REVIEW ARTICLE

Assessing the Impact of Neurofeedback on Cognitive Function in Individuals with Autism Spectrum Disorder: A Systematic Review

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ABSTRACT

Objectives

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by qualitative deficits in behavior and social interaction patterns. Recently, cognitive impairments commonly associated with ASD have been well-documented. Neurofeedback (NFB) has been proposed as a potential treatment for individuals with autism, but its effectiveness in improving cognitive issues remains uncertain despite multiple trials. This review aims to summarize the estate of documents regarding the cognitive efficacy of NFB for participants with ASD.

Materials & Methods

Conducting a systematic review adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, this study scrutinized NFB studies specific to ASD treatment. Its inclusion criteria focused on studies involving individuals with ASD without comorbidities, employing JBI checklists to assess study quality. Utilizing PubMed, Embase, Web of Science, PsycINFO, and Scopus, supplemented by manual paper reviews, we initially identified 474 papers. After deduplication and full-text review, 12 studies were selected for analysis.

Results

Findings revealed that 83% of the chosen studies highlighted a positive impact of NFB on cognition in individuals with ASD. The findings suggest NFB as a promising alternative treatment, demonstrating efficacy in addressing attention, memory, executive function, and speech difficulties. Additionally, six studies indicated sustained long-term effectiveness of NFB in improving cognitive functioning among ASD patients.

Conclusion

This review supports the potential of NFB as a viable intervention for cognitive challenges in ASD. Furthermore, the results hint at broader applications of NFB beyond ASD, suggesting efficacy in addressing conditions like Attention Deficit/Hyperactivity Disorder (ADHD), sleep apnea, depression, and epilepsy.

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Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by qualitative deficits in patterns of behavior and social interaction, leading to repetitive activities (1). According to the Autism and Developmental Disabilities Monitoring System, approximately one in thirty-six children have ASD (2). The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) classifies ASD as a continuum that includes Asperger's disorder, childhood disintegrative disorder, Autistic disorder, and pervasive developmental disorder not otherwise specified (3). The noticeable symptoms of ASD are categorized into deficits in social communication and interaction, as well as restricted interests and repetitive behaviors (4).

Cognition refers to the mental processes and abilities enabling individuals to perceive, think, and comprehend the world around them (5). The cognitive domain encompasses various aspects of mental function that can be evaluated to understand an individual's cognitive capabilities. These domains are hierarchical, with lower levels addressing more basic sensory and cognitive processes and upper levels addressing elements of executive function and cognitive control (6). Executive function tasks often involve coordinating multiple senses, attention, perception, and other less complex functions, while simple sensory tasks require processing at a lower level. Cognitive impairments associated with ASD are well-documented and include difficulties with attention, such as sustaining and shifting attention, memory impairments, language difficulties, and deficits in executive function, including problems with planning, cognitive inflexibility, and inhibitory control (7).

While various treatments, including pharmacological, behavioral, and biofeedback strategies, have been developed to alleviate specific symptoms for some individuals, no confident cure is currently available for this condition (8). Neurofeedback (NFB) or electroencephalogram (EEG) biofeedback is one of the therapies provided to patients with ASD (9, 10). The NFB involves patients receiving information about their brain activity in a visual or auditory form, enabling them to gain control over their brain activity and regulate it to achieve desired outcomes. Believingly, NFB produces beneficial behavioral changes in autistic children by regulating abnormal connections within and between neural circuits (11).

Research on the effects of NFB performed on patients diagnosed with ASD shows that improvements in social behavior and electrophysiological behavior are obtained in several cases (12). Other research studies imply that NFB has no or little effect on treating ASD (13). This review aims to summarize the estate of documents regarding the cognitive efficacy of NFB for participants with ASD. Previously, some literature assessed the impact of NFB as a treatment for Children with attention deficit hyperactivity disorder (ADHD) (14). The present study assesses the role of NFB in improving cognitive impairment. As cognitive components are not independent, this study focuses on four domains: language, memory, attention, and executive function.

Materials & Methods

The present systematic review followed the methodological guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (15). Figure 1.

