Applications of Neurofeedback in Treating Autism Spectrum Disorder: A Scoping Review

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Abstract. Autism spectrum disorder (ASD) is a neurodevelopmental condition that affects social communication and behavior. Neurofeedback is used to help people control their brain waves based on feedback, and it can treat ASD. This review aims to find improvements in neurofeedback treatment in individuals with ASD, identify areas lacking research, and summarize new enhancements in neurofeedback technology. A library discovery system was searched for papers about neurofeedback treatment for autism. Eligible articles were original research about neurofeedback treatment for autism in English from 2015 or later. Neurofeedback treatment was very effective; only one study didn't find improvements compared to the control group. In the studies, neurofeedback treatment improved attention, executive function, facial recognition, behavior, communication, (lower) aggression, and social interaction. Favorable changes in alpha activity, delta activity, mu suppression, and theta/beta ratios were observed. Innovations in neurofeedback for ASD include fMRI, mobile games, and AI. There is a lack of research on females with autism and the effects of neurofeedback in autistic adults. Future research should prioritize females and adults; more high-quality studies are needed.

Keywords: Autism Spectrum Disorder; Neurofeedback; Scoping Review; Females with Autism.

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by persistent difficulties in social communication, including poor nonverbal communication, struggles with relationships, impaired reciprocity, and repetitive behaviors, such as repetitive movements, specific routines, and highly focused interests [1]. Symptoms emerge in early childhood, though they may not be apparent until later developmental stages. According to the U.S. Centers for Disease Control and Prevention, approximately 1.68% of children in the United States are diagnosed with ASD [1], highlighting its public health significance. [1].

Neurofeedback, a noninvasive technique that trains individuals to modulate their brain activity using real-time feedback, has been investigated as a therapeutic intervention for ASDs [2,3]. Based on the brain patterns, positive or negative feedback is shown, and the person will try to improve their brain waves. It targets different frequencies, including delta, theta, alpha, sensorimotor rhythm, beta, and gamma [2]. Clinical studies have reported improved attention, executive function, behavior, and social interaction.

Despite growing interest, existing reviews of neurofeedback in ASD remain limited in scope. For example, Rezaee et al. conducted a systematic review focusing only on cognition improvements [4]. Salemi & Saffarinia conducted a narrative review that lacked comprehensiveness [6].

This paper aims to review how neurofeedback can improve various categories for individuals with ASD, identify research gaps, and summarize recent innovations in neurofeedback technology for ASD. A scoping review design was selected because it allows for broad mapping of the evidence base and systematically identifying research gaps [5].

2. Literature Survey

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [7]. No official protocol was registered. However, a plan was made regarding data table columns, the objectives, and the search strategy. Searches were

conducted through a library discovery system covering multiple databases, including OpenAIRE, MEDLINE, and Academic Search Index. The keywords "autism neurofeedback" were used, with filters set to academic journal articles published in English (or undetermined, later verified as English) from 2015 onward. Articles were manually screened by title and abstract, with inclusion limited to original research on neurofeedback interventions in individuals with ASD. Duplicates were removed, and the most recent search was performed on August 5, 2025.

Data extraction was performed using Microsoft Excel. For each study, the author recorded improvements, study design, control group, sample size, number of ASD participants, age range, mean age, proportion of females, and citation. Participant numbers reflected the largest dataset in final analyses, while ASD-specific counts were listed only when studies included non-ASD participants. Age ranges were taken from study samples or eligibility criteria and rounded as necessary; mean ages represented ASD participants and were calculated or adapted from reported values and rounded to the nearest tenth. Female percentages represented ASD participants specifically, were reported or calculated directly, and were rounded to one decimal place. Cells were marked "Not Calculated" when sample differences across analyses prevented accurate computation.

3. Results

3.1 Research Overview

After searching for the keywords, 1394 papers were found. After applying year and source type filters, 502 articles were found. 359 sources were in English, and 103 were in an undetermined language. After being checked for eligibility, 23 papers were included in this review.

