SPORMETRE
The Journal of Physical Education and Sport Sciences
Beden Eğitimi ve Spor Bilimleri Dergisi

DOI: 10.33689/spormetre.1676676
Research Article

Geliş Tarihi (Received): 23.04.2025 Kabul Tarihi (Accepted): 07.07.2025 Online Yayın Tarihi (Published): 30.09.2025

EFFECT OF PHYSICAL ACTIVITY INTERVENTION ON COGNITIVE DEVELOPMENT IN AUTISM SPECTRUM DISORDER*

Sevim Akşit[1†], Bülent Ağbuğa[2]
[1] Düzce University, Faculty of Sports Sciences, Düzce, Türkiye
[2] Pamukkale University, Faculty of Sports Sciences, Denizli, Türkiye

Abstract: Electroencephalography (EEG) signals are frequently used in mental workload assessments. Therefore, spectral analysis in Autism Spectrum Disorder (ASD) is considered necessary to shed light on the aetiology, to develop intervention programs to reduce symptoms, to determine the effects of these methods, and to understand the development of neuronal activity. The aim of this study was to examine the effects of physical activity based on a differential learning approach on brain activation, autism symptoms and repetitive behavioral changes in children with ASD. In the study, a pre-test and post-test design with a control group from quantitative and experimental research designs was used. 21 children with ASD were included in the study by criterion sampling method. Data were collected with EEG, Gilliam Autistic Disorder Rating Scale-2 and Repetitive Behaviors Scale-Revised-Turkish Version. The results of the study show that the intervention decreased the severity of repetitive compulsive behaviors and significantly improved social interaction in children with ASD. In addition, EEG findings revealed neurophysiological changes, including increased theta and gamma band power in the frontal region, decreased low alpha band power in the parieto-occipital region and increased gamma band power in the midline.

Keywords: Physical activity, autism spectrum disorder, differential learning approach, EEG, cognitive development

OTİZM SPEKTRUM BOZUKLUĞUNDA FİZİKSEL AKTİVİTE MÜDAHALESİNİN BİLİŞSEL GELİŞİM ÜZERİNDEKİ ETKİSİ

Öz: Elektroensefalografi (EEG) sinyalleri, zihinsel iş yükü değerlendirmelerinde sıklıkla kullanılmaktadır. Otizm Spektrum Bozukluğu (OSB) alanında spektral analizler, etiyolojiye ışık tutmak, semptomları azaltmak amacıyla müdahale programları geliştirmek, bu yöntemlerin etkilerini belirlemek ve nöral aktivitenin değişimini anlamak için önemlidir. Bu çalışmanın amacı, farklılıkla öğrenme yaklaşımı temelli fiziksel aktivite müdahalesinin OSB'li çocuklarda beyin aktivasyonu, semptomları ve tekrarlayan davranışlardaki değişiklikler üzerindeki etkisini incelemektir. Çalışmada, nicel ve deneysel araştırma tasarımlarından kontrol grublu ön ve son test tasarımı kullanılmıştır. OSB tanısı almış 21 çocuk, ölçüt örnekleme yöntemiyle çalışmaya dahil edilmiştir. Veriler EEG, Gilliam Otistik Bozukluk Derecelendirme Ölçeği-2 ve Tekrarlayıcı Davranışlar Ölçeği-Revize-Türkçe Versiyonu ile toplanmıştır. Çalışma sonuçları, müdahalenin OSB'li çocuklarda tekrarlayan kompulsif davranışların şiddetini azalttığını, sosyal etkileşimi anlamlı düzeyde geliştirdiğini göstermektedir. Ayrıca EEG bulguları, frontal bölgede teta ve gama bant güçlerinde artış, parieto-oksipital bölgede düşük alfa bant gücünde azalma ve orta hatta yer alan gama bant gücünde artış olmak üzere, nörofizyolojik değişiklikler olduğunu ortaya koymuştur.

Anahtar Kelimeler: Fiziksel aktivite, otizm spektrum bozukluğu, farklılıkla öğrenme yaklaşımı, EEG, bilişsel gelişim

---

* *This article is derived from the doctoral dissertation titled "Effects of Physical Activity Intervention on Brain and Cognitive Development in Children Diagnosed with Autism Spectrum Disorder: An EEG Study," prepared by Sevim Akşit under the supervision of Prof. Dr. Bülent Ağbuğa at Pamukkale University. The dissertation was also presented as an oral presentation at the 21st Sports Sciences Congress held in Antalya, Türkiye.*

† *Corresponding: Sevim Akşit, Asst. Prof. Dr., E-mail: sevim.askim@gmail.com*

INTRODUCTION

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder characterized by high heterogeneity. The pathophysiology of ASD is complex, and its exact cause is not understood, but neuronal differences in ASD are thought to affect brain structure and function. Neuroimaging studies have revealed excessive connections in some brain areas and inadequate connections in other regions. Additionally, a pattern shows that brain volume tends to overgrow (Kim et al., 2021; Zhao et al., 2022). While individuals with ASD experience repetitive behaviours, there may be delays in the development of many essential functions, such as social interaction and communication (Lord et al., 2018). The literature reports that 0.6% of people worldwide have ASD (Salari et al., 2022). This situation has increased the demand among professionals for behavioural and educational interventions aimed at reducing or managing the core symptoms of ASD (Höfer et al., 2019).

It has been stated that physical exercise improves social communication, cognitive and psychological functions, and quality of life (Akşit and Yılmaz, 2024; Shahane et al., 2024; Yano and Hosokawa, 2023). Neuroscience research shows that physical activity can affect the brain and cognition (Stillman et al., 2020). However, research on the effect of exercise on cognitive processes in individuals with ASD is limited (Liang et al., 2022). Interventions targeting the underlying neural mechanisms that govern core autistic symptoms are needed (Gandhi and Lee, 2021). For this reason, a limited number of studies in this field provide findings that may serve as biomarkers in ASD, and these studies use tools that measure brain activity such as Electroencephalography (EEG) (McVoy et al., 2019).

