KMAN PUBLISHING INSTITUTE
Journal Website

Article history:
Received 11 October 2024
Revised 18 December 2024
Accepted 22 December 2024
Published online 01 January 2025

Journal of Assessment and Research in Applied Counseling

Volume 7, Issue 1, pp 16-26

E-ISSN: 3041-8518

The Effect of Transcranial Direct Current Stimulation (tDCS) on the Balance of Children with Autism Spectrum Disorder: A Randomized Controlled Trial

Farnaz. Torabi[1*], Hasan. Sepehri Bonab[1*], Farshad. Sharifi[1*]

[1] Department of Physical Education and Sport Sciences, Peyame Noor University,Tehran, Iran

*** Corresponding author email address**: f.torabi@pnu.ac.ir

Article Info

Article type:
Original Research

How to cite this article:
Torabi, F., Sepehri Binab, H., & Sharifi, F. (2025). The Effect of Transcranial Direct Current Stimulation (tDCS) on the Balance of Children with Autism Spectrum Disorder: A Randomized Controlled Trial. *Journal of Assessment and Research in Applied Counseling. 7*(1), 16-26.

http://dx.doi.org/10.61838/kman.jarac.7.1.3

ABSTRACT

Objective: The aim of the present study was to investigate the effect of transcranial direct current stimulation (tDCS) on the static and dynamic balance of children with autism.

Methods and Materials: This quasi-experimental study used a purposive and convenience sampling method to select 30 male children with autism from the city of Ardabil, aged between 5 and 12 years. After selection, the participants were randomly assigned to either the experimental group (tDCS) or the control group. Dynamic balance (during walking and based on center of pressure fluctuations) and static balance (based on center of pressure fluctuations) were assessed using the Bertec force plate, with the center of pressure displacements measured in the mediolateral (ML) and anteroposterior (AP) directions. The data were filtered using a 20 Hz low-pass Butterworth filter. The tDCS intervention was applied with an intensity of 2 milliamps to the left primary motor cortex for 5 weeks, with 15 sessions of 20 minutes each, using a two-channel TDCS device, Medinataab, made in Iran.

Findings: The results of a two-way repeated measures analysis of variance showed significant differences in both static and dynamic balance between the experimental and control groups in terms of the center of pressure path direction along the anteroposterior and mediolateral axes. The experimental group, with a lower mean oscillation of the center of pressure path, demonstrated better balance.

Conclusion: Based on the obtained results, it can be concluded that transcranial direct current stimulation (tDCS) has the potential to significantly improve both static and dynamic balance in children with autism.

Keywords: *Autism, static and dynamic balance, transcranial direct current stimulation, center of pressure path.*

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition with an early onset, caused by changes in the brain and other unknown factors, leading to challenges in social, communicative, and behavioral domains (Date et al., 2024). The prevalence of ASD is 3 to 5 times higher in boys than in girls, and over the past 10 years, it has increased from 1 in 68 children to 1 in 36 children (Maenner, 2023). With the rising diagnosis of ASD, understanding the underlying mechanisms of this disorder and how to support those affected by it has become more important than ever.

To diagnose ASD, individuals must meet five criteria: deficits in social communication and interaction, repetitive behaviors and fixed interests, impairment in functioning, early onset (early childhood), and the disorder cannot be better explained by an intellectual disability (Araujo et al., 2023). Autism spectrum disorder is comorbid with intellectual disabilities, speech disorders, and motor deficits, including walking disorders, abnormal motor symptoms, poor balance, lack of coordination, and clumsiness (Kang et al., 2024), as well as delays in gross motor skills, object control, ball exercises, balance, and drawing skills (Taheri, 2009). Additionally, postural control disorders are consistently observed in individuals with ASD. These disorders manifest as increased postural sway, absence of ankle strategies, and differences in weight distribution while standing (Date et al., 2024). Postural control is also essential for the development of early gross and fine motor skills, such as crawling, standing, climbing stairs, hand manipulation skills, motor planning, and basic movement execution (Mnejja et al., 2023). Postural control maintains both static and dynamic balance, both of which are affected by ASD (Bojanek et al., 2020). Therefore, in addition to communication and behavioral challenges, ASD is also associated with motor deficits. One of the most important of these deficits is problems with static and dynamic balance, which have a significant impact on the daily activities and quality of life of these children (Cheung, 2020). Static balance refers to the ability to maintain the body in a stable position under various conditions, while dynamic balance refers to the ability to maintain stability while moving or changing body positions (Lengkana et al., 2020). Recent studies show that children with autism exhibit significant deficits in both static and dynamic balance compared to their typically developing peers, which can lead to secondary problems such as reduced ability to perform daily activities, participation in social activities (Bregnard, 2022), social-communication disorders like anxiety and social isolation (Lidstone et al., 2020), impaired sensory integration and body awareness, and an increased risk of falls in children with ASD (Doumas et al., 2016).

When evaluating static and dynamic balance in individuals with ASD using various methods, they have been found to perform poorly compared to typically developing individuals. In balance assessments involving walking and force plates, the displacement of the center of pressure/ground reaction force is reported as postural deviations, and these patterns can accurately reflect the changes resulting from intervention exercises (Lim et al., 2018; Minshew et al., 2004). Additionally, fMRI or EEG have been used in some studies to record neurophysiological and morphological changes in the nervous system due to therapeutic exercises (Bo et al., 2022; Philip et al., 2012).