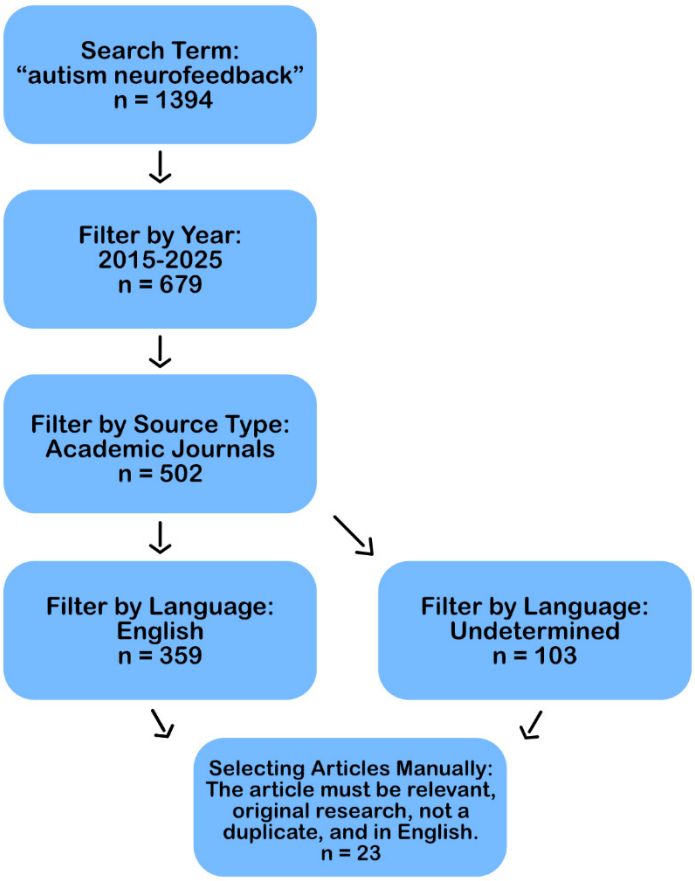

Figure 1. Search Methods Flowchart

Table 1. Data Collected on Included Studies

Improvements in	Number of Participants	Number of Participants with ASD	Study Type	Control Group	Range of Ages	Average Age	Percentage of Females	Citation
Expressive language and awareness	41	N/A	Placebo-controlled, randomized	Fake neurofeedback	3-6	4.5	24.4%	(Wang et al., 2024)
Continued attention to simple stimuli	49	19	Controlled	No neurofeedback	16-24	17.7	22.4%	(Gacek et al., 2024)
Executive function	30	13	Controlled	Neurotypical	18-32	22.8	0.0%	(Pereira et al., 2024)
Executive function, processing speed, and working memory	35	N/A	Not controlled	N/A	7-17	10.9	31.4%	(Saleem & Habib, 2024)
Higher alpha activity, less delta activity; less aggression, more inhibition, better error sensitivity	41	N/A	Controlled	Standard treatment	Not reported	14.1	0.0%	(Auer et al., 2025)
Not better than the control group	36	N/A	Controlled, randomized	Standard treatment	12-17	14.7	0.0%	(Klöbl et al., 2023)
Higher alpha activity, less delta activity; less severe ASD symptoms (better social understanding and motivation)	41	N/A	Controlled, randomized	Standard Treatment	12-17	14.1	0.0%	(Konicar et al., 2021)
Social attention	5	N/A	Not controlled	N/A	3-6	3.8	20.0%	(Lyu et al., 2023)
Attention	23	N/A	Controlled, randomized	Cartoons	4-13	8.0	Not reported	(Mercado et al., 2021)
Better at recognizing expressions	15	N/A	Not controlled	N/A	Not reported	19.9	0.0%	(Direito et al, 2021)
Cognitive, communication, language, and social scores	80	40	Controlled, randomized	watching video without feedback	Not reported	5.6	Not reported	(Kang et al., 2025)
Behavior, better mu suppression	7	N/A	Case series	N/A	6-8	6.9	14.2%	(LaMarca et al., 2023)
Social, thought, and attention categories; lower theta activity and higher beta activity (lower theta/beta ratio)	42	N/A	Not controlled	N/A	6-12.5	8.1	21.4%	(Mekkawy, 2021)
Sleep, attention/learning, sensory, behavioral, emotional, and physical categories	1	N/A	Case study	N/A	5	5.0	0.0%	(Rauter et al., 2022)
Recognition of feelings, cognitive flexibility	12	N/A	Not controlled	N/A	12-18	14.6	50.0%	(Werneck-Rohrer et al., 2021)
Language, attention, cooperation; less aggression, restlessness	1	N/A	Case study	N/A	9	9.0	0.0%	(Avirame et al., 2016)
Social, communication, executive function, decrease in autistic and problem behaviors	34	N/A	Placebo-controlled, randomized	Fake neurofeedback	2-18 years	Not calculated	Not calculated	(Carrick et al., 2018)
Decreased autism symptoms, more human mirror neuron system activation	17	10	Controlled	Neurotypical	Not reported	13.3	30.0%	(Datko et al., 2016)
Facial recognition, less activity in posterior superior temporal sulcus (shows better facial recognition)	4	2	Controlled	Neurotypical and/or Fake neurofeedback	12-16	11.5	0.0%	(Liu et al., 2016)
More activity in the fusiform face area, which is involved in facial recognition	11	5	Controlled	Neurotypical, with either real or fake neurofeedback	14.1-19.5	16.5	0.0%	(Pereira et al., 2019)

