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Enhancing neuromuscular training effect on balance and gait in autistic children by transcranial direct current stimulation

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Abstract

Background: Both of transcranial direct current electrical stimulation (tDCS) and neuromuscular training (NMT) have used to relive motor deficits in neurological disease.

Aim: We decided to investigate augmenting effect of tDCS and NMT to improve static and dynamic balance and gait parameter in autism spectrum disorder (ASD).

Materials and Methods: 24 children with ASD aged 6-10 years old were randomly assigned to one of three groups: NMT+ sham, anodal tDCS, and NMT + tDCS. NMT consisted of 10 sessions motor training (each for 40 min). tDCS training was performed with 1.5 mA on left primary motor cortex for 20 min. Pre-test and post-test evaluations included static and dynamic balance and gait parameters (length and width of stepping and speed of gait).

Results: Although improvement of variables were seen in all groups, but in post intervention comparison, combined group was better in static and dynamic balance and gait parameters than two other groups. NMT was more effective than tDCS only in dynamic balance.

Conclusion: Our findings were indicated tDCS enhance NMT effect on neuromuscular function in ASD, so regarding the augmented effect in combination of NMT and tDCS, it can be considered in rehabilitation of motor deficits in these children.

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1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by defects in relationships and social interactions; restricted interests and repetitive behaviors. In addition, ASD is accompanied with high prevalence of motor impairment (87%) [1]. Children with ASD have a delay in the initiation and development of fundamental motor skills, poor coordination including gross-motor impairments in whole-body and fine-motor coordination problems such as handwriting/drawing difficulties [1]. More over unstable movements, postural and balance stability deficit [2] and abnormal gait patterns [3] were seen in ASD children.

Postural control difficulties was explained as a result of the visual and somatosensory processing deficits in ASD [4]. Maintenance of postural stability and balance is dependent on the integrity of inputs received from the visual and motor sense systems. In people with autism, lack of integration of the central nervous system usually leads to deficit in sensory inputs registration problems. In fact, this sensory processing disorder is defined as an abnormal behavioral response to a stimulus, which is caused by the lack of correct processing of sensory information in the temporal cortex and communication brain areas [5]. The sensory processing disorders include three patterns of hyper-reactivity, hypo-reactivity and delayed reaction [6].

Due to frequency and severity of motor coordination disorders in ASD such as balance control deficit, some investigators consider it as a core disorder that affects daily function of these children [7]. Therefore, gait and balance improvement are included in motor coordination investigation in ASD.

Different forms of interventions such as water-based interventions, animal-assisted therapies, balance training, virtual reality and brain stimulation were used to improve balance and gaiting in ASD children [8, 9]. As one of safe and effective methods in rehabilitation, transcranial direct current electrical stimulation (tDCS) of the brain has recently been introduced. tDCS produces low-amplitude direct current that modulate cortical excitability without harmful side effects [10]. Stimulation with anodic direct current increases the rest potential of the neuronal membrane while with cathodic current decreases its potential [11]. tDCS is an easy to use; cheap, safe and non-invasive tool in the motor rehabilitation of patients [12].

Regarding the probable underlying defect in ASD such as abnormal synaptic development and brain cortical plasticity [13], tDCS has been considered as an effective rehabilitation tool in these patients. An increase in the volume of cortical gray matter in the frontal and parietal regions plays an important role in motor control and learning disorder in children with ASD compared to normal children [14].

It is expected that tDCS targeting motor cortex can reduce motor dysfunctions in ASD. In some investigations effectiveness of tDCS in ASD including motor planning [15], improve of hypo-activity or hyperactivity of dorsolateral prefrontal cortex [16, 17], speech function [18], cognitive function [19], motor disorders like balance control [20] has shown.

On the other hand neuromuscular training is combination of core stability, balance, strength, agility, and plyometric exercises which improves the ability of nervous system to produce a fast and optimal muscle-firing pattern [21]. The neuromuscular coordination generates strength, range of movement and proprioceptive [22]. Applying of neuromuscular training in ASD children make improvement of lower body power, dynamic and static balance [23, 24]. More over, previous studies showed this kind of training make improvement in kinetic of gait in these children [25].

Some studies have revealed that training effect can optimized by applying of tDCS before treatment intervention [26]. The augmenting effects were seen in stoke disease [27], pain relief on common musculoskeletal conditions [28], Parkinson disease [29] and healthy persons [30].

As mentioned before some neuroanatomy and neuro-function disorders were seen in ASD which can potentially produce different results.