The causes of these problems have been attributed by researchers to abnormal connections between primary sensory and motor areas (Stoit et al., 2013), disturbances in frontal-striatal communication, and increased gray matter surface area and volume in the frontal-parietal network (Mahajan et al., 2016), as well as issues in the prefrontal, premotor, and cerebellar regions, leading to deficits in motor impairments (Pérez et al., 2014). Morris et al. (2022) relate postural control and balance deficits to sensory integration between visual, vestibular, and somatosensory inputs, and with the increasing severity of autism, postural sway increases, and balance becomes further compromised (Morris et al., 2022). Studies on individuals with autism have shown a significant increase in cortical gray matter volume and surface area in the anterior parietal regions involved in motor control and learning in children with ASD compared to typically developing children (Moradi & Movahedi, 2019), reduced activation in the motor cortex and lateral premotor cortex, supplementary motor area, and cerebellum during rhythmic and sustained finger tapping tasks in individuals with autism (Dana et al., 2019), decreased cortical excitability during a finger movement task in ASD compared to the control group (Bayatpour et al., 2019), and increased hand dominance, indicating reduced left hemisphere motor dominance (Rezaei et al., 2016). These findings underscore the importance of targeting and activating cortical regions in individuals with autism.

Various intervention programs have been implemented by researchers to improve motor skills and balance in individuals with ASD, including hydrotherapy and taekwondo (Ansari et al., 2021), tai chi (Sarabzadeh et al., 2019), virtual reality games (Ghobadi et al., 2019; Jelsma et al., 2014), skating and dancing (Arzoglou et al., 2013; Casey

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518

et al., 2015). Most of these programs have demonstrated their effectiveness in improving balance (Ajzenman et al., 2013; Ansari et al., 2021; Casey et al., 2015) and motor performance (Hocking et al., 2022) in individuals with ASD. Reviews on postural control (Date et al., 2024; Djordjević et al., 2022; Hariri et al., 2022) have highlighted the effectiveness of exercise interventions on postural control in individuals with ASD; however, due to methodological differences, further study is needed in this area to generalize the results. The use of animals to improve balance, movement, and exercise repetition has challenged an individual's postural stability and led to sensory integration across proprioceptive, vestibular, and tactile senses, influencing postural control. Despite the effectiveness of such programs, the lack of studies in this area limits the applicability of the findings (Hayakawa & Kobayashi, 2011). In exercise interventions like kata, movement on the legs and muscle strength coordination, as well as interhemispheric integration, appear to improve balance in autism. Regular balance exercises have led to functional and structural improvements in the motor cortex, basal ganglia, and cerebellum, and combining these exercises with cortical stimulation in the primary motor cortex and rhythmic auditory exercises have aided in sensory-motor integration, neuroplasticity, and ultimately improved postural control. However, most of these studies have not addressed the changes in the underlying mechanisms. Such structural and functional differences in the nervous systems of individuals with autism present challenges, and the possibility that transcranial direct current stimulation (tDCS) in the motor cortex could help improve motor functions in this clinical group is supported.

The transcranial direct current stimulation (tDCS) technique is a non-invasive, painless, and simple brain stimulation method that enhances brain pathways, such as from the cortex to the muscles (motor cortex excitability), and promotes cortical plasticity (Charman et al., 2011). One study indicated that transcranial stimulation of the primary motor cortex may improve dynamic balance in both young and elderly healthy individuals (Jansiewicz et al., 2006). Mousavi Sadati and Rashidzadeh (2020) reported that transcranial direct current stimulation of the cerebellum combined with balance exercises might improve vestibular processing and postural control in the elderly, facilitating motor learning and adaptation (Mousavi Sadati & Rashidzadeh, 2020). It has even been reported that tDCS on the primary motor cortex may have beneficial effects on autism ranking scales and the autism treatment evaluation checklist in individuals with autism (Vernazza-Martin et al., 2005). Mahmoodifar and Sotoodeh (2020) indicated that tDCS might enhance motor skill training for children with autism spectrum disorder, but replication with larger samples, including participants with varying autism symptoms and different tDCS stimulation polarities, is necessary to confirm the practical use of this non-invasive brain stimulation. The only study conducted in this area using tDCS for balance and postural control in children with autism was by Mahmoodifar and Sotoodeh (2020), which combined anodal tDCS on the primary motor cortex with motor and balance exercises, leading to significant improvements in balance and motor performance in children with autism (Mahmoodifar & Sotoodeh, 2020). Given the crucial role of balance in motor development and functional abilities in children, examining both static and dynamic balance in this group is particularly important. Therefore, in addition to cognitive and behavioral aspects, the use of tDCS exercise interventions can provide valuable insights into changes in static and dynamic balance and their effectiveness in postural control. These interventions, by improving control strategies and motor learning, will help in postural control development, reducing injury risk, improving motor skills, participating in physical activities, interacting with others, and ultimately improving the quality of life for these children. Furthermore, the results could inform effective therapeutic interventions for balance in individuals with autism.

2. Methods and Materials

2.1. Study Design and Participants

The research method in this study is quasi-experimental, and its target population consists of children with autism in Ardabil city during the years 1403–142 (Gregorian Calendar: 2024–2025). To determine the sample size, the G*Power software was used to calculate a minimum sample size of 30 participants with a statistical power of 0.80, an effect size of 0.95, and a significance level of 0.05. Purposeful and convenience sampling was employed to select 30 male children with autism aged 5–12 years. The participants included individuals with moderate and mild autism spectrum disorder (according to the diagnostic grading by GARS, as documented in their files) from psychiatric clinics and welfare centers in Ardabil city. They were identified and referred by a child psychiatrist and were then randomly assigned to two groups: the experimental group (transcranial direct current stimulation) and the

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518

control group. Before the commencement of the study, the study protocol was approved by the ethics committee of Payame Noor University and the Welfare Organization. Written consent was obtained from the parents of the children for their participation in the study. Before the test, the objectives and methods of the study were briefly explained to both the participants and their parents, and upon arrival at the laboratory, the participants' height, weight, and age were recorded.