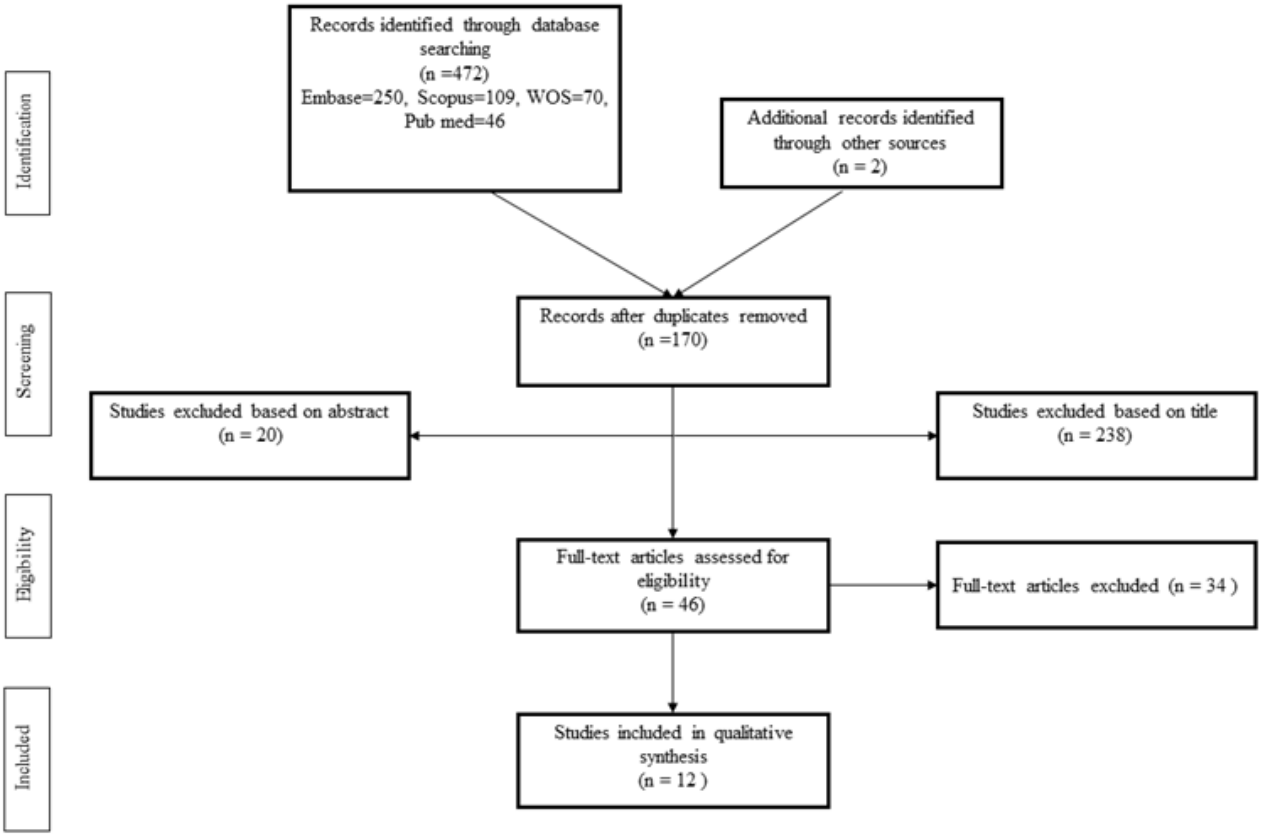

Figure 1. PRISMA flow chart of study selection process

Ethical considerations

This systematic review does not involve human, animal, or human data collection, so it did not require ethical approval.

Inclusion criteria

This review established inclusion criteria by following the patient/population, intervention, comparison, and outcomes (PICO) framework.

Population

The present review included studies involving individuals diagnosed with ASD. The diagnosis of ASD was established based on interviews with parents or caregivers, as well as the presence of a specific EEG pattern associated with autistic disorders. Participants with comorbid neurological or psychological conditions such as ADHD, brain injury, and epilepsy were excluded. No restrictions were found based on gender or age.

Intervention

This study encompassed all studies utilizing NFB as a treatment for ASD patients, regardless of the specific protocol, duration, number of sessions, or intensity. The evaluation of NFB in these studies considered any targeted changes in cognitive states.