Electroencephalography (EEG), which enables the examination of brain activation (Wantzen et al., 2022), is widely used to evaluate the effectiveness of interventions due to its high sensitivity in detecting changes in cognitive workload and brain functions (Duru, 2019). EEG studies conducted with individuals with ASD have shown increased alpha frequency during rest, accompanied by decreased activity in regions such as the precuneus, posterior cingulate cortex, and medial frontal gyrus (Wantzen et al., 2022). Alpha activity is considered an important neuromarker for cognitive processes (Dickinson et al., 2018) and has been shown to be modifiable through psychological interventions (Enriquez-Geppert et al., 2017). Furthermore, increased gamma oscillations at rest have been associated with ASD, while neurofeedback interventions have been reported to reduce the theta/beta ratio and enhance gamma frequency (Van Diessen et al., 2015; Wang et al., 2016). A study on Chinese mind-body exercises found high theta coherence between the posterior and anterior brain regions, which was linked to improved memory. These findings highlight the interaction among various brain regions involved in memory processes (Chan et al., 2015). In conclusion, gamma, alpha, and theta activities are key indicators for neuroscientifically evaluating the effects of interventions on brain functions and behavioral patterns. In this context, high-sensitivity neuroimaging methods such as EEG can serve as important tools for evaluating the effects of physical activity-based interventions on brain function in individuals with ASD. Neuroscientific indicators—particularly gamma, alpha, and theta activities may offer valuable insights into the potential therapeutic effects of differential learning approach-based physical activities on brain activation and behavioral symptoms.

For this reason, it aims to determine the effect of the intervention on specific behavioural symptoms, such as repetitive behaviours in ASD, along with the change in brain activation. Studies have suggested that learning with different approaches can support cognitive development (for example, Sert, 2020). Learning according to the learning with difference approach occurs by taking advantage of repeated movements and variations without corrections during the skill acquisition process (Schöllhorn et al., 2012). For this reason, it has been argued that sudden changes in the brain can make the learning process more effective (Schöllhorn, 1994, 2000). In the literature, it is stated that integrating cognitive-motor exercises (Zhang et al., 2023) and the learning approach with difference (Sert, 2020) into educational programs applied to 20 to 24 children with ASD has a positive effect on motor skills and learning. It has been concluded that cognitive features such as attention may contribute to developing cognitive features.

Therefore, this study aimed to investigate the effects of physical activity based on the learning with differences approach on brain and cognitive development in children with autism using EEG data. Brain activation will likely increase after differential learning approach-based physical activity, indicating that cognitive development is supported. However, improvements are expected in the repetitive behavioural symptoms of children with ASD. We also offer assessment and intervention recommendations for professionals working with children with ASD. The fact that no study has been found in the literature examining the neurological effects of physical activity based on a differentiated learning approach on autistic children increases the unique value of our study.

METHODS

Participants

A quantitative research method was used in this study, and its design was pre- and post-test with control group. The sample size for this study was calculated using the power analysis program G Power 3.1 (Faul et al., 2007) after a literature review (Choktanomsup et al., 2017). As a result of the power analysis, it was determined that the minimum required sample size was at least 10 participants, taking into account the t-test in independent groups for 95% statistical power (1-β) and (d = 2,460) effect size at the $\alpha = 0.05$ significance level. For this study, 112 children (Figure 1) with ASD enrolled in four different institutions were evaluated. After the eligibility assessment according to the criterion sampling method, 21 children were determined to be suitable. Accordingly, the participants were assigned to the experimental (n = 11) and control (n = 10) groups.

Figure 1 Determination stage of the sample group

Registration (n=112)
Eligible (n=53)

Exclusions
Does not meet inclusion criteria (n=5)
Health problem (n=4) — n=24
Transportation problem (n=10)
Refused EEG measurement (n=10)
Withdrawal from study (n=2) — n=22
Last EEG measurement could not be taken (n=1) — n=21

Inclusion criteria: a) having been diagnosed with ASD by a child psychiatrist, b) age (6-12), (Nekar et al., 2022; Macoun et al., 2021; Rafiei Milajerdi et al., 2021), c) Autistic Disorder Index Scores are 100 and below, d) physical and social fitness to do sports, e) absence of any neurological, physical, hearing or visual impairment, f) There is no history of other additional diagnoses. Since EEG measurements can be difficult for children under six years of age, the results of the literature review were taken into account (Rafiei Milajerdi et al., 2021), the age range for this study It is determined as 6-12. None of the participants took neurological medications or were subjected to additional psychological interventions during the study.

The demographic characteristics of the participants are as follows: Autistic index scores range from a minimum of 55 to a maximum of 96. The average age was calculated as 8.1 in the control group and 8.0 in the experimental group. The gender distribution of the control group was 80% male and 20% female; and the experimental group was 81.8% male and 18.2% female.

Measures

EEG Measurements

EEG measurements were performed in a quiet test room after 12:00 pm during the day. The children and their families received explicit instructions from the researcher, who also made sure there was no visual or auditory stimulation and no sleep deprivation. In addition, children were told to sit still, be quiet, and obey adults. The first preparation period of the participants for EEG recording varied between 40 minutes on average, the second preparation period ranged between 5-8 minutes, and the data recording time varied between 10-15 minutes. During this period, valid and reliable data was obtained for 5 minutes. Subjects were asked to close their eyes during the last 2 minutes of the data collection process, and no visual or auditory stimuli were used during the recording. We measured EEG from 27 different channels using the Neurovirtual-BWIII/EEG device with a sampling rate of 2048 Hz. 10-20 electrode placement points were used to place the electrodes on the participants' skulls. These data were filtered with a lowpass cutoff frequency of 80 Hz and a highpass filter with 0.1 Hz cutoff frequency. Furthermore, a 50 Hz notch filter is used. Throughout the measurements, every impedance was maintained at or below 5 kΩ. The left earlobe was connected to a ground electrode, and the right earlobe to a reference electrode. These preprocessed data were then examined in detail using BW analysis. We marked the artifacts manually and removed them from further analysis. We marked the epochs whose absolute amplitudes values are greater than 150 μV and a gradient threshold value of 50 μV were used for artifact identification. 18 electrodes for analysis; frontal - Frontal(F), (Fp1, Fp2, F7, Fz, F4 and F8), midline (Fz, Cz, Pz), left centro-parietal (LCP), (C3, P3), right centro It is divided into 5 regions: parietal (RCP), (C4, P4) and parieto-occipital (PO) (P3, P4, Pz, O1 and O2).

In this study, beta, delta, theta, gamma and alpha band power values of EEG data were calculated. Spectral features were calculated separately for each electrode and averaged spatially. For this purpose, 1-second time windows were applied to the EEG. The period signal was assumed to be quasi-stationary over this time length (Blanco et al., 1995), which allowed us to calculate the power spectrum by applying the Fourier Transform (FFT) to each period window. Since band power distribution may vary depending on the frequency bands of individuals, we normalized frequency spectrum based on its total value for each individual. Finallly, we achieved spatially normalized unitless power spectral values of each frequency band.