Continue from Table 1

Higher gamma activity, lower theta/beta ratio; attention, social interaction (less social withdrawal), less hyperactivity	18	N/A	Not controlled	N/A	Not reported	13.2	22.2%	(Wang et al., 2016)
Mu suppression, social, communication, less severe ASD symptoms, personal hygiene, social motivation, coping ability, expression	13	N/A	Not controlled	N/A	6-17	11.5	7.7%	(Friedrich et al., 2015)
Attention, anxiety, rule-following, behavior	12	N/A	Within subjects	N/A	4-11	4.5	Not reported	(Mercado et al., 2019)

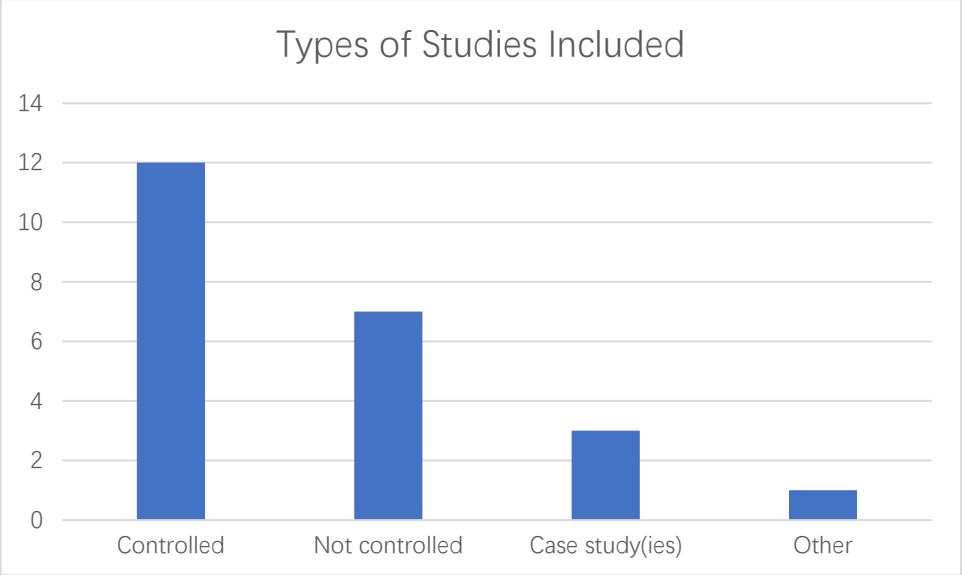

Figure 2. Types of Studies Included

Among the reviewed articles, 12 studies were controlled [2, 8-18], 7 studies were not controlled [2, 16, 19-23], 3 studies were case studies or case series [24-26], and 1 study was another format [27], as shown in Figure 2. Only two studies in this review were randomized and placebo-controlled [2, 9].