Comparison

This review included studies that compared NFB with a comparator intervention or usual care. For studies with no comparator, the NFB results were assessed before and after the intervention.

Outcome

This review included studies directly evaluating

any component of cognition. The effect of NFB on social cognition was not investigated.

Types of studies

This review included experimental designs, such as pre-post studies, case studies, and randomized clinical trials. Only studies published in English were included. Studies evaluating other interventions with NFB, such as biofeedback and repetitive transcranial magnetic stimulation (rTMS), were excluded.

Search strategy

Five electronic databases (PubMed, Scopus, Web of Science, PsycINFO, and Embase) were searched. The search was performed on 22 September 2023. Keywords were neurofeedback, NFB, NF intervention, NF training, brainwave biofeedback, brainwave feedback, EEG feedback, EEG biofeedback, autistic disorder, autistic spectrum disorder, autism spectrum disorder, autism, asperger syndrome, cognition, "awareness, perception, attention, memory, language, speech, executive function. Appendix 1 includes a complete search strategy in the PubMed database.

Study selection

All references identified from 2000 to 2023 were imported into a citation manager (EndNote). Subsequently, duplicates were removed. Two authors independently screened the titles and abstracts of the remaining references. Any references that did not meet the inclusion criteria were excluded. The full text of the remaining studies was then retrieved and assessed for eligibility.

Quality assessment

Two reviewers (LGh, NB) assessed the quality of the references included. The JBI checklist for quasi-experimental studies, consisting of nine questions, and the JBI checklist for randomized clinical trials, consisting of 13 questions, were used (16). The total score of each study, indicating its quality, was calculated as the percentage of "yes" answers. Studies with a total score below 50% were classified as "low" quality, those with a score between 50% and 75% were classified as "moderate" quality, and those with a score above 75% were classified as "high" quality. Any conflicts were resolved through discussion, and a third person was involved if necessary. This review included all studies and did not exclude studies of poor quality.

Data extraction

The authors independently extracted data from the included studies. The following information was included: The collected: authors, year of publication, study design, criteria for inclusion and exclusion, demographic characteristics of the participants (gender, number of participants), intervention, and measures used to assess outcomes.

Results

Literature search results

Four hundred seventy-four studies were identified through electronic database searches and manual searching. After removing duplicates, 304 papers remained for assessment. Three studies were not available in full text. After reviewing the full text of the available studies, only 12 met this systematic review's inclusion criteria. One of the main

reasons for excluding some full-text papers was their use of NFB in conjunction with other forms of treatment, such as rTMS (repetitive transcranial magnetic stimulation) (17). The second most common reason for exclusion was the presence of comorbidities in patients, such as hyperactivity disorder (18). Third, some studies only reported the total score of a test or questionnaire, including sub-scores unrelated to cognition. Fourth, some studies focused on evaluating other benefits of NFB and did not assess cognitive effects (19). Table 1 summarizes the study characteristics, including author, year of publication, study aim, number of participants, type of NFB protocol, number of sessions, and trial results. Two hundred sixty participants ranging from 2 to 23 years old were included. Three studies included only male participants (20-22). Three studies had only one participant (20, 23, 24). The participants' gender was not reported in one study (25).

Outcome

Among the twelve studies examined, two showed no clinical improvement with using NFB (10, 26). However, five studies demonstrated that NFB improved attention (20, 22, 23, 25, 27). Additionally, four studies showed improvement in executive function (20, 24, 27, 28), and three focused on language and speech and found positive effects of NFB (21, 24, 29). One study even reported an increase in IQ scores and significant improvement in memory (28). Mekkawy (30) conducted a study on the impact of NFB on social, attention, and thought domains. Using the child behavior checklist, he compared the results and found that thirty-seven out of forty-