Gilliam Autistic Disorder Rating Scale-2 (TV-GARS-2)

TV-GARS-2 scale, which evaluates ASD symptoms and autistic disorder in individuals with ASD between the ages of 3-23, consists of 42 items. In addition to the total score, TV-GARS-2 can also produce scores for its three subscales (stereotypic behaviors, social interaction, and communication). The scale is scored on a four-point scale. While the scale's total score is converted into standard scores and gives an Autism Disorder Index score, a higher total score indicates that the child is more likely to have ASD. According to reports, the scale has good internal consistency; its internal consistency coefficients range from.77 to.85 (Diken et al., 2012; Gilliam, 1995, 2005). The Turkish version (Diken et al., 2012) was used in the current study. Total raw score and subscale scores were used to compare differences between pre-and post-intervention assessments. An expert applied the scale.

Repetitive Behavior Scale-Revised-Turkish Version (RBS-R-TV)

The RBS-R-TV scale, which evaluates the severity of repetitive behaviors and the severity of the disorder in individuals with ASD, consists of 43 items. In addition to the total score, RBS-R-TV can also produce scores for its six subscales (stereotypic behaviors, self-destructive behaviors, compulsive behaviors, ritual behaviors, sameness/ uniformity behaviors, and limited behaviors). The scale is scored on a four-point scale. The high total score on the scale indicates the seriousness of the child's daily life and social difficulties. The scale has been reported to have excellent reliability ($\alpha = 0.97$) (Ökcün-Akçamuş et al., 2019). In the current study, the Turkish version was used. Comparisons of the pre- and post-intervention (Figure 2) assessment differences were made using the total raw score and subscale scores.

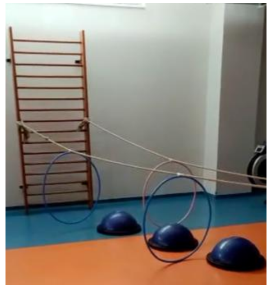
Statistical Analysis

SPSS 27 program was used to examine the intervention's neural and repetitive behavioral effects. Dependent variables for neural data are alpha, gamma, theta, beta, and delta band powers. The scores on the scales represent the dependent variable for repetitive behavioral data. First, the power spectrum was calculated using FFT for EEG to determine the intervention program's effects. Secondly, to evaluate the statistical difference between the dependent variables before and after the intervention, t-tests were applied in dependent groups within the group, and t-tests were applied in independent groups between the groups. Within-group effect sizes (t-tests in dependent groups) were determined using Cohen's d. Access scores for the effect size of differences between groups (t-tests in independent groups) were calculated and determined using Cohen's d.

Intervention Program

Differential approach-based physical activity intervention is based on a differentiated learning approach that supports the child's creativity potential and cognitive development. The program was structured with support from a special education expert and the literature (Cai et al., 2020; Rafiei Milajerdi et al., 2021; Nekar et al., 2022; Strofylla et al., 2021; Wang et al., 2020). The intervention was implemented for 14 weeks, 180 minutes per week. Two independent volunteer trainers implemented the intervention program. The first volunteer educator has 15 years of experience with individuals with ASD, and the second has 10 years of experience. Before the intervention, volunteer educators were given training on the intervention program. Additionally, observation reports were kept by the researcher during the application sessions. The researcher and the participants' families accompanied each intervention session (Figure 2).

Figure 2 Intervention Program

Development Dimension	Exercise	Aim	
Physical and Cognitive Development 	One-handed and two-handed ball bouncing, one-handed diagonal ball bounce, Two-handed – alternating ball bouncing, Accurate shooting and hitting	Hand-eye coordination development, Development of visual perception and motor planning skills, Coordination skill development exercises for the skills needed in the physical development dimension are applied in the form of a track or in a harmonious program within the session	
	Playgrounds and simple sports games, Games based on the use of tools and materials, Walking and running exercises	Gross motor skill development within the scope of basic motor skills sub-dimension	
	Matching colors game, carrying the ball in the hoop, fishing game	Basic motor skills sub-dimension development of fine motor skills	
	Soft and hard game, Light and heavy game	Development of sensory processing skills within the scope of sensory-motor skills sub-dimension	
	Swinging- Spinning, Game of jumping two feet in circles, standing / walking /running on balance material, balancing (balance bench, one foot on the floor, two feet with eyes closed)	Vestibular system development	
	Matching colors tracks, End of track puzzles	Development of visual perception processing skills	
Social and Cognitive Development 	Green light – red light, Pretend game, Adapted team games, Job sharing and rotation games, Communication with various team games, Creating games freely, Modified team games, Time-space games (Timed missions, Space shared missions), Games with materials of different weights and textures	Development of the skill of using visual signs within the scope of communication skills sub-dimension, Acquiring and developing collaboration skills within the scope of the empathy development skills sub-dimension, Supporting skills within the scope of creating and executing a goal-oriented plan, Development of sensory motor skills	

RESULTS

EEG measurement: Brain activation; neural effects

To determine the effect of the intervention program on the dependent variables (alpha, gamma, theta, beta, and delta band powers) for neural data, EEG band power differences between the pre-and post-tests were examined. When pre-and post-test scores were compared between groups, the Theta band power of the frontal region of children with ASD (t = 2.13, p < .05), low alpha band power of the upper middle and posterior regions (t = -2.15, p < .05), gamma-band power of the frontal region (t = - 2.27, p < .05), gamma-band power of the midline (t = -2.64, p < .05) scores. There was a significant increase in EEG theta, low alpha, and gamma band power in the experimental group after the intervention (p < .05) (Table 1, Figure 3, Figure 4).

Table 1. T-Test results in independent groups regarding EEG band power differences between FFT post-test and pre-test

Regional Band Power	Group	N	Mean Difference	SD	t	P
Theta Frontal Region	Control	10	0.00	0.03	2.13	**.045***
	Experiment	11	0.02	0.01		
Low Alpha Upper Mid and Back Region	Control	10	-0.01	0.02	-2.15	**.044***
	Experiment	11	0.02	0.05		
Gamma Frontal Region	Control	10	-0.02	0.02	-2.27	**.034***
	Experiment	11	0.01	0.04		
Gamma Midline	Control	10	-0.02	0.02	-2.64	**.016***
	Experiment	11	0.01	0.04		

***p<0.05**

Figure 3 Boxplot graphs of EEG post-test and pre-test scores in control and experimental groups

