a one-minute rest period in the sitting position. Stabilometric evaluations were conducted in a single session prior to and immediately following the training protocol.

The children first received an explanation of the procedures, then remained at rest for 20 minutes. Two raters were in charge of the procedures to ensure blinding and the reliability of the results. Rater 1 was in charge of placing the electrodes and the administration of tDCS (active or placebo). Rater 2 supervised the virtual reality mobility training. Both the children and Rater 2 were blinded to the allocation to the different groups.

The intervention consisted of a single session of tDCS using two sponge (non-metallic) electrodes (5 × 5 cm) moistened with saline solution. The anodel electrode was positioned over the primary motor cortex, following the 10–20 International Electroencephalogram System, and the cathode was positioned over the supra-orbital region on the contralateral side[24]. In the experimental group, a 1-mA current was applied to the primary motor cortex region for 20

Table 1. Sway velocity before and after treatment in the AP and ML directions of the control and experimental groups with the eyes open (EO) and the eyes closed (EC) (Units: cm/s)

		Foam mat		Ground	
		Pre	Post	Pre	Post
Control group					
COP-AP	EO	12.52±2.56	13.26±1.87	15.97±3.83	14.48±2.46
	EC	10.83±1.73	12.07±1.45	11.01±1.63	12.62±1.97
COP-ML	EO	10.87±2.41	12.91±2.11**	11.67±4.07	12.26±3.24*
	EC	10.47±3.08	10.64±1.79*	11.67±4.07	11.92±2.31
Experimental group					
COP-AP	EO	10.78±1.46	12.91±1.55	10.80±1.66	13.66±1.99**
	EC	9.85±1.31	13.13±1.58	9.52±0.47	13.21±1.93*
COP-ML	EO	8.68±1.30	12.90±2.09*	9.58±2.03	11.96±2.05**
	EC	9.17±1.18	10.93±1.56*	9.58±2.03	12.45±2.21**

Mean values (±SD) and significant differences between pre-and post-treatment are reported.
*$p < 0.05$; **$p < 0.001$: Bonferroni post hoc tests

minutes while the children performed the virtual reality mobilty training. The device has a knob that allows the operator to control the intensity of the current. In the first ten seconds, the stimulation was gradually increased until it reached 1 mA, and it was gradually diminished in the last ten seconds of the session. In the control group, the electrodes were positioned at the same sites and the device was switched on for 30 seconds, giving the children the initial sensation of the 1 mA current, but no stimulation was administered during the rest of the virtual reality training. This is considered a valid control procedure in studies involving tDCS.

Mobility training with virtual reality was performed for 20 minutes with simultaneous tDCS (active or placebo). The children used their habitual braces and gait-assistance devices, when necessary. The braces were placed by the physiotherapist and an assessment of the gait-assistance device was performed and adjustments were made when necessary to achieve the proper size.

Mobility training with virtual reality was conducted using an XBOX 360™ with a Kinect™ (motion sensor) was used for mobility training. The Your Shape: Fitness Evolved 2012™ game was selected for aerobic exercises (walking and walking with obstacles). The children were instructed to stand at a distance of 2 to 3 meters in front of the motion sensor for the estimation of height and the calculation of the body mass index. Training was performed in a specific room of the Human Movement Analysis Laboratory of the University, measuring 250 × 400 cm. A screen measuring 200 × 150 cm was projected on the wall and stereo speakers were used to provide adequate visual and auditory stimuli.

The displacement of the center of pressure (COP) of the feet on the force plate in the anteroposterior (AP) and mediolateral (ML) directions was used to analyze body sway. Prior to the analysis, the signals were filtered using a low-pass Butterworth filter with a cutoff frequency of 10 Hz. Body sway was determined based on the oscillation area of the COP, displacement, mean sway velocity and oscillation frequency in the AP and ML directions. For the oscillation area (cm^2), was estimated using principal component analysis, was used to calculate the area of the ellipse from the COP-AP and COP-ML data considered for 95% of the data[25]. Mean displacement (cm) was calculated as the sum of the distances of all the consecutive points of the COP trajectory divided by the number of points[26]. Sway velocity (cm/s) was calculated as on the total distance divided by the signal capture time[27]. The displacement frequency (Hz) was determined as the frequency of 80% of the spectral power of the COP[28].

The Kolmogorov-Smirnov test was used to determine the distribution of the data. For this purpose, Repeated measures MANOVAs with the Bonferroni post hoc tests was used to determine differences between the experimental and control groups considering the following factors: group (experimental and control), treatment (pre-and post-treatment) vision (eyes open and eyes closed), foot support (ground and foam mat) and direction of COP oscillation (AP and ML). Levene's test was used to determine the evenness of variance between the groups. The level of significance was chosen as 5% ($p < 0.05$). All statistical tests were performed with using of the SPSS 20.0 program (SPSS Inc., Chicago, USA).

RESULTS

The analysis of the immediate effect of tDCS on oscillation area, displacement, oscillation frequency and body sway velocity in the AP and ML directions revealed a statistically significant interaction only for sway velocity (Table 1).