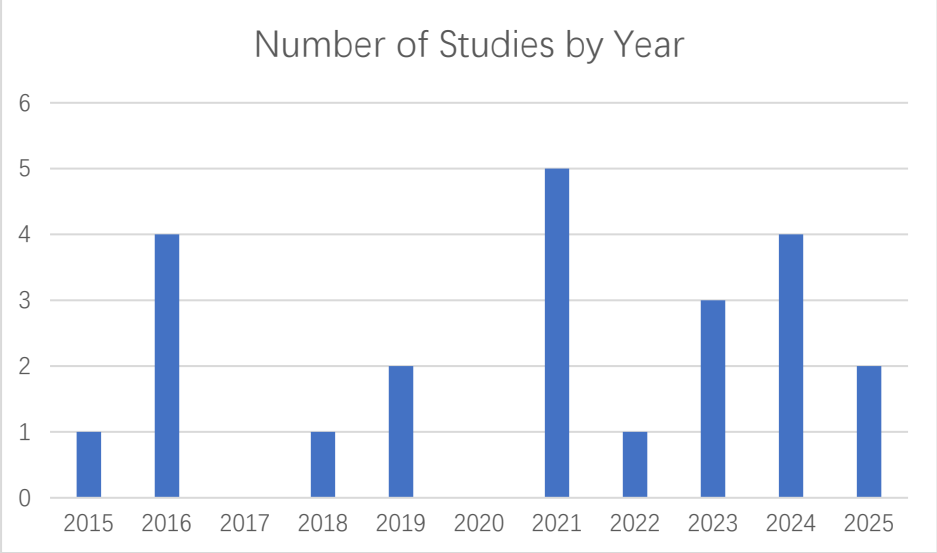

Figure 3. Number of Studies by Year

Figure 3 shows that studies from multiple years were included, with more recent years being the most recent.

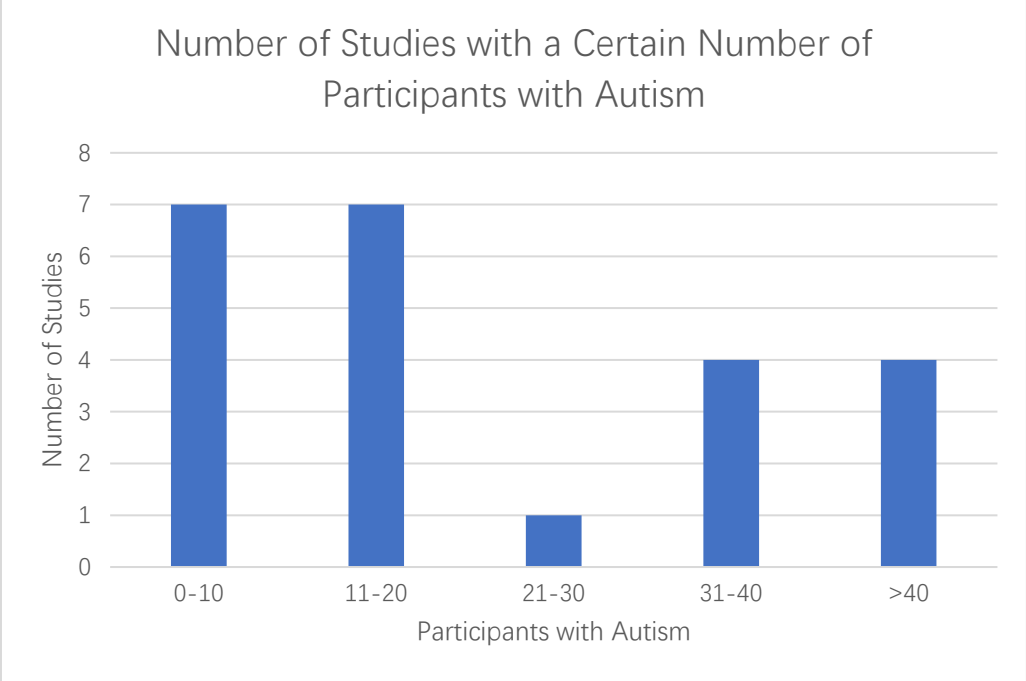

Figure 4. Number of Studies with a Certain Number of Participants with Autism

According to Figure 4, many studies had small sample sizes, which may affect the reliability of their results.

3.2 Neurofeedback Treatment Effects

Neurofeedback treatment has many different positive effects on people with autism spectrum disorder. The treatments in the included studies were generally very successful. Only one study found that neurofeedback treatment was not better than the control group [13]. Here, the improvements found in two or more studies are described.

Gacek et al., Lyu et al., Mercado et al., Mekkawy, Avirame et al., and Wang et al. (in different studies) all found that neurofeedback treatment improves the attention of individuals with ASD [11,15,20,21,24,28]. Mercado et al. found improvements in attention twice in separate studies [15,27].

Pereira et al., Saleem & Habib, and Carrick et al. conducted separate studies that showed that neurofeedback treatment helps the executive function of people with ASD [9,16,22].