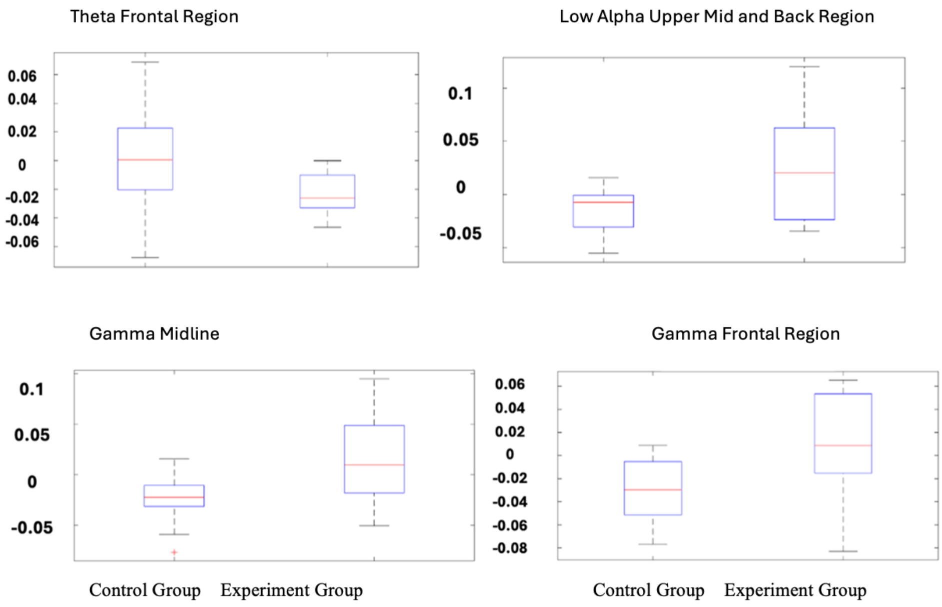
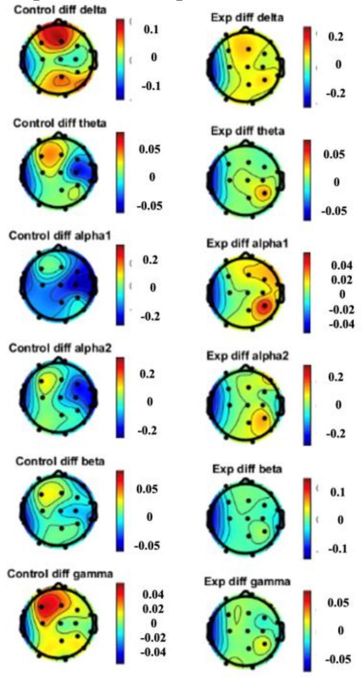


Figure 4 Topographies of EEG post-test and pre-test scores in control and experimental group



Repetitive Behavioral Measurements

Skewness (Control group: -.525 to .474, Experimental group: -.329 to .469) and kurtosis (Control group: -1.665 to 1.265, Experimental group: -1.011 to -334) of the data obtained from the TV-GARS-2 scale. 334) has a normal distribution according to its values (Garson, 2012). It was observed that there was no significant difference between the subscales and total scores of the TV-GARS-2 scale in the t-test findings in the dependent groups regarding the pre-and post-test of the control group ($p < .05$). However, in the t-test findings in the dependent groups regarding the pre-test and post-test of the experiment, communication ($t=2.82$, $p < .018$*), social interaction ($t=5.85$, $p < .000$*) and total scores of TV-GARS-2 ($t =4.58$, $p < .001$*), it was observed that there was a significant difference between. In the independent groups t-test findings regarding the pre-test of the Control and the Experimental Group, there was no significant difference between the subscales and total scores of the TV-GARS-2 scale ($p < .05$), but when the post-test scores of the Control and the Experimental Group were compared; It was observed that there was a significant difference between social interaction ($t = 2.40$, $p < . 05$) and total scores of the TV-GARS-2 scale ($t = 2.28$, $p < .05$) (Table 2).

Table 2. Independent group t-test results for control and experimental groups for TV-GARS-2 sub-dimensions post-test scores

	Group	N	Mean	SD	t	P
Stereotypic Behavior	Control	10	17.60	7.19	1.66	.114
	Experiment	11	12.18	7.74		
Communication	Control	10	20.20	8.41	1.30	.203
	Experiment	11	15.73	7.12		
Social Interaction	Control	10	20.00	7.11	2.40	**.028***
	Experiment	11	12.00	8.14		
TV-GARS-2	Control	10	57.80	17.90	2.28	**.034***
	Experiment	11	39.91	18.02		

***p< 0.05**

The data obtained from the RBS-R-TV scale are normal according to the skewness (Control Group: -1021 to 1.553, Experimental Group: -1.021 to 1.969) and kurtosis (Control Group: -1.744 to 1.400, Experimental Group: -1.655 to 1.279) values. It can be said that it shows a distribution (Garson, 2012). According to the t-test findings in the dependent groups regarding the RBS-R-TV pre-and post-test, there was a significant difference between the limited behaviors scores ($t = 2.6$, $p < .05$) in the Control Group, but in the Experimental Group;

stereotypical behaviors (t= 4.18, p < .002*) self-destructive behaviors (t=2.76, p < .020*) compulsive behaviors (t=3.59, p < .05*) ritualistic behaviors (t=4.32, p < .002*), sameness/uniformity (t=3.20, p < .009*), limited behaviors (t=3.06, p < .012*) and total scores (t=4.92, p< .001*) has been seen. The results of the independent groups t-test for the pre-test of the RBS-R-TV Control and Experimental Group show that the sameness/uniformity behaviors sub-dimension pre-test scores differ significantly (t=2.54, p <.019*). When the post-test scores of the Control and Experimental Group were compared, there was a significant difference between compulsive behaviors (t=4.40, p < .05), sameness/uniformity behaviors (t=4.54, p < .05) and total scores (t=4.87, p < .05) (Table 3). However, within the scope of this research, the sameness/uniformity behaviors subscale was considered a limitation.