In the comparison of the pretreatment and post-treatment evaluations of sway velocity in the control group, significant differences were only found in the ML direction under both visual conditions (eyes open and eyes closed) with the foam mat as the support base and only with the eyes open when the ground was the support base.

In the experimental group, significant differences in sway velocity were found only in the ML direction under both visual conditions (eyes open and eyes closed) when the foam mat was used and in both the AP and ML directions under both visual conditions when the floor was the support base.

DISCUSSION

The present study describes the effects of a single session of tDCS combined with virtual reality mobility training on the static balance of children with CP. The literature offers studies on the effects of tDCS combined with other physiotherapy modalities for adults with neurological disorders stemming specifically from a stroke and Parkinson's disease[29], as well as some studies involving patients with CP. The findings of these studies indicate the considerable potential of this form of stimulation in the treatment of neurological disorders and the investigation of changes in cortex excitability[29–31]. Short-term tDCS is reported to have short-term effects, whereas long-term administration is reported to have lasting effects on neuroplasticity[30]. tDCS is a way of to modulating cortex activity to enhance and prolong the functional gains achieved in physical therapy. Stimulation causes a change in dysfunctional cortex excitability allowing that physical therapy to mold the functional pattern of cortex activity through the activation of neural networks specific to the activity in question[29].

According to Minhas et al.[32], a current of 1 mA is adequate for children and was therefore used in the present study. The positioning of the electrodes was based on the description given by Fregni et al.[24], with the anode placed over the primary motor cortex and the cathode placed over the supraorbital region. This configuration was also used in previous studies involving the same CP population conducted by Grecco et al.[33, 34] and Duarte et al.[35]. In the present investigation, a statistically significant difference between groups was only found with regard to body sway velocity. Comparing children with typical development to those with CP, Gatica et al.[36] found a greater body sway velocity only with the eyes open in the patients with CP, and a greater oscillation area only with the eyes closed. In the present study, sway velocity was significantly greater in the ML direction in both groups only with the eyes open when the foam mat was used as the support base. The control group exhibited greater ML oscillation on the ground only with the eyes open, and the experimental group exhibited greater AP and ML oscillations under both visual conditions (eyes open and eyes closed) when the ground was the support base.

Cherng et al.[14] conducted a study involving children with typical development and those with CP using a foam mat for the proprioceptive stimulus of the feet. The children were evaluated three times under each condition (eyes open, eyes closed and the use of a headset to alter the sensory environment). No statistically significant differences between the groups were found in static balance on the floor with the eyes open and with the closed. However, when the sensory environment was altered, the children with CP exhibited a reduction in static balance, with an increase in the oscillation area in comparison to the control group.

In a study involving children with CP and those with typical development, Donker et al.[37] evaluated static balance with the eyes open, the eyes closed and real-time visual feedback of the COP. They authors found less postural control in the group with CP, and body sway was more irregular when visual feedback was provided, which confirmed the expected imbalance when one's attention is drawn to another function. Rose et al.[38] found that children with CP exhibited greater body sway in comparison to children with typical development with the eyes open, but found no significant differences between groups with the eyes closed.

Damiano et al.[39] conducted a study with three groups of children: one with hemiparetic CP, one with diparetic CP, and one with typical development. They authors found greater oscillation area in the AP and ML directions in both groups of children with CP in comparison to the group with typical development, while sway velocity was only greater in the group with hemiparesis.

Duarte et al.[35] conducted a longitudinal study of tDCS (active and placebo) combined with treadmill training for children with CP over 10 consecutive days, with evaluations performed before, immediately after and one month after the intervention. Statistically significant reductions in AP and ML COP area were found with the eyes open and with the eyes closed in the group submitted to active tDCS, which was maintained until to the follow-up evaluation. Salem et al.[40] found an improvement in balance in the one-leg stance test in a pilot study involving children with delayed motor development. In another pilot study, Gordon et al. [41] found a 7% improvement in the Gross Motor Function Measure among children with CP.

tDCS studies generally have involved adults patients and have analyzed its of the effect on the balance among stroke survivors[42–44] or sedentary individuals with obesity[45]. Games facilitate improvements in static and dynamic balance during functional tasks by stimulating the displacement of the center of body mass and changes in the support base[46, 47]. Moreover, games are a viable option for aerobic exercise and therefore promoting physical fitness, which in line with the recommendations of the American College of Sports Medicine[48, 49].

Practical guidelines for the use of virtual reality in the treatment of children with CP were published in February 2012[50]. Although there are few studies involving this population, the findings demonstrate improvements in postural control, balance, upper limb function, selective motor control and gait[50]. The effects of tDCS combined with virtual reality mobility training are promising with regard to improvements in balance, as demonstrated in longitudinal studies with the techniques applied separately. We believe that the results of the immediate effect of the combination of these two methods are of considerable importance to future investigations in this line of research.

Based on the findings of the present study, a single session of anodal tDCS over the primary motor cortex combined with virtual reality mobility training appears elicits to lead to an increase in body sway velocity in the anteroposterior and mediolateral directions on stable ground with the eyes open and the eyes closed, however, an the increase in sway velocity only occurs in the mediolateral direction with the eyes open and with the eyes closed only occurred when proprioceptive information (foam mat foot support) was also provided.

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