2.2. Measures

2.2.1. Static and Dynamic Balance

Static and dynamic balance were assessed during the pre-test and post-test sessions using a Bertec force plate (Model FP6090-06-PT, USA) to collect data on center of pressure displacement. The tests were conducted with the participants in the Health and Fitness Center of Payame Noor University. The force plate was positioned in the middle of a 20-meter track. After a warm-up, for dynamic balance assessment, each individual walked the 20-meter track three times, placing their dominant foot on the force plate at the midpoint of the track. For static balance, each participant stood on the force plate three times for 30 seconds, and ground reaction forces along the X and Y axes were recorded, representing the anterior-posterior and medial-lateral directions, respectively. Data validation was carried out to ensure accuracy throughout different stages and methods. In the first stage, after the completion of each trial, the force plate signals were checked in the relevant software, and the signal characteristics (e.g., continuity of the signal) were verified to ensure their accuracy. It should be noted that this data verification process was performed in consideration of previous studies, credible sources, and knowledge gathered by the researchers throughout the investigation and literature review process. Any issues identified in the recorded data that could reduce the validity and reliability of the data led to the exclusion and re-execution of the trial. Raw data obtained from the force plate were filtered to remove noise. A low-pass Butterworth filter with a 20 Hz cutoff frequency was used to filter the force plate output (Lee & Sun, 2018; Wikstrom et al., 2005). The resulting data output included center of pressure changes in the medial-lateral (COPx) and anterior-posterior (COPy) directions, which were recorded during both static and dynamic balance assessments. The parameters used for static and dynamic balance were the displacement distance of the center of pressure, calculated for each participant using the following equations:

Equation 1. Displacement distance of the center of pressure in the anterior-posterior direction (mm):

$$PLAPcop = \sum^{n-1} \sqrt{(x_{i+1} - x_i)^2}$$

Equation 2. Displacement distance of the center of pressure in the medial-lateral direction (mm):

$$PLMLcop = \sum^{n-1} \sqrt{(y_{i+1} - y_i)^2}$$

These equations calculate the displacement distance of COP in the AP and ML directions, indicating how much the COP has moved and the distance traveled during standing or walking. Therefore, an individual's stability during standing or walking is determined. The greater the COP oscillation, the longer the displacement distance, which is inversely related to balance (Kavyani Boroujeni et al., 2023; Satvati et al., 2013).

2.3. Intervention

2.3.1. Transcranial Direct Current Stimulation Protocol

During the therapeutic intervention, each participant received 15 sessions of transcranial direct current stimulation (tDCS) in a one-on-one setting, with 3 sessions per week and each session lasting 20 minutes. The tDCS was administered using a two-channel Medinazeb tDCS device manufactured in Iran. The tDCS protocol involved placing the anode electrode (16 cm²) over the left primary motor cortex, at the 10-20% Cz point, based on the 10-20 electrode system, after preparing the electrode by placing it inside a wet pad. The cathode electrode (24 cm²) was placed over the right frontal area to prevent lateral current flow. A direct current of 2 mA was applied using the anode and cathode electrodes (Minhas et al., 2012; Poortvliet et al., 2018). The large size of the cathode electrode makes it functionally ineffective without impacting the anode electrode (Stagg & Nitsche, 2011). According to previous studies by de Moura, Aparisiu, Greco, Brononi, and Hesse (2019), the primary motor cortex was selected as the stimulation site to improve balance. The systematic review indicated that tDCS targeting the primary motor cortex can enhance voluntary control and balance performance (de Moura et al., 2019). The transcranial direct current stimulation interventions and balance assessments were performed in a double-blind manner by specialists at the Health and Fitness Center of

Payame Noor University. To prevent any cognitive and motor interference with the tDCS effects, participants sat comfortably in a chair during the application of tDCS. The control group did not receive any treatment during the therapeutic and training intervention phase, but for ethical reasons, they were provided with similar treatment sessions after the completion of the study.

2.4. Data analysis

Independent t-tests were used to examine differences in age, height, and weight characteristics. The Shapiro-Wilk test was applied to determine the normality of the data distribution. Repeated measures analysis of variance (ANOVA) with a 2-group factor and 2-time points was used to test the hypotheses during the pre-test and post-test phases. The assumptions for this test (normality of error distribution using the Shapiro-Wilk test, homogeneity of variance using Levene's test, and independence of errors using the Runs test and Box's test for covariance matrix equality) were verified and confirmed ($P > 0.05$). The hypotheses were tested at a significance level of 0.05, and all statistical calculations were performed using SPSS software (version 25).

3. Findings and Results

Using an independent samples t-test, it was found that there were no significant differences between the two groups in terms of age, weight, and height at the pre-test stage ($p > 0.05$). The results of the comparison of the two groups at the pre-test stage in demographic data are summarized in Table 1, which shows that these factors do not affect the participants' balance.

Table 1

Demographic Information of Participants

Variable	Control Group	Experimental Group	p Value
Age (years)	10.18 ± 1.68	10.26 ± 0.79	0.540
Weight (kg)	31.50 ± 7.60	34.93 ± 12.75	0.414
Height (cm)	132.36 ± 10.36	130.53 ± 6.32	0.351

The p-values for all intervening variables between the two groups are greater than 0.05, indicating that these variables do not have an effect on the participants' balance.

To investigate the impact of transcranial direct current stimulation (tDCS) intervention on the static balance of children with autism, a repeated-measures analysis of variance (2×2) was used with the between-subjects factor (group) and within-subjects factor (time) at both the pre-test and post-test stages. Given the homogeneity of the covariance matrix, multivariate tests were conducted. The results, as shown in Table 2 and Figure 1, indicated that for the center of pressure (COP) displacement in the anteroposterior (AP) direction, there was a significant main effect of the group and a significant interaction, but the main effect of time was not significant. Given the significant interaction effect, the post-hoc one-way test showed that there were no significant differences between the two groups at the pre-test stage ($p = 0.4$), but the difference between the groups at the post-test stage was significant ($p < 0.05$).