Table 3. Independent group t-test results for control and experimental groups for RBS-R-TV sub-dimensions post-test scores

	Group	N	Mean	SD	t	*P*
Stereotypic Behavior	Control	10	5.90	5.23	2.21	0.33
	Experiment	11	2.00	2.00		
Self- Destructive Behaviors	Control	10	3.60	3.56	2.61	0.13
	Experiment	11	54	1.03		
Compulsive Behaviors	Control	10	10.30	4.19	4.40	**.000***
	Experiment	11	2.90	3.41		
Ritual Behaviors	Control	10	8.60	3.83	2.33	0.32
	Experiment	11	4.36	4.47		
Sameness/Uniformity Behaviors	Control	10	12.10	5.17	4.54	**0.00***
	Experiment	11	3.63	2.94		
Limited Behaviors	Control	10	2.30	1.82	-37	.713
	Experiment	11	2.63	2.24		
RBS-R-TV	Control	10	43.00	13.43	4.87	**0.00***
	Experiment	11	16.09	11.70		

***p< 0.05**

Considering the within-group effect sizes TV-GARS-2 (d=.76) and RBS-R-TV (d=1.09) values in the Experimental Group, it was seen to have a large effect. On the other hand, in the Control Group, the within-group effect sizes TV-GARS-2 (d=.17), and RBS-R-TV (d=.41) values showed a small effect. It has a large effect between groups for TV-GARS-2 (d=.1.88) and RBS-R-TV (d=1.69). Effect size values for the theta frontal region (d=.71), low alpha upper middle and back region (d=.95), gamma frontal region (1.00), and gamma midline (d= 1.16) among the inter-group EEG Band Powers indicate a large effect (Cohen, 1988) (Table 4).

Table 4. Intra-group and inter-group effect sizes (Cohen's d)

		Repetitive Behavioral Measurements			**EEG measurement**		
			Intra-Group	**Inter-Group**		**Inter-Group**	
TV-GARS-2	Total scores	Experiment	0.76	1.88	**EEG**	Theta Frontal Region	-0.71
		Control	0.17			Low Alpha Upper Mid and Back Region	-0.95
RBS-R-TV	Total scores	Experiment	1.09	1.69		Gamma Frontal Region	-1.00
		Control	0.41			Gamma Midline	1.16

DISCUSSION AND CONCLUSION

This study was designed using a pre-test–post-test control group model to evaluate the effect of a physical activity intervention program based on a differentiated learning approach for individuals with ASD. EEG and effect size results revealed that, under resting conditions, the Experimental Group exhibited low alpha power in the upper-middle and posterior regions, a significant increase in gamma and theta power in the frontal region, and a notable increase in midline gamma power. These changes suggest that the intervention positively influenced brain activities related to memory, sensory processing, creativity, behavioral flexibility, insight, visualization, problem solving, and the perception of visual and other bodily stimuli, thereby enhancing attention. The strong effect of the intervention on these brain regions aligns with previous studies highlighting the functional importance of alpha oscillations (Chan and Ouyang, 2024; Comsa et al., 2019; Magosso et al., 2019). Furthermore, the increases in theta and gamma activity in the frontal region reflect neural activations associated with attention and cognitive control processes. High gamma frequencies have also been linked to autistic traits, possibly due to increased neural inhibition and enhanced visual discrimination abilities in individuals with ASD (Dickinson et al., 2015). In this context, the EEG findings support the conclusion that the intervention is effective not only behaviorally but also at the neurobiological level.

The analysis of Repetitive Behavior Measurements and effect sizes revealed a significant difference between the post-test scores of the Control and Experimental Groups on the TV-GARS-2 scale and in overall social interaction. Additionally, significant differences were found in the total scores of compulsive behaviors and the RBS-R-TV scale. Children in the Experimental Group demonstrated lower levels of ASD-related symptoms and reduced severity of repetitive behaviors. This shows that the intervention has positive effects at the behavioral level and is consistent with previous studies on children with ASD (Colcombe and Kramer, 2003; Sert, 2020; Stillman et al., 2020; Zhang et al., 2023). In addition, EEG and effect size results also support these findings.

Previous studies have shown that physical activity supports social, sensory, motor, and cognitive development, and this has been associated with increased theta, gamma, and alpha power (Canolty et al., 2006; Foxe and Snyder, 2011; Knyazev, 2007; Sharma and Singh, 2015). In individuals with ASD, findings regarding brain activation suggest that the relationship between EEG power and the severity of repetitive behaviors is particularly linked to the alpha band (Carter Leno et al., 2018). Furthermore, increased gamma activity has been strongly associated with selective attention and working memory (Jensen et al., 2007; Ray et al., 2008). Gamma oscillations are involved in sensorimotor integration, perceptual binding, and cognitive functions (Buzsáki and Wang, 2012), which may contribute to reductions in repetitive behaviors in individuals with ASD (Casanova et al., 2021). Theta activity also plays a key role in cognitive processing (Kitaura et al., 2017), with increased theta in the frontal regions being associated with executive functions (Jensen and Tesche, 2002). Moreover, the interplay between theta and gamma frequencies has been shown to enhance working memory capacity, supporting successful memory recall and motor learning (Guerra et al., 2018; Lisman and Buzsáki, 2008; Lisman and Jensen, 2013). Therefore, increasing theta and gamma power may support cognitive functioning and contribute to a decrease in repetitive behaviors in individuals with autism.

However, findings regarding electrophysiological spectrum analysis in individuals with ASD remain inconsistent. Discoordination between neurons has been associated with abnormal gamma band activity (Casanova et al., 2021). While increased resting-state gamma activity has been reported in individuals with ASD, a reduction in gamma responses during visual tasks has also been observed (Orekhova et al., 2007; Snijders et al., 2013; Van Diessen et al., 2015). These discrepancies may be influenced by age and developmental factors. Moreover, reduced theta band activity and lower frontal perfusion patterns have been reported in individuals with ASD compared to typically developing children (Chan et al., 2007; Wang et al., 2016). A linear decrease in the theta/beta ratio was also observed during neurofeedback sessions (Wang et al., 2016). According to some researchers, these variations in brain wave activity may underlie attention deficits, heightened anxiety, and social behavior problems commonly seen in ASD (Fauzan and Amran, 2015).

According to the results of this study, a significant increase in gamma and theta power in the frontal regions and in gamma power at the midline was observed. This increase is thought to be due to theta and gamma frequency oscillations occurring in the same brain regions and interacting through a process known as cross-frequency coupling. This interaction may be related to the memory states of the oscillations, memory performance, and the effects of disruptive oscillations on memory. Cognitive studies show a strong connection between theta-gamma oscillations and recalled memories (Lisman and Jensen, 2013). It is also suggested that this interaction may be due to the significant interactions between the phase-amplitude parameters of alpha, theta, and gamma band power (Canolty et al., 2006).