Table 1. Overview of studies on the efficacy of NFB for cognition

Author	Aim	Participants		Design	Intervention	Result
		Experimental	Control			
Jarusiewicz 2002 (29)	Show Efficacy of Neurofeedback for Children in the Autistic Spectrum	(n=12) Male:11 Female:1 MA=7 yrs	(n=12) Male:11 Female:1 MA=7 yrs	Randomized pretest–posttest control group	20 sessions for 30 minutes of EEG neurofeedback	Neurofeedback training resulted in a 26% average reduction in total ATEC, compared to 3% for the control group. speech/ language/ communication, 29% ($p < .001$); and sensory/cognitive awareness, 17% ($p < .001$).
Coben 2007 (20)	Testing Neurofeedback for Autistic Spectrum Disorder.	a 5-year boy with a diagnosis of PDD-NOS		Case study	EEG neurofeedback for 15-minute, twice per week for a total of 20 sessions.	Neuropsychological testing showed improvements on tests of attention, comprehension, and sequencing/motor planning.
Pineda et al. 2008 (22) Study 1	Regulating mu rhythms via neurofeedback training can renormalize mu suppression and improve behavior in children diagnosed with ASD.	(n=5) Male:5 MA=9.3 yrs	Placebo condition (n=3) Male:3	Randomized pretest–posttest control group	NFB for 3 sessions for 30 minutes in week for ten week	By assessing ATEC test, clear increase in the sensory/cognitive awareness (SCA) dimension compared to a decrease shown by those in the placebo group.
Pineda et al. 2008 (22) Study 2	Regulating mu rhythms via neurofeedback training can renormalize mu suppression and improve behavior in children diagnosed with ASD.	(n=9) Male:6 Female:3 MA=9.4 yrs	(n=10) Male:10 MA=10.1 yrs	Double-blind randomized pretest–posttest control group	NFB for 3 sessions for 30 minutes in week for ten weeks	There was improvement in attention. there was general positive change in ATEC, except the sensory/ cognitive awareness dimension.
Kouijzer et al. 2009 (27)	Improving their level of executive control in patients with ASD.	(n=7) Male:6 Female:1 MA= 9.6 yrs	(n=7) Male:6 Female:1 MA=10.6 yrs	non-randomized pre-test–post-test control group	NFB for 40 sessions, twice a week.	Executive function tasks include: Attentional control, Cognitive flexibility, and Goal setting were found to be significantly improved.

Continued Table 1.

Kouijze et al. 2013 (10)	Improving their level of executive control in patients with ASD and evaluating other NFB effects.	EEG biofeedback (n=13) Male:10 Female:10	SC-group (n=12) Male:9 Female:10 Waiting list (n=13) Male:11 Female:2	Randomized pretest–posttest control group	40 sessions of NFB training for 45 min over 20 weeks' period	In comparison to SC and waitlist group there was no specific clinical improvement after EEG-biofeedback. There was just significant improvement in cognitive flexibility , but not for inhibition, planning, attention, and working memory.
Zivoder et al. 2015 (24)	Describe neurofeedback (NFB) as a treatment in Autistic spectrum disorder (ASD) children	Case 1: male;5 yrs Case 2: Female; 5,5 yrs Case 3: Male; 4 yrs	No control group	Case study	EEG neurofeedback	Case1: better understanding, improving speech, improving communications and motor skills and attention span. Case 2: after 30 sessions of training, she had better attention span. Case3: better functioning in emotional and social aspects and focusing. Motor skills became better.
Anzalone et al. 2016 (23)	Introducing a small humanoid robot to stimulate attention towards a joint activity.	(n=1) 17 years old woman With proactive robot	The same as participant With static robot	Pilot study	3 sessions during a single week: each session has been divided in an experimental condition and in a control condition randomly.	Results indicated significant improvement in attention in the group of intervention.
Carrick et al. 2018 (26)	Investigating the effect of the Mente Autism device in children affected by ASD by comparing pre and post EEG.	(n=17) Male:15 Female:2 Active group receiving NFB using the Mente device	(n=17) Male:13 Female:4 control group receiving NFB using the Sham device	Randomized pretest–posttest control group	Auditory neurofeedback Both groups used the device each morning for 45 minutes over a 12-week comparing the result of questionnaire pre and post intervention.	For both the Active and Control group the Speech/ Language Communication and the Sensory/ Cognitive Awareness of the ATEC had worsen.
Mercado et al. 2021(25)	Describing the results of using FarmerKeeper as a tool to support the neurofeedback therapies of children with autism.	(n=13) used FarmerKeeper MA=8 yrs	(n=13) used Cartoons	Randomized pretest–posttest control group	13 sessions of neurofeedback	Pre- and post-assessment evaluation exhibited all children with autism improve their attention, attentional control and sustained attention. Two children with autism no longer indicated attention impairments in the post-assessment evaluation.
Mekkawy 2021 (30)	Understanding correlation between EEG brain waves and NFB training and improving cognitive abilities in ASD patients.	(n=42) Male:33 Female:9 MA=7.8 yrs	No control group	Pre-posttest clinical trial	Each child received 40 sessions of NFB treatment, given 3 times a week.	Results indicated significant improvement in attentional span, cognitive flexibility in addition to social interaction for children in the studied group where their parents reported improvement on the CBCL questionnaire subscales.
Direito et al. 2021 (21)	demonstrating the feasibility of real-time functional magnetic resonance imaging neurofeedback.	(n=15) Male: 15 MA=20 yrs	The same as NFB group	Within-group clinical trial	Five sessions of fMRI-nfb (4weekly sessions and the last approximately 1month later)	6months after the last training session, and comparing with the baseline, the patients sustained and improved in ATEC , ATEC Speech/Language/Communication and ATEC Sociability
Saleem et al. 2023 (28)	Investigating whether NFB can improve cognitive functions in children with ASD	(n=35)	No control group	Pre-posttest clinical trial	30 sessions of NFB training for 20 min over 10 weeks' period	Children showed a statistically significant improvement in executive functions (Inhibitory Control and Attention and Cognitive Flexibility), Processing Speed and Working Memory.