Additionally, the analysis of static balance in the COP displacement in the mediolateral (ML) direction showed that both the main effects of time and group were significant, but the interaction effect was not significant. The deviation in the COP displacement in the ML direction was reduced in the experimental group, and the static balance in this direction increased at the post-test stage (as shown in Table 2 and Figure 1).

Table 2

Results of the Repeated-Measures ANOVA for the Dependent Variable of Static Balance Between the Two Groups

Variables	Source of Variation	Degrees of Freedom	F	Wilks' Lambda	p Value	Effect Size (η^2)
PLAP COPx	Group	1,28	20.3	-	< 0.001	0.42
	Time	1,28	2.4	0.92	0.13	0.07
	Group × Time	1,28	9.62	0.74	0.004	0.25
PLML COPy	Group	1,28	11.48	-	0.002	0.29
	Time	1,28	10.19	0.73	0.003	0.26
	Group × Time	1,28	2.68	0.91	0.11	0.08

COPX = Center of Pressure Displacement in the Mediolateral Direction, COPY = Center of Pressure Displacement in the Anteroposterior Direction.

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518

Figure 1

Difference Between the tDCS and Control Groups in the COP Displacement in the Anteroposterior Direction (Static Balance) Across Pre-Test and Post-Test Stages

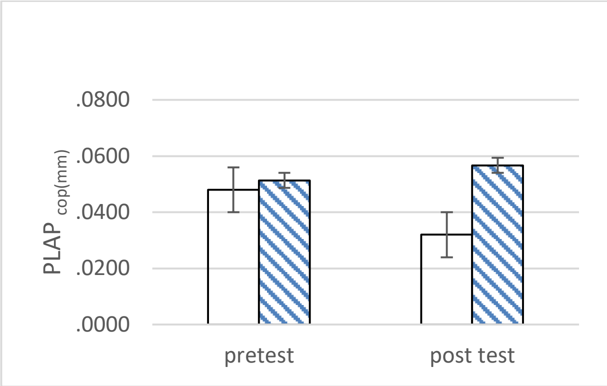
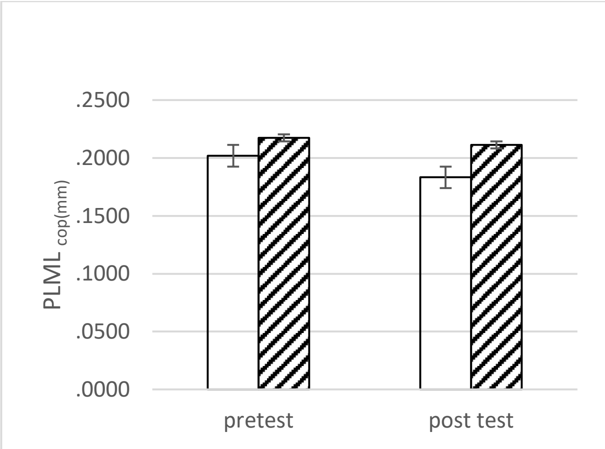


Figure 2

Difference Between the tDCS and Control Groups in the COP Displacement in the Mediolateral Direction (Static Balance) Across Pre-Test and Post-Test Stages



For the dynamic balance variable, the COP displacement in the anteroposterior direction, since the residual errors in one of the groups were not normally distributed, the data were first normalized. Using repeated-measures ANOVA (2×2) with the between-subjects factor (group) and within-subjects factor (time) at both the pre-test and post-test stages, the results, after applying the Greenhouse-Geisser correction, as shown in Table 3, revealed that the main effect of the group and the interaction effect were significant, but the main effect of time was not significant.

The effect of time on the changes in COP displacement in the mediolateral direction was statistically significant, but neither the main nor the interaction effects were significant for dynamic balance in the anteroposterior direction. In static balance, the residual errors for COP displacement in the mediolateral direction were normally distributed. The results of the repeated-measures ANOVA (2×2) indicated that the main effects of group and time were not significant, but the interaction effect was significant. Post-hoc tests between the groups showed no significant differences at the pre-test stage ($p = 0.87$), but at the post-test stage, the experimental group (0.106 ± 0.04) and the control group (0.227 ± 0.117) showed significant differences ($p = 0.001$). Therefore, the experimental group demonstrated greater dynamic balance in the mediolateral direction with less fluctuation.

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518

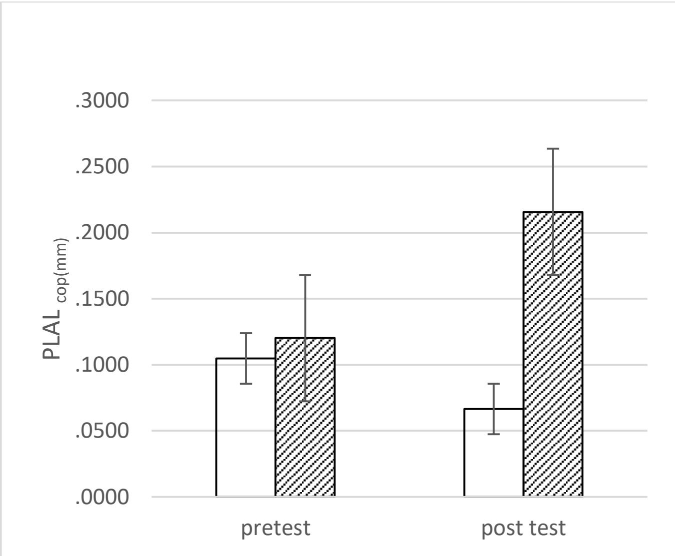
Table 3

Results of the Repeated-Measures ANOVA for the Dependent Variable of Dynamic Balance Between the Two Groups at the Pre-Test and Post-Test Stages.