Limitations

Although this study provides evidence supporting the neural effectiveness of the intervention program, several limitations must be acknowledged. First, while increased alpha power was associated with reduced anxiety levels, the Experimental Group also showed increases in both gamma and theta power. However, it remains unclear whether these changes are directly related to improvements in autism symptoms, particularly in relation to theta band activity. Further research is required to clarify these associations. Second, due to difficulties in accessing the sample group, a pre-test/post-test control group design was employed, which may limit the generalizability of the findings. Third, the exclusion of typically developing children limited the ability to interpret the effectiveness of the intervention within a broader developmental context. Fourth, although participants' autistic index scores were evaluated prior to the intervention, a significant difference was observed in the sameness/monotony behavior variable between the Experimental and Control Groups at the pre-test stage. No significant change was found in this variable in the Control Group between pre- and post-tests. However, a significant improvement was observed in the Experimental Group, suggesting that the intervention and/or special education may have influenced these scores. Nevertheless, sameness/monotony behavior is a common symptom in individuals with ASD and may manifest differently across individuals. In some cases, interventions targeting this behavior may trigger aggressive responses or temper tantrums. Therefore, the reduction in sameness/monotony scores in both groups highlights the potential impact of the intervention and/or concurrent educational programs. However, the variability of this symptom across individuals is acknowledged as a limitation in this study.

Conclusions

This study examined the neural effects of a physical activity intervention grounded in the differential learning approach in children with ASD, with a particular focus on changes in repetitive behaviors. The findings reveal that the intervention led to significant improvements in behavioral outcomes, accompanied by increased low alpha, theta, and gamma frequency activity in various brain regions. These results suggest that physical activity interventions, particularly those based on the differential learning approach, can induce neurobiological changes and support developmental processes in children with ASD. Moreover, the study provides novel insights into the assessment of intervention outcomes by incorporating electrophysiological measures, offering an objective and quantifiable approach to evaluating program efficacy. These findings not only contribute to the growing body of evidence on the neural basis of behavioral improvements in ASD but also highlight potential directions for future research and the development of more targeted intervention strategies.

Ethical Approval

Before commencing measurements, the present study received ethical clearance from the Ethics Committee of Pamukkale University (Number: E-60116787-020-137615). In addition, written informed consent was obtained from the parents of all participants in the study in accordance with the requirements of the ethics committee.

Funding

The article derived from the doctoral thesis titled “Effects of Physical Activity Intervention on Brain and Cognitive Development in Children Diagnosed with Autism Spectrum Disorder: An EEG Study” was supported by Pamukkale University Scientific Research Projects Coordination Unit (Project Number: 2022EĞBE003).

Acknowledgements

I would like to sincerely thank Pamukkale University Scientific Research Projects Coordination Unit for their support. I would also like to express my sincere gratitude to Prof. Dr. Hakan Levent Gül from Medical Park Hospitals Group and Istanbul Rumeli University, and Prof. Dr. Adil Deniz Duru from Marmara University Faculty of Sports Sciences for their valuable contributions and continuous support during this process.

REFERENCES

Akşit, S., & Yılmaz, E. B. (2024). Egzersiz müdahalelerinin otizm spektrum bozukluğunda bilişsel sürece etkisi ile ilgili yapılmış çalışmaların sistematik derlemesi. *Akdeniz Spor Bilimleri Dergisi*, 7(1), 70-88. DOI: https://doi.org/10.38021asbid.1400492

Blanco, S., Garcia, H., Quiroga, R. Q., Romanelli, L., & Rosso, O. A. (1995). Stationarity of the EEG series. *IEEE Engineering in Medicine and Biology Magazine*, 14(4), 395-399. DOI: 10.1109/51.395321

Buzsáki, G., & Wang, X. J. (2012). Mechanisms of gamma oscillations. *Annual Review of Neuroscience*, 35, 203-225. DOI: 10.1146/annurev-neuro-062111-150444

Canolty, R. T., Edwards, E., Dalal, S. S., Soltani, M., Nagarajan, S. S., Kirsch, H. E., … & Knight, R. T. (2006). High gamma power is phase-locked to theta oscillations in human neocortex. *Science*, 313(5793), 1626–1628. https://doi.org/10.1126/science.1128115

Cai, K., Yu, Q., Herold, F., Liu, Z., Wang, J., Zhu, L., ve Zou, L. (2020). Mini-basketball training program improves social communication and white matter integrity in children with autism. *Brain Sciences*, 10(11), 803. DOI: 10.3390/brainsci10110803

Carter Leno, V., Tomlinson, S. B., Chang, S. A. A., Naples, A. J., & McPartland, J. C. (2018). Resting-state alpha power is selectively associated with autistic traits reflecting behavioral rigidity. *Scientific Reports*, 8(1), 11982. DOI: 10.1038/s41598-018-30445-2

Casanova, M. F., Shaban, M., Ghazal, M., El-Baz, A. S., Casanova, E. L., & Sokhadze, E. M. (2021). Ringing decay of gamma oscillations and transcranial magnetic stimulation therapy in autism spectrum disorder. *Applied Psychophysiology and Biofeedback*, 46, 161-173. DOI: 10.1007/s10484-021-09509-z

Chan, A. S., Han, Y. M., Sze, S. L., & Lau, E. M. (2015). Neuroenhancement of memory for children with autism by a mind–body exercise. *Frontiers in Psychology*, 6, 1893. https://doi.org/10.3389/fpsyg.2015.01893

Chan, A. S., Sze, S. L., & Cheung, M. C. (2007). Quantitative electroencephalographic profiles for children with autistic spectrum disorder. *Neuropsychology*, 21(1), 74–81. https://doi.org/10.1037/0894-4105.21.1.74. DOI: 10.1037/0894-4105.21.1.74

Chan, K. L. R., & Ouyang, G. (2024). Impact of child-centered play therapy intervention on children with autism reflected by brain EEG activity: A randomized controlled trial. *Research in Autism Spectrum Disorders*, 112, 102336. DOI: 10.1016/j.rasd.2024.102336

Choktanomsup, K., Charoenwat, W., & Sittiprapaporn, P. (2017). Changes of EEG power spectrum in moderate running exercises. In 2017 14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 9-12. EEE. DOI: 10.1109/ECTICon.2017.8096161

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences (2nd ed.).* Hillsdale, NJ: Lawrence Earlbaum Associates.