According to a study by Auer et al. and another survey conducted by Konicar et al., neurofeedback treatment for autism results in higher alpha activity and lower delta activity in individuals with ASD [8,14]. Low alpha activity is linked to more intense ASD symptoms, and delta activity is higher in people with ASD; therefore, the alpha and delta activity changes are beneficial [8].

LaMarca et al. and Friedrich et al. found improvements in mu suppression after neurofeedback treatment [19,25]. This is important because people with ASD have less mu suppression [25].

In the studies conducted by Mekkawy and Wang et al., the theta/beta ratios of the participants were lowered after neurofeedback treatment [21,28]. Lower theta/beta ratios are correlated with better attention [28]. They also result in better social behavior and communication in children with autism [21].

Neurofeedback treatment can improve facial recognition in autistic individuals. In a study by Liu et al., activity in the posterior superior temporal sulcus decreased after neurofeedback, showing improved facial recognition [18]. Additionally, Pereira et al. found that neurofeedback increased activity in the fusiform face area, which is involved in facial recognition [17].

In the studies conducted by LaMarca et al., Rauter et al., Carrick et al., and Mercado et al., neurofeedback improved the behavior of the participants [9,25-27]. Wang et al., Kang et al., and Avirame et al. found improvements in language [2,12,29]. According to studies conducted by Kang et al., Carrick et al., and Friedrich et al., neurofeedback can improve the communication of individuals with autism [9,12,19]. Auer et al. and Avirame et al. found decreased aggression in the participants after neurofeedback treatment [8, 24]. In the studies conducted by Konicar et al., Lyu et al., Mekkawy, Carrick et al., and Wang et al., the participants improved in aspects of social interaction after neurofeedback treatment [9,14,20,21,28]. These include social attention and lower social withdrawal [20,28].

3.3 Comparison of Neurofeedback Treatment to Standard Treatment

Traditional methods of treating autism spectrum disorder include therapy and medications [30]. However, medications can have harmful side effects. Multiple medications for autism can cause weight gain, irritability, and sedation [30]. Rahmani et al. found that neurofeedback treatment generally doesn't cause side effects and found a pooled prevalence of 0.05 [29]. (Nevertheless, their paper focused on neurofeedback for ADHD and epilepsy, so it is possible that their results would be different if they concentrated on ASD.)

Additionally, neurofeedback treatment may be more effective than traditional methods. According to the study by Auer et al., the neurofeedback group's alpha activity increased. In contrast, that of the control group (standard treatment) decreased, and delta activity decreased more in the neurofeedback group [8]. Higher alpha and lower delta activity are beneficial when treating ASD [8]. Konicar et al. found that ASD symptoms improved significantly in the neurofeedback group compared to the control group (treatment as usual) [14]. However, Klöbl et al. found that the neurofeedback group did not improve more than those receiving standard treatment [13].

3.4 Gaps in Research

3.4.1 Autistic Females in Neurofeedback Studies

Females are often excluded from autism research due to the use of diagnostic tests (that are unfair to females) before studies and the difficulties in getting a diagnosis for females [31]. The findings from this review corroborate this. 9 studies had an entirely male sample. 10 studies included females. 3 studies did not report the participants' sex, and 1 study was not included (see Notes on Table 1) in the data for the percentage of females [9, 12, 15, 27]. The percentages of females in the studies were low. The lowest rate was 7.7% (other than studies with an all-male sample), and the highest was 50% [19, 23]. The average percentage of females was 12.8% in the studies reviewed.

3.4.2 Ages of Participants in Studies

The range of ages across all studies included in this review is 3 to 32 years, which shows that there are studies on neurofeedback treatment for autistic individuals of many different age groups. The lowest age range was 3 to 6, and the highest was 18 to 32 [2], [16]. The average age ranged from 3.8 to 22.8 years old [16], [20]. Many studies focused on children and teenagers. Only two studies had participants with an average age over 18 [16], [32].

4. Innovations in Neurofeedback Treatment for ASD

New improvements have been made in neurofeedback treatment for ASD. Lyu et al. created a mobile video game for neurofeedback treatment for young children [20]. This is an essential improvement over more conventional neurofeedback treatment because children with ASD can use the mobile neurofeedback game at home, allowing for more regular treatment and more convenience [20]. The children participating in the field study also liked the game and wanted to play it again [20].