Variables	Source of Variation	Degrees of Freedom	F	Sum of Squares	p Value	Effect Size (η^2)
PLAP COPx	Group	1,27	14.16	0.098	< 0.001	0.34
	Time	1,27	0.96	0.012	0.33	0.034
	Group × Time	1,27	5.27	0.065	0.03	0.16
PLML COPy	Group	1,28	1.34	0.024	0.25	0.046
	Time	1,28	0.153	0.001	0.69	0.005
	Group × Time	1,28	25.04	0.098	< 0.001	0.47

Figure 3

Difference Between the tDCS and Control Groups in the COP Displacement in the Anteroposterior Direction (Dynamic Balance) Across Pre-Test and Post-Test Stages



4. Discussion and Conclusion

The aim of the present study was to determine the effect of tDCS on static and dynamic balance in children with ASD. The results showed that there were significant differences between the experimental and control groups. Under static and dynamic balance conditions, the experimental group demonstrated lower variance in the center of pressure (COP) path length in both anterior-posterior and medial-lateral directions, indicating better balance.

The findings of the current study regarding the positive effect of tDCS on static and dynamic balance align with previous studies (Duarte et al., 2014; Jansiewicz et al., 2006; Mahmoodifar & Sotoodeh, 2020; Mousavi Sadati & Rashidzadeh, 2020) which reported the positive impact of tDCS on dynamic balance in healthy individuals (Jansiewicz et al., 2006), the combination of tDCS training with balance exercises for postural control in elderly individuals (Mousavi Sadati & Rashidzadeh, 2020), the combination of tDCS with treadmill walking for balance improvement in individuals with cerebral palsy (Duarte et al., 2014), and the combination of tDCS with balance exercises for improving static and dynamic balance in children with autism (Mahmoodifar & Sotoodeh, 2020).

In explaining the obtained results, it can be said that tDCS enhances neuroplasticity, which refers to the brain's ability to reorganize itself by creating new neural connections and redistributing blood flow in the stimulated area. This is especially effective in improving motor skills and balance in children with ASD (Araujo et al., 2023). Therefore, the individual’s performance in response to external stimuli improves, and their balance increases as a result of these interactions. However, the mechanism of tDCS is not limited

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518

to changes in the membrane potential of neural cells. tDCS, which targets the dorsolateral prefrontal cortex (DLPFC), can alter functional connectivity in key neural networks, such as the sensorimotor network, which is critical for balance and motor control (Kang et al., 2024). By modulating cortical excitability, tDCS can enhance the efficiency of neural pathways related to motor control, thereby improving balance (Mahmoodifar & Sotoodeh, 2020). Changes in synapses occur through alterations in the synaptic strength of NMDA or GABA receptors on cortical cells and cortico-spinal pathways (Mousavi Sadati & Rashidzadeh, 2020; Wikstrom et al., 2005).

According to the studies conducted, tDCS is a feasible technique for children and adolescents, which does not lead to significant adverse effects in the short term. The disturbances caused are apparently temporary and transient, and compared to other brain stimulation techniques, the side effects are limited and mild. tDCS, as a non-pharmacological method, can be a suitable and low-risk option in combination with traditional physiotherapy treatments for gait disorders and upper limb spasticity in children with neurological conditions. Given that the development of the nervous system and brain leads to better adaptive behaviors and higher intelligence in individuals, appropriate stimulation and selected activities can strengthen the nervous system and brain, leading to improved outcomes in children with autism (Stagg & Nitsche, 2011). In the present study, the protocol for applying transcranial brain stimulation was organized in a way that, with proper stimulation, had a significant impact on improving balance in children with autism.

While tDCS holds promise for improving balance in children with ASD, attention to individual variability in response to this treatment is essential. Factors such as the specific brain areas targeted, the duration and intensity of stimulation, and its combination with other therapies may affect the outcomes. Further research is needed to optimize protocols and understand the long-term effects of tDCS in this population. Differences in sample sizes and the number of training sessions, which sometimes range from 10 to 220 sessions, can limit methodological generalization. Although motor exercises are safe, enjoyable, and motivating, the effectiveness of such studies has not sufficiently addressed neural plasticity markers and underlying mechanisms, particularly considering structural and functional changes. This aspect requires more attention in future studies.

Children with ASD, who may have limited physical activity levels and a lack of interest in interaction and communication, are likely to face greater challenges. Therefore, comparing different therapeutic and training methods to identify the most appropriate approach for this group will be essential. It is also hypothesized that the severity of symptoms may affect postural fluctuations and balance in these individuals, and thus controlling the severity of the disorder in future studies is recommended. Therefore, the use of complementary methods such as cortical direct stimulation for enhancing training methods and reducing intervention time could be beneficial. Additionally, it is recommended that future studies consider the long-term sustainability of the effects and outcomes, as this aspect has been limited in previous research.

It seems that, considering the specific characteristics of this group, there has been less focus on them in the studies conducted. Evaluating the impact of interventions on functional and structural outcomes, such as brain imaging, could be valuable. Postural instability is a common symptom in ASD, and interventions aimed at improving it are deemed essential. Individuals with ASD have fewer opportunities to engage in physical activity-based social programs, and there is a lack of long-term recreational interventions that are motivating and enjoyable for this population. Therefore, the first step should be the implementation of exercise interventions using direct cortical stimulation to develop and improve postural control and balance in this group. Ultimately, to foster greater interaction, physical activity-based social programs for this population should be provided.

The results of the present study show that tDCS has the potential to improve static and dynamic balance in children with ASD. This non-invasive brain stimulation method, when applied to specific brain regions (using direct current with the anode electrode placed on the left and the cathode electrode on the right), can enhance balance in children with ASD by modulating neural activity and connectivity. Based on the results, tDCS appears to be a non-pharmacological, low-risk, and promising method for improving balance and postural control in children with ASD, which can be used in conjunction with conventional therapies. This method influences both neural and structural performance, but further research is needed to optimize protocols, examine long-term effects, and control the severity of the disorder.