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science*, 14(2), 125-130. DOI: 10.1111/1467-9280.t01-1-01430

Comsa, I. M., Bekinschtein, T. A., & Chennu, S. (2019). Transient topographical dynamics of the electroencephalogram predict brain connectivity and behavioural responsiveness during drowsiness. *Brain Topography*, 32(2), 315–331. https://doi.org/10.1007/s10548-018-0689-9

Dickinson, A., DiStefano, C., Senturk, D., & Jeste, S. S. (2018). Peak alpha frequency is a neural marker of cognitive function across the autism spectrum. *European Journal of Neuroscience*, 47(6), 643–651. https://doi.org/10.1111/ejn.13645

Dickinson, A., Bruyns-Haylett, M., Jones, M., & Milne, E. (2015). Increased peak gamma frequency in individuals with higher levels of autistic traits. *European Journal of Neuroscience*, 41(8), 1095-1101. https://doi.org/10.1111/ejn.12881

Diken, İ. H., Ardıç, A., Diken, Ö., & Gilliam, J. E. (2012). Gilliam otistik bozukluk derecelendirme ölçeği-2 Türkçe versiyonu'nun (GOBDÖ-2-TV) geçerlik ve güvenirliğinin araştırılması: Türkiye standardizasyon çalışması. *Eğitim ve Bilim,* 37(166).

Duru, A.D. (2019). Determination of ıncreased mental workload condition from eeg by the use of classification techniques. *International Journal of Advances in Engineering and Pure Sciences*, 1, 47- 52. https://doi.org/10.7240/jeps.459420

Enriquez-Geppert, S., Huster, R. J., & Herrmann, C. S. (2017). EEG-neurofeedback as a tool to modulate cognition and behavior: *A review tutorial. Frontiers in Human Neuroscience*, 11, 51. https://doi.org/10.3389/fnhum.2017.00051

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175-191. doi: 10.3758/bf03193146.

Fauzan, N., & Amran, N. H. (2015). Brain waves and connectivity of autism spectrum disorders. *Procedia-Social and Behavioral Sciences*, 171, 882-890. doi: 10.1016/j.sbspro.2015.01.204

Foxe, J. J., & Snyder, A. C. (2011). The role of alpha-band brain oscillations as a sensory suppression mechanism during selective attention. *Frontiers in Psychology*, 2, 10747. https://doi.org/10.3389/fpsyg.2011.00154

Gandhi, T., & Lee, C. C. (2021). Neural mechanisms underlying repetitive behaviors in rodent models of autism spectrum disorders. *Frontiers in Cellular Neuroscience*, 14, 592710. https://doi.org/10.3389/fncel.2020.592710

Garson, G. D. (2012). *Testing statistical assumptions.* Statistical Associates Publishing.

Gilliam, J. E. (2005). *Gilliam autism rating scale (2nd ed.).* Pro-Ed.

Gilliam, J. E. (1995). *Gilliam autism rating scale (GARS).* Pro-Ed.

Guerra, A., Bologna, M., Paparella, G., Suppa, A., Colella, D., Di Lazzaro, V., Brown, P. & Berardelli, A. (2018). Effects of transcranial alternating current stimulation on repetitive finger movements in healthy humans. *Neural Plasticity.* Article 4593095. https://doi.org/10.1155/2018/4593095

Höfer, J., Bachmann, C., Kamp-Becker, I., Poustka, L., Roessner, V., Stroth, S., ... & Hoffmann, F. (2019). Willingness to try and lifetime use of complementary and alternative medicine in children and adolescents with autism spectrum disorder in Germany: A survey of parents. *Autism*, 23(7), 1865-1870. DOI: 10.1177/1362361318823545

Jensen, O., Kaiser, J., & Lachaux, J. P. (2007). Human gamma-frequency oscillations associated with attention and memory. *Trends in Neurosciences*, 30(7), 317-324. DOI: 10.1016/j.tins.2007.05.001

Jensen, O., & Tesche, C. D. (2002). Frontal theta activity in humans increases with memory load in a working memory task. *European Journal of Neuroscience*, 15(8), 1395-1399. DOI: 10.1046/j.1460-9568.2002.01975.x

Kim, D., Lee, J. Y., Jeong, B. C., Ahn, J. H., Kim, J. I., Lee, E. S., ... & Han, C. E. (2021). Overconnectivity of the right Heschl's and inferior temporal gyrus correlates with symptom severity in preschoolers with autism spectrum disorder. *Autism Research,* 14(11), 2314-2329. DOI: 10.1002/aur.2609

Kitaura, Y., Nishida, K., Yoshimura, M., Mii, H., Katsura, K., Ueda, S., ... & Kinoshita, T. (2017). Functional localization and effective connectivity of cortical theta and alpha oscillatory activity during an attention task. *Clinical Neurophysiology Practice,* 2, 193-200. https://doi.org/10.1016/j.cnp.2017.09.002

Knyazev, G. G. (2007). Motivation, emotion, and their inhibitory control mirrored in brain oscillations. *Neuroscience & Biobehavioral Reviews*, 31(3), 377-395. DOI: 10.1016/j.neubiorev.2006.10.004

Liang, X., Li, R., Wong, S. H., Sum, R. K., Wang, P., Yang, B., & Sit, C. H. (2022). The effects of exercise interventions on executive functions in children and adolescents with autism spectrum disorder: A systematic review and meta-analysis. *Sports Medicine*, 52(1), 75-88. DOI: 10.1007/s40279-021-01545-3

Lisman, J., & Buzsáki, G. (2008). A neural coding scheme formed by the combined function of gamma and theta oscillations. *Schizophrenia Bulletin,* 34(5), 974-980. DOI: 10.1093/schbul/sbn060

Lisman, J. E., & Jensen, O. (2013). The theta-gamma neural code. *Neuron,* 77(6), 1002-1016.

Lord, C., Elsabbagh, M., Baird, G., & Veenstra-Vanderweele, J. (2018). Autism spectrum disorder. *The Lancet*, 392(10146), 508-520. doi:10.1016/s0140-6736(18)31129-2

Macoun, S. J., Schneider, I., Bedir, B., Sheehan, J., ve Sung, A. (2021). Pilot study of an attention and executive function cognitive intervention in children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 51, 2600-2610. DOI: 10.1007/s10803-020-04723-w

Magosso, E., De Crescenzio, F., Ricci, G., Piastra, S., & Ursino, M. (2019). EEG alpha power is modulated by attentional changes during cognitive tasks and virtual reality immersion. *Computational intelligence and neuroscience*, 2019, 7051079. https://doi.org/10.1155/2019/7051079

McVoy, M., Lytle, S., Fulchiero, E., Aebi, M. E., Adeleye, O., & Sajatovic, M. (2019). A systematic review of quantitative EEG as a possible biomarker in child psychiatric disorders. *Psychiatry Res.*, 279, 331–44. DOI: 10.1016/j.psychres.2019.07.004

Nekar, D. M., Lee, D. Y., Hong, J. H., Kim, J. S., Kim, S. G., Seo, Y. G., ve Yu, J. H. (2022). Effects of augmented reality game-based cognitive–motor training on restricted and repetitive behaviors and executive function in patients with autism spectrum disorder. *In Healthcare*, 10, 10. DOI: 10.3390/healthcare10101981