Direito et al. and Pereira et al. used fMRI neurofeedback instead of the standard EEG neurofeedback [16], [32]. fMRI might be better in some situations because fMRI has superior spatial

resolution compared to EEG [32]. Pereira et al. used neurofeedback that targeted the left dorsolateral prefrontal cortex, which is used for executive function [16]. Direito et al. used neurofeedback that targeted the superior temporal sulcus, which recognizes facial expressions and social cues [32].

Wang et al. incorporated artificial intelligence into neurofeedback treatment for ASD, showing potential for more use of AI in neurofeedback for ASD in the future [2]. The AI set mu activity scores to regulate the size of an oval or the speed of actions during tasks [2].

5. Discussion

The studies included in this review show that neurofeedback is an effective treatment for ASD. However, there is a lack of research on females, as many studies have focused exclusively on males or had low percentages of females. Additionally, many studies focused on children and teenagers, showing a lack of research on the effects of neurofeedback in autistic adults. The included studies were from many different years and were of varying types (controlled, not controlled, case studies, or other). They also found varying outcomes with different improvements after neurofeedback treatment.

It is possible that the lack of females in research on neurofeedback for ASD is not significant. Werneck-Rohrer et al. did not find sex differences in treatment results assessed in their study, specifically facial recognition and mental flexibility [23]. Also, neurofeedback caused improvements in both sexes. However, their study had a small sample size and other factors that may have affected their results [23]. As a result, more research is needed to understand this field further.

The results were consistent with previous findings. In a systematic review by Rezaee et al., 83% of the included studies showed positive effects in people with ASD [5]. In their narrative review, Salemi & Saffarinia found that neurofeedback treatment had various beneficial effects for individuals with ASD [6]. They also found that it could improve behavior, social skills, and attention.

5.1 Limitations

Some articles were excluded from this review; as a result, part of the scientific literature on neurofeedback treatment for ASD is not a part of this article's conclusions. For example, the review only included papers from 2015 onwards, so it doesn't contain findings from earlier years. Additionally, only documents in English were included, so the review excludes research results reported in other languages.

There weren't any restrictions on how rigorous the studies needed to be for inclusion in this review, so some of the articles' conclusions may not be entirely reliable. Some had a minimal sample size or were case studies. Results from the small groups of people included in those studies might not apply to other individuals with autism. Additionally, the lack of a control group in some studies might have affected the validity of their findings.

Studies included in this review generally lacked females or did not include enough females in their samples. The ratio of males to females with ASD is 3 to 1 [33]. Although ASD is more common in males, there is a significant population of autistic females who were not represented enough in the samples of the studies included. However, it is unclear if this is a significant limitation, as one study didn't find differences in improvements between sexes.

One person conducted this scoping review. Generally, scoping reviews are performed by a team that includes someone with knowledge in the field being researched, someone with expertise in scoping reviews, and a librarian [34]. Additionally, the group uses discussions to determine which papers to include [34]. Because there was only one reviewer, there were no discussions, possibly resulting in bias in the articles included. This could have affected the findings of this paper.

5.2 Future Directions

Future studies on neurofeedback for autistic individuals should include more females. The studies in this review mainly had males or consisted of entirely male samples, and the results of

neurofeedback treatment may differ in females. They should also be conducted in randomized and placebo-controlled studies with larger sample sizes. These changes would result in higher-quality studies. Many studies reviewed lacked control groups or had small sample sizes. More studies should focus on the effects of neurofeedback in adults with ASD. The articles included generally focused on children and teenagers; there is a lack of research on the effects of neurofeedback in adults with autism.

6. Conclusion

This paper aimed to identify the positive effects that neurofeedback treatment can have on autistic individuals, to look for research gaps, and to review recent improvements in neurofeedback technology for people with ASD. Neurofeedback can have numerous positive effects, including improvements in attention, executive function, facial recognition, behavior, communication, (lower) aggression, and social interaction. It can also result in beneficial changes in alpha activity, delta activity, mu suppression, and theta/beta ratios. Research on neurofeedback for ASD treatment has included samples with large proportions of male participants, and some samples were all-male. Most studies focused on children and teenagers. Improvements have been made in neurofeedback treatment for people with ASD, including the use of fMRI, mobile games, and AI.

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