So, the aim of the present study is evaluating simultaneous applying of neuromuscular training and tDCS in balance and gait dysfunction in children with ASD. Motor cortex activity in neuromuscular training [31] can be strengthened by tDCS. We hypothesized that combining the motor cortex training with tDCS intervention and neuromuscular training would have a synergistic effect.

2. Materials and Methods

2. 1. Participation

This randomized clinical trial was conducted in a rehabilitation center in Ahvaz city in 2022. The participants which consisted of 24 boys with ASD were randomly assigned in one of three groups including: neuromuscular training (NMT) group, anodal tDCS group, and sham tDCS+ NMT group. The ASD children were referred by a psychologist based on the DSM-V diagnostic criteria [32]. The participants aged 6-10 years with IQ>60 measured by the Wechsler Intelligence Scale, normal vision and hearing, without seizer or other neurologic and musculoskeletal disorders that affects balance or gait were included in this study. Other inclusion criteria were ability to communicate and comprehend with training instructors, ability to tolerate tDCS and perform the motor instructions.

2. 2. Instrument

2. 2. 1. Gilliam Autism Rating Scale (GARS-2)

GARS-2 was used to access the severity of ASD [33]. The questionnaire consists of 42 items on a 4-pointLikert scale that provides information about these subscales: communication, stereotypes, and social interaction. The questionnaire was filled by parents subjects with GARDS>52 were included in study.

2. 2. 2. Stork leg standing test

The test was used to assess static balance [34]. The participants were requested to stand comfortably on both feet with hands on the hip and then lift leg and place the toes of that foot opposite the knee of the supporting leg. After that on command the subjects raise the heel and stand on their toes as they were asked. The time recording was started as the heel was raised from the floor. The time recording was stopped if the hands move from the hips or the supporting foot swiveled or moved in any direction, or the non-supporting foot lost contact with the knee, or the heel of the supporting foot touched the floor.Test has high reliability [35] and was repeated for three times.

2. 2. 3. Tandem gait test

Tandem gait was used to evaluate dynamic balance [36]. The participants were asked to walk 10 steps on a straight path with the heel of the leading foot touching the toe of the following foot. Test was performed with closed eye and crossed arm and was repeated for two times. The number of correct tandem steps, whether or not they were consecutive was the reported as outcome. Opening the eye, more than 2 cm between the feet and taking the side step were defined as error.

2. 2. 4. Gait

Spatio-temporal parameters, including step length, step width, gait speed and cadence, were measured by pouring powder to a distance of 10 m on the ground [37]. Then subjects were asked to walk the defined distance. The step length was obtained by measuring the distance between the heel of one limb and the heel of the next. The step width was calculated by measuring the distance of two points from the center point of each heel as a reference, and the step cadence was obtained from the number of steps recorded per minute by a stopwatch [38]. To measure the gait speed, the subjects were asked to walk a distance of 10 m with a maximum speed. By dividing the measured time by the desired distance, the person's gait speed was obtained in m/s.

2. 3. Procedure

2. 3. 1. tDCS

In order to brain stimulation, a portable tDCS device (Activa-dose) was used through placing anode and cathode on left primary motor cortex (M1) and supraorbital region respectively according to the International System of Electrode Placement EEG 10-20 [20]. The electrodes which was inserted in 5.5*7.5 sponge soaked by saline and then fixed head by two elastic bands. A 1.5 mA direct current stimulation was delivered for 20 min in anodal stimulation, but the current was switched off after 20 sec in sham stimulation. tDCS training were conducted for 10 sessions (three times a week).

2. 3. 2. Neuromuscular training

In order to improve static and dynamic balance, series of motor training including walking on a board on the toes, stepping with a foot in front of the other, throwing a ball into a basket, jumping into a hula hoop and so on were performed (Table 1). Training consisted of 10 sessions with 40 min duration which the difficulty of the exercises were increased compared to the previous session [20]. In tDCS+ NMT group, neuromuscular training was performed immediately after tDCS session (Figure 1).