5. Limitations and Suggestions

One limitation of the current study is the relatively small sample size, which may impact the generalizability of the results. Additionally, variations in the number of stimulation sessions across studies, ranging from 10 to 220, suggest methodological inconsistencies that could influence the outcomes and make comparison difficult. Furthermore, the study primarily focused on short-term effects, and the long-term sustainability of tDCS effects was not assessed. Finally, individual differences in response to tDCS, such as brain area targeting, stimulation duration, and intensity, were not fully explored, which limits the understanding of the treatment's effectiveness across different individuals with ASD.

Future research should aim to address these limitations by including larger, more diverse sample sizes to increase generalizability. Studies investigating the long-term effects of tDCS on balance and motor skills in children with ASD are crucial to understanding its sustainability. Additionally, more research is needed to explore individual differences in response to tDCS, including the impact of varying brain areas targeted, different stimulation intensities, and the combination of tDCS with other therapeutic interventions. Longitudinal studies assessing the effects of tDCS on neural plasticity, behavior, and cognitive development could provide valuable insights into its broader benefits for children with ASD.

The findings of this study suggest that tDCS could serve as a promising non-pharmacological intervention for improving balance and motor skills in children with ASD. This has important clinical implications, particularly in enhancing postural control and facilitating participation in physical activities. It could be integrated into existing therapy regimens alongside traditional physiotherapy techniques to provide a comprehensive approach to managing motor difficulties in children with ASD. Additionally, incorporating tDCS into rehabilitation programs could potentially reduce the reliance on pharmacological treatments, offering a safer and less invasive option. Future clinical practices may benefit from considering the combination of tDCS with other targeted interventions for improving overall functionality in this population.

Acknowledgments

We would like to express our appreciation and gratitude to all those who cooperated in carrying out this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

Authors' Contributions

All authors equally contributed in this article.

References

Ajzenman, H. F., Standeven, J. W., & Shurtleff, T. L. (2013). Effect of hippotherapy on motor control, adaptive behaviors, and participation in children with autism spectrum disorder: A pilot study. *The American journal of occupational therapy*, *67*(6), 653-663. https://doi.org/10.5014/ajot.2013.008383

Ansari, S., Hosseinkhanzadeh, A. A., AdibSaber, F., Shojaei, M., & Daneshfar, A. (2021). The effects of aquatic versus kata techniques training on static and dynamic balance in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *51*, 3180-3186. https://doi.org/10.1007/s10803-020-04785-w

Araujo, M. O., Tamplain, P., Duarte, N. A., Comodo, A. C., Ferreira, G. O., Queiróga, A., Oliveira, C. S., & Collange-Grecco, L. A. (2023). Transcranial direct current stimulation to facilitate neurofunctional rehabilitation in children with autism spectrum disorder: a protocol for a randomized, sham-controlled, double-blind clinical trial. *Frontiers in Neurology*, *14*, 1196585. https://doi.org/10.3389/fneur.2023.1196585

Arzoglou, D., Tsimaras, V., Kotsikas, G., Fotiadou, E., Sidiropoulou, M., Proios, M., & Bassa, E. (2013). The effect of [alpha] traditional dance training program on neuromuscular coordination of individuals with autism. *Journal of Physical Education and Sport*, *13*(4), 563. https://www.researchgate.net/publication/259459570_The_effect_of_a_tradinional_dance_training_program_on_neuromuscular_coordination_of_individuals_with_autism

Bayatpour, M., Shojaei, M., & Kashi, A. (2019). Perceived Motor Competence in 9-10 old Years Boys with Developmental Coordination Disorder: Comparison the Effect of Selected Physical, Metal and Compound Training. https://www.researchgate.net/publication/351711213_Perceived_Motor_Competence_in_9-10_old_Years_Boys_with_Developmental_Coordination_Disorder_Comparison_the_Effect_of_Selected_Physical_Metal_and_Compound_Training