Orekhova, E. V., Stroganova, T. A., Nygren, G., Tsetlin, M. M., Posikera, I. N., Gillberg, C., & Elam, M. (2007). Excess of high frequency electroencephalogram oscillations in boys with autism. *Biological Psychiatry*, 62(9), 1022-1029. https://doi.org/10.1016/j.biopsych.2006.12.029

Ökcün Akçamuş, M. Ç., Bakkaloğlu, H., Demir, Ş., & Bahap Kudret, Z. (2019). Otizm spektrum bozukluğunda Tekrarlayıcı Davranışlar Ölçeği-Revize Türkçe Sürümünün geçerlilik ve güvenilirlik çalışması. *Anadolu Psikiyatri Dergisi*, 20. Doi: 10.5455/apd.42649

Rafiei Milajerdi, H., Sheikh, M., Najafabadi, M. G., Saghaei, B., Naghdi, N., & Dewey, D. (2021). The effects of physical activity and exergaming on motor skills and executive functions in children with autism spectrum disorder. *Games for Health Journal*, 10(1), 33-42. https://doi.org/10.1089/g4h.2019.0180

Ray, S., Niebur, E., Hsiao, S. S., Sinai, A., & Crone, N. E. (2008). High-frequency gamma activity (80–150 Hz) is increased in human cortex during selective attention. *Clinical Neurophysiology*, 119(1), 116-133. https://doi.org/10.1016/j.clinph.2007.09.136

Salari, N., Rasoulpoor, S., Rasoulpoor, S., Shohaimi, S., Jafarpour, S., Abdoli, N., ... & Mohammadi, M. (2022). The global prevalence of autism spectrum disorder: a comprehensive systematic review and meta-analysis. *Italian Journal of Pediatrics,* 48(1), 112. https://doi.org/10.1186/s13052-022-01310-w

Schöllhörn, I., Hegen, P., & Davids, K. (2012). The nonlinear nature of learning-a differential learning approach. *The Open Sports Sciences Journal*, 5(1). DOI: 10.2174/1875399X01205010100

Schöllhorn, W. I. (2000). Practical consequences of systems dynamic approach to technique and strength training. *Acta Academiae Olympique Estonia*, 8, 25–37.

Schöllhorn, W. (1994). *Comparison of biomechanical movement patterns by means of orthogonal reference functions*. In ISBS-Conference Proceedings Archive.

Sert, G. (2020). *Otizmli çocuklarda uygulanan farklılıkla öğrenme egzersizlerinin denge ve üst ekstremite koordinasyonu üzerine etkisi*. Düzce Üniversitesi, Sağlık bilimleri Enstitüsü, Beden Eğitimi ve Spor Anabilim Dalı. Yüksek Lisans Tezi.

Shahane, V., Kilyk, A., & Srinivasan, S. M. (2024). Effects of physical activity and exercise-based interventions in young adults with autism spectrum disorder: A systematic review. *Autism*, 28(2), 276-300. DOI: 10.1177/13623613231169058

Sharma, A., & Singh, M. (2015). Assessing alpha activity in attention and relaxed state: An EEG analysis. *International Conference on Next Generation Computing Technologies*. 508-513. DOI: 10.1109/NGCT.2015.7375171

Snijders, T. M., Milivojevic, B., & Kemner, C. (2013). Atypical excitation–inhibition balance in autism captured by the gamma response to contextual modulation. *NeuroImage: Clinical*, 3, 65-72. DOI: 10.1016/j.nicl.2013.06.015

Stillman, C. M., Esteban-Cornejo, I., Brown, B., Bender, C. M., & Erickson, K. I. (2020). Effects of exercise on brain and cognition across age groups and health states. *Trends in Neurosciences*, 43(7), 533-543. DOI: 10.1016/j.tins.2020.04.010

Strofylla, G., Charitou, S., Asonitou, K., ve Koutsouki, D. (2021). Efficacy of 6-Month Adapted Aerobic Program on Motor Proficiency, BMI and Cognitive Abilities of Students with Autism Spectrum Disorder: Three Case Reports. *Open Journal of Social Sciences,* 9(9), 153-166. DOI: 10.4236/jss.2021.99011

Van Diessen, E., Senders, J., Jansen, F. E., Boersma, M., & Bruining, H. (2015). Increased power of resting-state gamma oscillations in autism spectrum disorder detected by routine electroencephalography. *European Archives of Psychiatry and Clinical Neuroscience,* 265, 537-540. DOI 10.1007/s00406-014-0527-3

Wang, Y., Sokhadze, E. M., El-Baz, A. S., Li, X., Sears, L., Casanova, M. F., & Tasman, A. (2016). Relative power of specific EEG bands and their ratios during neurofeedback training in children with autism spectrum disorder. *Frontiers in Human Neuroscience,* 9, 723. https://doi.org/10.3389/fnhum.2015.00723

Wang, J. G., Cai, K. L., Liu, Z. M., Herold, F., Zou, L., Zhu, L. N., ve Chen, A. G. (2020). Effects of mini-basketball training program on executive functions and core symptoms among preschool children with autism spectrum disorders. *Brain sciences,* 10(5), 263. DOI: 10.3390/brainsci10050263

Wantzen, P., Clochon, P., Doidy, F., Wallois, F., Mahmoudzadeh, M., Desaunay, P., ... & Guillery-Girard, B. (2022). EEG resting-state functional connectivity: evidence for an imbalance of external/internal information integration in autism. *Journal of Neurodevelopmental Disorders,* 14(1), 1-14. https://doi.org/10.1186/s11689-022-09456-8

Yano, N., & Hosokawa, K. (2023). The importance of comprehensive support based on the three pillars of exercise, nutrition, and sleep for improving core symptoms of autism spectrum disorders. *Frontiers in Psychiatry*, 14, 1119142. https://doi.org/10.3389/fpsyt.2023.1119142

Zhang, Y., Tian, H., Tao, Y., Li, Y., Wang, D., ve Qin, L. (2023). A study on the effects of three game intervention programs on executive functions of preschool autistic children. *International Journal of Developmental Disabilities,* 1-11. https://doi.org/10.1080/20473869.2023.2215606

Zhao, H. C., Lv, R., Zhang, G. Y., He, L. M., Cai, X. T., Sun, Q., ... & Fu, B. (2022). Alterations of prefrontal-posterior information processing patterns in autism spectrum disorders. *Frontiers in Neuroscience,* 15, 768. https://doi.org/10.3389/fnins.2021.768219