Table 1. Selected neuromuscular exercises

Goal	Procedure	Time
Improving of trunk & abdominal muscles, balance	1. Lying on Swiss ball & hold ball with stomach and touching ground with hands in front and foots in behind of ball. 2. Take 10 small balls from the ground and threw them into basket.	Depend on subject ability
Improving balance, catching & aiming	Sitting on Swiss ball and catching and throwing the small ball to trainer with each hand (10 times).	Improving dynamic balance
Improving dynamic balance	Walking on toes on a balance stick (5cm*2m).	Improving dynamic balance
Improving dynamic balance	Heel to toe walking on a balance stick (5cm*2m).	Improving dynamic balance
Strengthening power of leg muscles	Hopping with one leg in to 5 hula hoops that are replaced in zigzag pattern, distance can be increased next sessions according to subjects progress.	Improving dynamic balance

Figure 1. Neuromuscular and tDCS training

2. 4. Statistic

Normality of variables were evaluated by Shapiro-wilk test. A paired t-test was used to compare within-group variables. In addition, regarding the homogeneity of variance and regression slope, analysis of covariance (ANCOVA) was used to compare differences between post-test scores of three groups, using baseline values as covariates. If the results were significant, the Bonferroni post hoc-test was used to searching between groups differences. The p-value level below 0.05 was defined as significant. We performed statistical analysis using IBM SPSS software, version 22.

3. Results

Anthropometric characteristics of participant are presented in Table 2.

Baseline comparisons between initial and final values were done in three groups by using paired-samples -tests for all depending variables (Table 3). As presented in Table.3, improvement of all variables relative to baseline except walking cadence were significant in each of three groups.

ANCVOVA was performed to assess the effect of interventions (tDCS, NMT and combined effect) as independent variables adjusting by baseline dependent values (Table 4). Before applying of ANCOVA pre-assumption including normality, homogeneity and equality of variances was checked.

Table 2. The comparison of characteristics of participant between groups

	Groups			P-value
	tDCS	**NMT+ Sham**	**NMT+ tDCS**	
Age (years)	8.5±2	8.25±1.66	8.5±1.6	0.95
Hieght (cm)	121.62±10.32	123.62±10.39	123.62±12.85	0.92
Weight (kg)	18.62± 3.2	18.37±3.42	18.5±2.13	0.98
BMI	19.32±3.68	22.46±3.72	21.30±4.45	0.64
GARS	95.36±24.61	97.80±26.45	93.41±21.48	0.82
IQ	75.48±9.39	73.21±7.93	74.85±9.83	0.8

Table 3. Baseline comparisons of the dependent variables in both experimental setups by paired t-test

Groups	Variables	Pre-test	Post-test	t-test	P-value
tDCS	Static balance	5.29±1.20	7.49±1.37	-13.990	0.0001
	Dynamic balance	5.87±1.45	7.87±1.55	-7.483	0.0001
	Step length	104.12±5.30	110.87±4.61	-8.727	0.0001
	Step width	14.62±5.29	11.57±3.22	9.744	0.0001
	Walking cadence	117.0±3.85	117.87±4.48	-7.761	0.155
	Walking speed	116.25±4.59	122.37±4.59	-1.594	0.0001
NMT+ Sham	Static balance	5.12±1.49	7.28±1.36	-10.980	0.0001
	Dynamic balance	5.37±2.06	8.62±2.55	-10.370	0.0001
	Step length	104.25±4.30	116.25±6.08	-12.253	0.0001
	Step width	13.75±1.91	8.87±1.88	13.000	0.0001
	Walking cadence	117.0±4.31	130.0±4.37	-14.031	0.826
	Walking speed	117.0±4.50	118.25±3.53	-0.228	0.0001
NMT+ tDCS	Static balance	5.31±1.64	9.42±2.39	-11.449	0.0001
	Dynamic balance	5.75±1.98	10.37±1.92	-25.276	0.0001
	Step length	104.25±4.30	116.25±6.08	-14.967	0.0001
	Step width	13.75±1.91	8.87±1.88	16.523	0.0001
	Walking cadence	117.50±4.50	118.25±3.53	-11.465	0.265
	Walking speed	117.0±4.31	130.0±4.37	-1.210	0.0001

Table 4. Analysis of covariance results

Variable	Groups	Mean squared	df	F	*P*	Eta squared
Static balance	NMT+ tDCS	9.345	2	19.517	0.001	0.661
	tDCS	7.437				
	NMT+ Sham	7.412				
Dynamic balance	NMT+ tDCS	9.355	2	23.415	0.001	0.710
	tDCS	7.492				
	NMT+ Sham	7.597				
Step length	NMT+ tDCS	10.289	2	24.490	0.001	0.680
	tDCS	7.659				
	NMT+ Sham	8.927				
Step width	NMT+ tDCS	116.540	2	21.212	0.001	0.567
	tDCS	111.289				
	NMT+ Sham	110.421				
Walking cadence	NMT+ tDCS	9.332	2	13.073	0.001	0.692
	tDCS	11.258				
	NMT+ Sham	10.920				
Walking speed	NMT+ tDCS	129.331	2	22.491	0.769	0.026
	tDCS	122.558				
	NMT+ Sham	123.486				

In post-hoc test, static and dynamic balance showed significant more improvement in combined (NMT+tDCS) group relative to other groups (*P*<0.0001). There was not significant difference in static balance between tDCS and NMT groups, but in dynamic balance more improvement was seen in NMT relative to tDCS group (*P*<0.05). Moreover, post-hoc test of length and width of step and walking speed showed more improvement in combined(NMT+tDCS) group relative to other groups (*P*<0.05), but significant difference was not seen between tDCS and NMT groups.