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518

Bo, J., Acluche, F., Lasutschinkow, P. C., Augustiniak, A., Ditchfield, N., & Lajiness-O'Neill, R. (2022). Motor networks in children with autism spectrum disorder: a systematic review on EEG studies. *Experimental Brain Research*, *240*(12), 3073-3087. https://doi.org/10.1007/s00221-022-06483-8
Bojanek, E. K., Wang, Z., White, S. P., & Mosconi, M. W. (2020). Postural control processes during standing and step initiation in autism spectrum disorder. *Journal of Neurodevelopmental Disorders*, *12*, 1-13. https://doi.org/10.1186/s11689-019-9305-x
Bregnard, T. (2022). *The Connection Between Structural Zinc Coordination and Protein Function: PML and UBE3A* University of Connecticut]. https://ctda-dev1-lib.grove.ad.uconn.edu/node/3160373
Casey, A. F., Quenneville-Himbeault, G., Normore, A., Davis, H., & Martell, S. G. (2015). A therapeutic skating intervention for children with autism spectrum disorder. *Pediatric Physical Therapy*, *27*(2), 170-177. https://doi.org/10.1097/PEP.0000000000000139
Charman, T., Pickles, A., Simonoff, E., Chandler, S., Loucas, T., & Baird, G. (2011). IQ in children with autism spectrum disorders: data from the Special Needs and Autism Project (SNAP). *Psychological medicine*, *41*(3), 619-627. https://doi.org/10.1017/S0033291710000991
Cheung, W. C. (2020). *A longitudinal analysis of the relations between social, communication, and motor skills among students with autism* University of Illinois at Urbana-Champaign]. https://pubmed.ncbi.nlm.nih.gov/34677754/
Dana, A., Hamzeh Sabzi, A., & Christodoulides, E. (2019). The effect of virtual reality exercises on dynamic balance of children with developmental coordination disorder. *Journal of Humanities Insights*, *3*(03), 123-128. https://www.researchgate.net/publication/382798844_Effects_of_Attentional_Focus_on_Learning_a_Balance_Task_among_Children_with_DCD
Date, S., Munn, E., & Frey, G. C. (2024). Postural balance control interventions in autism spectrum disorder (ASD): A systematic review. *Gait & Posture*. https://doi.org/10.1016/j.gaitpost.2024.01.034
de Moura, M. C. D. S., Hazime, F. A., Marotti Aparicio, L. V., Grecco, L. A., Brunoni, A. R., & Hasue, R. H. (2019). Effects of transcranial direct current stimulation (tDCS) on balance improvement: a systematic review and meta-analysis. *Somatosensory & motor research*, *36*(2), 122-135. https://doi.org/10.1080/08990220.2019.1624517
Djordjević, M., Memisevic, H., Potic, S., & Djuric, U. (2022). Exercise-based interventions aimed at improving balance in children with autism spectrum disorder: a meta-analysis. *Perceptual and Motor Skills*, *129*(1), 90-119. https://doi.org/10.1177/00315125211060231
Doumas, M., McKenna, R., & Murphy, B. (2016). Postural control deficits in autism spectrum disorder: the role of sensory integration. *Journal of Autism and Developmental Disorders*, *46*, 853-861. https://doi.org/10.1007/s10803-015-2621-4
Duarte, N. d. A. C., Grecco, L. A. C., Galli, M., Fregni, F., & Oliveira, C. S. (2014). Effect of transcranial direct-current stimulation combined with treadmill training on balance and functional performance in children with cerebral palsy: a double-blind randomized controlled trial. *PLoS One*, *9*(8), e105777. https://doi.org/10.1371/journal.pone.0105777
Ghobadi, N., Ghadiri, F., Yaali, R., & Movahedi, A. (2019). The effect of active video game (Xbox Kinect) on static and dynamic balance in children with autism spectrum disorders. *Journal of Research in Rehabilitation Sciences*, *15*(1), 13-19. https://www.researchgate.net/publication/343775114_The_Effect_of_Active_Video_Game_Xbox_Kinect_on_Static_and_Dynamic_Balance_in_Children_with_Autism_Spectrum_Disorders
Hariri, R., Nakhostin-Ansari, A., Mohammadi, F., Memari, A. H., Oskouie, I. M., & Haghparast, A. (2022). An overview of the available intervention strategies for postural balance control in individuals with autism spectrum disorder. *Autism Research and Treatment*, *2022*(1), 3639352. https://doi.org/10.1155/2022/3639352
Hayakawa, K., & Kobayashi, K. (2011). Physical and motor skill training for children with intellectual disabilities. *Perceptual and Motor Skills*, *112*(2), 573-580. https://doi.org/10.2466/06.13.15.PMS.112.2.573-580
Hocking, D. R., Ardalan, A., Abu-Rayya, H. M., Farhat, H., Andoni, A., Lenroot, R., & Kachnowski, S. (2022). Feasibility of a virtual reality-based exercise intervention and low-cost motion tracking method for estimation of motor proficiency in youth with autism spectrum disorder. *Journal of NeuroEngineering and Rehabilitation*, *19*(1), 1. https://doi.org/10.1186/s12984-021-00978-1 10.1186/s12984-022-01039-x
Jansiewicz, E. M., Goldberg, M. C., Newschaffer, C. J., Denckla, M. B., Landa, R., & Mostofsky, S. H. (2006). Motor signs distinguish children with high functioning autism and Asperger's syndrome from controls. *Journal of Autism and Developmental Disorders*, *36*, 613-621. https://doi.org/10.1007/s10803-006-0109-y
Jelsma, D., Geuze, R. H., Mombarg, R., & Smits-Engelsman, B. C. (2014). The impact of Wii Fit intervention on dynamic balance control in children with probable Developmental Coordination Disorder and balance problems. *Human Movement Science*, *33*, 404-418. https://doi.org/10.1016/j.humov.2013.12.007
Kang, J., Li, Y., Lv, S., Hao, P., & Li, X. (2024). Effects of transcranial direct current stimulation on brain activity and cortical functional connectivity in children with autism spectrum disorders. *Frontiers in Psychiatry*, *15*, 1407267. https://doi.org/10.3389/fpsyt.2024.1407267
Kavyani Boroujeni, M., Karimi, M. T., & Akbari-Aghdam, H. (2023). Evaluation of Static and Dynamic Stability and Its Relationship With Fear of Falling in Patients With Mild to Moderate Knee Osteoarthritis. *Archives of Rehabilitation*, *24*(1), 76-95. https://doi.org/10.32598/RJ.24.1.3482.1
Lee, C. H., & Sun, T. L. (2018). Evaluation of postural stability based on a force plate and inertial sensor during static balance measurements. *Journal of Physiological Anthropology*, *37*, 1-16. https://doi.org/10.1186/s40101-018-0187-5
Lengkana, A. S., Rahman, A. A., Alif, M. N., Mulya, G., Priana, A., & Hermawan, D. B. (2020). Static and dynamic balance learning in primary school students. *International Journal of Human Movement and Sports Sciences*, *8*(6), 469-476. https://doi.org/10.13189/saj.2020.080620
Lidstone, D. E., Miah, F. Z., Poston, B., Beasley, J. F., & Dufek, J. S. (2020). Examining the specificity of postural control deficits in children with Autism Spectrum Disorder using a cross-syndrome approach. *Research in Autism Spectrum Disorders*, *72*, 101514. https://doi.org/10.1016/j.rasd.2020.101514 10.1016/j.rasd.2020.101546
Lim, Y. H., Lee, H. C., Falkmer, T., Allison, G. T., Tan, T., Lee, W. L., & Morris, S. L. (2018). Effect of optic flow on postural control in children and adults with autism spectrum disorder. *Neuroscience*, *393*, 138-149. https://doi.org/10.1016/j.neuroscience.2018.09.047
Maenner, M. J. (2023). Prevalence and characteristics of autism spectrum disorder among children aged 8 years-Autism and Developmental Disabilities Monitoring Network, 11 sites,