two patients showed statistical improvement after forty sessions, with the most significant change observed in the thoughts domain. Only one study mentioned using fMRI-NFB (21), and another evaluated the cognitive state using the autism treatment evaluation checklist score before and after treatment, showing statistical improvement (25). In one study, a farmer-keeper game was designed to apply NFB and investigate its effects on attention. The game measured total attention (represented as the percent of time with attention), attention control (represented as the number of times attention was lost), and sustained attention (measured as the duration of time attention was maintained) (25). To assess nonspecific and other effects of NFB, Kouijzer et al. (27) analyzed participants within randomized groups and found no specific effect. None of the studies reported any adverse effects of NFB. Various tests and questionnaires were used to assess the cognitive effects of NFB, summarized in Figure 2.

Methodological quality of the included studies

One of these twelve studies included two kinds

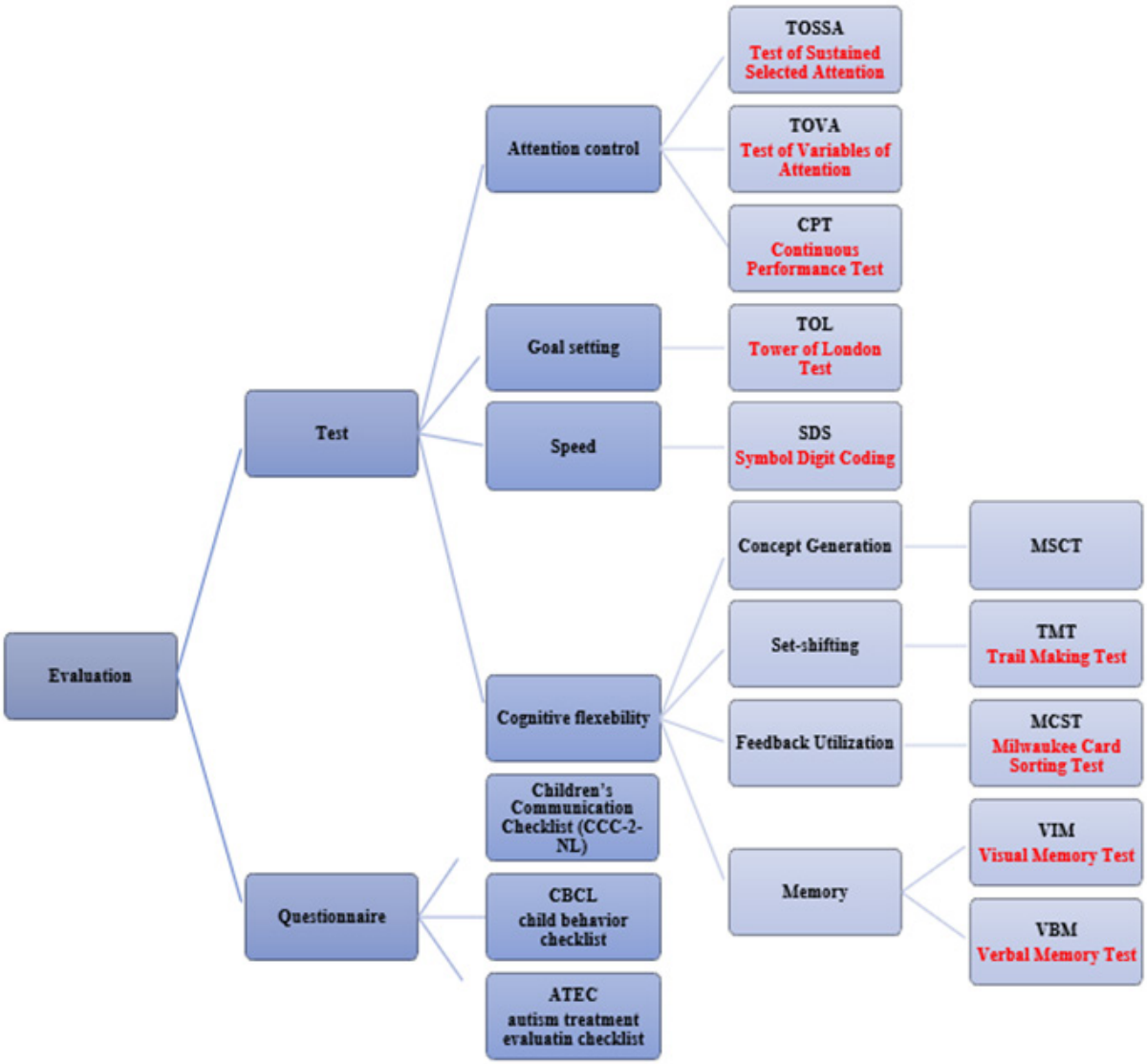

Figure 2. Tests and questionnaires applied to score cognitive function in patients with ASD