4. Discussion

Although balance and gait symptoms are not initial dysfunctions of children with ASD, but these abnormalities compromise their daily functioning and dependency. Therefore, motor rehabilitation by short term and effective interventions should be considered in these children. The present study aimed to investigate the effect of tDCS on left M1, NMT separately and in combination on balance and some parameters of gaiting in ASD children. This study was performed as a randomized sham-controlled clinical trial on 6-10 years ASD children. Our results showed improvement of dependent variables (static and dynamic balance, length and width of stepping and speed of gait) in all interventions relative to baseline.

In comparison of post intervention effects, combined group (tDCS+NMT) was more better in static and dynamic balance and gait parameters (length and width of stepping and speed of gait) than others, but comparison between NMT and tDCS showed that NMT was more effective than tDCS only in dynamic balance and no significant differences were found in other variables.

In general, our finding showed synergic effects of tDCS (as a neuro-stimulation intervention) and NMT in improving of balance and some of gaiting parameters in children with ASD. Similar results were reported in combination therapy of tDCS with other interventions in some neurologic disease [39, 40]. Combination of tDCS of M1 cortex and gait training on treadmill showed improvement of static balance in children with cerebral palsy [41]. In a double-blind study, benefits of tDCS combined with physical training on gait speed in Parkinson disease was reported [42].

Recently in a similar study, Mahmoodifar and Sotoodeh (2020) compared motor skill exercise effects with combination effect of anodal tDCS and motor training on the static and dynamic balance in children with ASD. They found more effectiveness of combination therapy [20]. Comparison to our study, gaiting of participants was not investigated in their study.

In a more recent study, the anodal tDCS showed positive effect on balance and gait training in children with ASD [20]. They investigated the difference between effectivity of anodal primary motor cortex (PMC) and cerebellar tDCS with sham tDCS effects. Their finding showed positive effect of tDCS in balance and gait training in participants. The novelty of our study was the investigation of effects of NMT and tDCS separately and in combination which showed positive effect of all interventions.

Improvement of static and dynamic balance and gait parameters were seen by tDCS (without other training) indicating facilitating effect of tDCS targeted motor cortex on corticospinal pathway. These effects are explained by lowering the threshold of neural firing that increase the functional connectivity of neural network [43].

The augmentation result of combined intervention is due to increased excitability and functionality by anodal tDCS in peripheral and central elements sensorimotor function. Anodal tDCS of M1 cortex induce more excitability [44] by increasing in activation of neural cells [45] and excitability of the motor cortex [46]. More over strengthening of corticospinal pathway and therefore positive affect on functional recovery were seen [47].

The underlying neurophysiological mechanism in augmented effect of tDCS on exercise could partially be explained by the interplay between central motor activation and fatigue inhibition induced by delaying the onset of supra-spinal fatigue [48].

Our study is the first study that showed a significant combination effect of tDCS and NMT on gait parameters in ASD children. Our results are in line with some investigations have done in Parkinson disease [42], cerebral palsy [49] and Multiple sclerosis [49]. Considering to relationship between dynamic balance and core strength in ASD children [50] and established combination therapy effectiveness on balance [20] M1 stimulation could use as an effective tool on both balance control and gait improvement in ASD.

Several limitations should be noted in the present study. The first limitation is the accessibility to few participants; The future study should be conducted by large size number of subjects.

Second limitation is investigation of immediate effect of interventions, long term effect of interventions need to be investigated in future studies.

The third limitation is accessing tools of balance and gait in participants which could be conducted by more objective and accurate instruments (like Biodex system and camera).

5. Conclusions

The present study showed augmented effect of tDCS as a neuro-stimulation tool on neuromuscular training in balance and walking dysfunction of children with ASD. Our finding can be considered in neuro muscular rehabilitation of these children.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical Consideration

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee IR.UT.SPORT.REC.1401.004 in Iran. The researcher informed parents about the study and then all of them fill out and signed consent forms for their child's participation in this research.

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