United States, 2020. *MMWR. Surveillance summaries*, *72*. https://doi.org/10.15585/mmwr.ss7202a1

Mahajan, R., Dirlikov, B., Crocetti, D., & Mostofsky, S. H. (2016). Motor circuit anatomy in children with autism spectrum disorder with or without attention deficit hyperactivity disorder. *Autism Research*, *9*(1), 67-81. https://doi.org/10.1002/aur.1497

Mahmoodifar, E., & Sotoodeh, M. S. (2020). Combined transcranial direct current stimulation and selective motor training enhances balance in children with autism spectrum disorder. *Perceptual and Motor Skills*, *127*(1), 113-125. https://doi.org/10.1177/0031512519888072

Minhas, P., Bikson, M., Woods, A. J., Rosen, A. R., & Kessler, S. K. (2012). Transcranial direct current stimulation in pediatric brain: a computational modeling study.

Minshew, N. J., Sung, K., Jones, B. L., & Furman, J. M. (2004). Underdevelopment of the postural control system in autism. *Neurology*, *63*(11), 2056-2061. https://doi.org/10.1212/01.WNL.0000145771.98657.62

Mnejja, K., García-Soidan, J. L., Romo-Perez, V., & Sahli, S. (2023). Postural balance under sensory manipulation predicted fine and gross motor skills in children from 5 to 6 years of age. *Acta Paediatrica*, *112*(7), 1524-1529. https://doi.org/10.1111/apa.16776

Moradi, H., & Movahedi, A. (2019). Effect of environment enrichment (SPARK perceptual-motor exercises) on the improvement of neurocognitive functions in children with developmental coordination disorder. *The Neuroscience Journal of Shefaye Khatam*, *7*(3), 23-31. https://doi.org/10.29252/shefa.7.3.23

Morris, P. O., Hope, E., & Mills, J. P. (2022). The non-fitness-related benefits of exergames for young individuals diagnosed with autism spectrum disorder: A systematic review. *Research in Autism Spectrum Disorders*, *94*, 101953. https://doi.org/10.1016/j.rasd.2022.101953

Mousavi Sadati, s. k., & Rashidzadeh, p. (2020). Effect of Cerebellar Transcranial Direct Current Stimulation on Balance and Sensory System of the Elderly. *Scientific Journal of Rehabilitation Medicine*, *8*(4), 195-205. https://medrehab.sbmu.ac.ir/article_1100837_e84d9541fbbe2d1f5a1783d9ff44576e.pdf

Pérez, V. S. C., Haas, A. N., & Wolff, S. S. (2014). Analysis of activities in the daily lives of older adults exposed to the Pilates Method. *Journal of bodywork and movement therapies*, *18*(3), 326-331. https://doi.org/10.1016/j.jbmt.2013.10.004

Philip, R. C., Dauvermann, M. R., Whalley, H. C., Baynham, K., Lawrie, S. M., & Stanfield, A. C. (2012). A systematic review and meta-analysis of the fMRI investigation of autism spectrum disorders. *Neuroscience & Biobehavioral Reviews*, *36*(2), 901-942. https://doi.org/10.1016/j.neubiorev.2011.10.008

Poortvliet, P., Hsieh, B., Cresswell, A., Au, J., & Meinzer, M. (2018). Cerebellar transcranial direct current stimulation improves adaptive postural control. *Clinical Neurophysiology*, *129*(1), 33-41. https://doi.org/10.1016/j.clinph.2017.09.118

Rezaei, S., Arabameri, E., & Sohrabi Sohrabi, M. (2016). Examination of the impact of an eight-week exclusive exercise on the balance of children with developmental coordination disorders. *Rehabilitation Medicine*, *5*(4), 57-64. https://medrehab.sbmu.ac.ir/article_1100280.html?lang=en

Sarabzadeh, M., Azari, B. B., & Helalizadeh, M. (2019). The effect of six weeks of Tai Chi Chuan training on the motor skills of children with Autism Spectrum Disorder. *Journal of bodywork and movement therapies*, *23*(2), 284-290. https://doi.org/10.1016/j.jbmt.2019.01.007

Satvati, B., Karimi, M. T., Tahmasebi Boldaji, R., & F, P. (2013). Standing stability evaluation in subjects with flat foot. *J Res Rehabil*, *8*(8), 1277-1284. https://jrrs.mui.ac.ir/article_16649_d24de89dae9bce2197bff7397f723b27.pdf

Stagg, C. J., & Nitsche, M. A. (2011). Physiological basis of transcranial direct current stimulation. *The Neuroscientist*, *17*(1), 37-53. https://doi.org/10.1177/1073858410386614

Taheri, E. (2009). *Effect of two months pilates exercises on lumbar lordosis in 15-18 years old girl students in Birjand* Birjand University]. https://journals.indexcopernicus.com/publication/2576576

Vernazza-Martin, S., Martin, N., Vernazza, A., Lepellec-Muller, A., Rufo, M., Massion, J., & Assaiante, C. (2005). Goal directed locomotion and balance control in autistic children. *Journal of Autism and Developmental Disorders*, *35*, 91-102. https://doi.org/10.1007/s10803-004-1037-3

Wikstrom, E. A., Tillman, M. D., Smith, A. N., & Borsa, P. A. (2005). A new force-plate technology measure of dynamic postural stability: the dynamic postural stability index. *Journal of Athletic Training*, *40*(4), 305. https://www.researchgate.net/publication/7368424_A_New_Force-Plate_Technology_Measure_of_Dynamic_Postural_Stability_The_Dynamic_Postural_Stability_Index

JARAC Assessment and Research in Applied Counseling
E-ISSN: 3041-8518