of studies (22). Six of these studies were quasi-experimental; the other seven were randomized clinical trials (Table 2, 3). Five of these studies were high quality (quality score>75%). Six of these studies were of moderate quality (quality score>50%), and the remainder were of low quality. Clinical appraisal found the studies to be methodologically heterogeneous. Due to the diversity in protocols and devices used for applying NFB, as well as differences in demographic features such as age and gender, conducting a meta-analysis of the data was not possible.

Discussion

This review examines the effectiveness of NFB treatment for cognitive problems in individuals with ASD. Among the studies included in the review, only two show no improvement in cognitive function (10, 26). The reasons for these contradictory results are unclear, but possibly that high drop-out rates and older participants may have influenced the outcomes. One study by Mercado et al. used a game-based NFB approach, but their conclusion was biased as they compared the results to those of a group watching

Table 2. Critical appraisal table for the assessment of risk of bias for randomized controlled trials

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Total
Jarusiewicz 2002	Y	Y	Y	U	U	Y	U	Y	Y	U	N	Y	Y	61%
Pineda et al. 2008 Study 1	Y	Y	Y	Y	N	Y	U	Y	Y	N/A	N	Y	Y	69%
Pineda et al. 2008 Study 2	Y	Y	Y	Y	Y	Y	U	Y	Y	N/A	N	Y	Y	77%
Kouijzer et al. 2009	Y	U	Y	N	U	Y	N	Y	Y	Y	N	Y	N	53%
Kouijze et al. 2013	Y	Y	Y	Y	N	Y	U	Y	Y	Y	Y	Y	Y	84%
Carrick et al. 2018	Y	N	Y	U	U	Y	U	Y	Y	Y	N	Y	Y	61%
Mercado et al. 2021	Y	U	Y	N	N	Y	U	Y	Y	N	N	Y	Y	53%

Q = Question; Y = Yes; N = No; U = Unclear; N/A = Not applicable
Total refers to the percentage of "yes" answers for each study, where a higher percentage indicates a higher quality study

Table 3. Clinical appraisal for quasi-experimental research

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total
Coben 2007	Y	U	N/A	N	Y	N	Y	Y	N	44%
Zivoder et al. 2015	Y	U	N/A	N	Y	N	Y	Y	U	44%
Anzalone et al. 2017	Y	U	N/A	N	Y	N	Y	Y	Y	55%
Mekkawy 2021	Y	U	Y	N	Y	Y	Y	Y	Y	77%
Direito et al. 2021	Y	U	Y	N	Y	Y	Y	Y	Y	77%
Saleem et al. 2023	Y	Y	Y	N	Y	Y	Y	Y	Y	88%

Q = Question; Y = Yes; N = No; U = Unclear; N/A = Not applicable;
Total refers to the percentage of "yes" answers for each study, where a higher percentage indicates a higher quality study

cartoons, which could have caused distraction (25). Additionally, some participants in studies by Carrick et al. (26) and Mekkawy (30) could not tolerate the EEG headsets, leading to non-cooperation and withdrawal. Notably, most results in these studies were based on reports from parents and caregivers, and no consensus is available on a standardized test to evaluate the efficacy of NFB. Only six studies followed up with participants, and none assessed long-term effects beyond six months after the end of the intervention (10, 21, 26-28, 30). Therefore, the long-term effectiveness of NFB remains unclear.

A similar study suggested that near-infrared

spectroscopy-based neurofeedback training was beneficial in improving working memory and executive function, but it did not investigate the effect of this method on autistic patients (31). This review presents new findings in autistic participants but, notably, acknowledges certain limitations when interpreting the results. Given these psychological concepts' interconnected and hierarchical nature, this review specifically focused on selecting studies centered on cognition. However, some significant studies were possibly overlooked due to the specific search terms, syntaxes, and study screening criteria employed. Furthermore, there were considerable variations in the NFB protocols utilized, the number of sessions conducted, and the severity of the disease being studied. Additionally, heterogeneity was observed in demographic features such as age and gender. To draw more robust conclusions, it is crucial to conduct well-designed randomized clinical trials. These trials should categorize participants by age and IQ scores while ensuring they are blind to their treatment assignment. These studies should include control groups to compare the outcomes between the control and NFB groups. Additionally, within-group comparisons should be conducted to assess the impact of factors such as age, intelligence quotient score, and gender on treatment outcomes. Importantly, individual differences, such as emotional instability or vocalization problems, may require modifications to the NFB protocol. This highlights the significance of intra-group comparisons. Furthermore, it is recommended to explore different session durations and protocols to determine the most effective approach for NFB therapy, as well as the minimum number of sessions required for optimal results. Notably, investigating the age range that yields the best outcomes is also crucial. The reviewed papers mainly concentrated on patient justifications. However, the impact of family environment and socioeconomic status should be considered, as these factors can significantly affect treatment outcomes.

In Conclusion

The findings from the present review provide encouraging evidence for the potential use of NFB as an alternative treatment for individuals with autism spectrum disorder, specifically in addressing attention, memory, executive functioning, and speech difficulties. This review highlights the need for further research to establish the statistical significance of NFB's impact on cognitive functioning in individuals with ASD. Moreover, the results suggest that NFB may have broader applications beyond ASD, such as in treating conditions like ADHD, sleep apnea, depression, and epilepsy.

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Authors' Contribution

All authors meet the ICMJE criteria for authorship. Leila Ghamkhar, Mohamad Mahdi Nasehi: Conceptualization, Mehdi Rezaee, Mohammad Effatpanah: methodology development, Leila Ghamkhar, Nazanin Barati: literature search and screening, Leila Ghamkhar, Nazanin Barati: Data extraction and synthesis, Mehdi Rezaee, Mohamad Mahdi Nasehi: risk of bias assessment,

Nazanin Barati: manuscript drafting, Mohammad Effatpanah: Critical review and revision, Leila Ghamkhar, Nazanin Barati: Writing - review & editing.

Conflict of Interest

The authors declare no conflict of interest in this study's conduct or the manuscript's preparation.

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