

Efficacy of Neurofeedback Training in Schizophrenia: A Systematic Review of Clinical, Cognitive, and Neurophysiological Outcomes

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Abstract

Background: Schizophrenia remains a disabling psychiatric disorder with incomplete response to pharmacotherapy, particularly for negative and cognitive symptoms. Neurofeedback (NF), a noninvasive neuromodulation approach, has garnered attention as an adjunctive therapy aimed at enhancing self-regulation of brain activity.

Objective: This review examines recent clinical evidence on the efficacy of neurofeedback training, especially electroencephalographic neurofeedback (EEG-NF), in improving the positive, negative, and cognitive symptoms of schizophrenia.

Methods: Data were synthesized from systematic reviews, meta-analyses, and randomized controlled trials (RCTs) published between 2015 and 2025 and indexed in PubMed, Web of Science, Scopus, and Embase databases.

Results: Across multiple RCTs and meta-analyses, sensorimotor rhythm (SMR) bands were identified across multiple RCTs and meta-analyses. Complementary reviews confirmed consistent improvements in self-regulation capacity, cognitive flexibility, and functional connectivity in the frontotemporal regions. Moreover, NF protocols focusing on impulsivity and aggression in male patients with schizophrenia demonstrated marked reductions in PANSS and MOAS scores after six weeks.

Conclusion: Contemporary evidence supports EEG-neurofeedback as an effective adjunct to pharmacotherapy in schizophrenia, especially for negative and cognitive symptom domains. However, heterogeneity in protocols, biomarkers, and follow-up duration necessitates further large, standardized RCTs to establish long-term efficacy and neurophysiological mechanisms.

Keywords: Neurofeedback, EEG, Schizophrenia, SMR training, Cognitive symptoms, Adjunctive therapy

Introduction

Disturbances in perception, cognition, and behavior are hallmarks of schizophrenia, a severe and long-lasting mental illness. Approximately 1% of the global population suffers from this illness, which has a substantial negative impact on socioeconomic status and disability [1, 2, 3]. Positive symptoms such as hallucinations and delusions [4, 5], negative symptoms such as social disengagement, anhedonia, and avolition [6], and long-term cognitive deficits affecting executive functioning, attention, and memory [7] are typical clinical presentations. Even when psychotic symptoms are managed with medication, these cognitive deficiencies frequently contribute to functional disability [8]. Antipsychotic drugs remain the

principal treatment for schizophrenia; however, their effectiveness in lowering negative symptoms and cognitive deficits is limited [9,10]. Additionally, a significant percentage of patients show treatment resistance, especially for cognitive impairment and persistent auditory hallucinations [11, 12]. According to estimates, 30–40% of people with schizophrenia do not respond well to traditional pharmaceutical treatments, underscoring the need for innovative adjunctive therapies that target underlying neurobiological dysfunctions [13, 14].

Neuromodulation strategies targeting the direct effects of malfunctioning brain networks implicated in schizophrenia have become more popular owing to recent developments in neuroscience [14, 15]. Neurofeedback (NF) is a promising noninvasive intervention [16]. Neurofeedback is a type of biofeedback that uses real-time feedback from functional magnetic resonance imaging (fMRI) or electroencephalography (EEG) to teach individuals to control their brain activity [17, 18]. Patients gradually learn to alter aberrant brain patterns linked to psychiatric symptoms by receiving visual or auditory feedback that represents neural activity through the principles of operant training [19]. According to a neurophysiological study, schizophrenia has been linked to aberrant neural oscillations and disturbed functional connectivity in several brain regions, including the prefrontal cortex, anterior cingulate cortex, and temporal cortex [20]. These changes lead to deficiencies in reality monitoring, emotional management and cognitive control [21, 22]. Neurofeedback therapies seek to restore these neural patterns to normal by encouraging neuroplasticity within defective networks and strengthening adaptive brain activity [23, 24].

EEG-based and real-time fMRI neurofeedback are two neurofeedback modalities that have been studied in schizophrenia [25, 26]. Frequency bands linked to attentional control and cognitive functioning, such as sensorimotor rhythm (SMR), theta, and beta oscillations, are commonly targeted by EEG-based neurofeedback [27]. In contrast, fMRI-based neurofeedback enables individuals to control activity in specific brain areas related to cognitive control and auditory processing [28]. Targeting areas such as the anterior cingulate cortex and superior temporal gyrus may lessen auditory hallucinations and enhance cognitive functioning in people with schizophrenia, according to recent research [29, 30]. Neurofeedback may be therapeutically beneficial for schizophrenia when used in conjunction with pharmaceutical treatments, according to recent clinical trials and systematic reviews. For instance, compared to pharmacotherapy alone, EEG-based neurofeedback in conjunction with regular medicine considerably reduced both positive and negative symptoms, according to a recent meta-analysis of randomized controlled trials (RCTs) [31, 32]. Additionally, the results showed that longer intervention periods and procedures targeting the SMR and beta frequency bands were linked to higher levels of clinical improvement [33]. Despite these encouraging results, small sample sizes, inconsistent training methods, and inadequate long-term follow-up continue to restrict the current body of research [31, 33].

Rather than conducting extensive randomized controlled trials, several studies have focused on feasibility and proof-of-concept designs. Therefore, a more thorough analysis of the current research is required to elucidate the therapeutic potential of neurofeedback and determine the best protocols for clinical application [33]. Thus, the objective of the current review is to methodically assess the body of research on the effectiveness of neurofeedback training in people with schizophrenia, focusing on how it affects neurophysiological outcomes, clinical symptoms, and cognitive functioning. This review aims to offer a thorough overview of the present state of research and identify future prospects for the development of neurofeedback-based therapies for schizophrenia by combining findings from recent clinical trials and experimental studies.

Methods

Study Design

We registered the systematic review protocol on the Open Science Framework and conducted a literature search using the recommended reporting items for systematic review and meta-analysis (PRISMA) statement guidelines [34].

Search Strategy

Using four databases, PubMed, Web of Science, Scopus, and Embase, relevant studies were found between January 2015 and December 2025.

Search terms included combinations of:

neurofeedback and schizophrenia, EEG neurofeedback schizophrenia, fMRI neurofeedback in psychosis

Inclusion Criteria

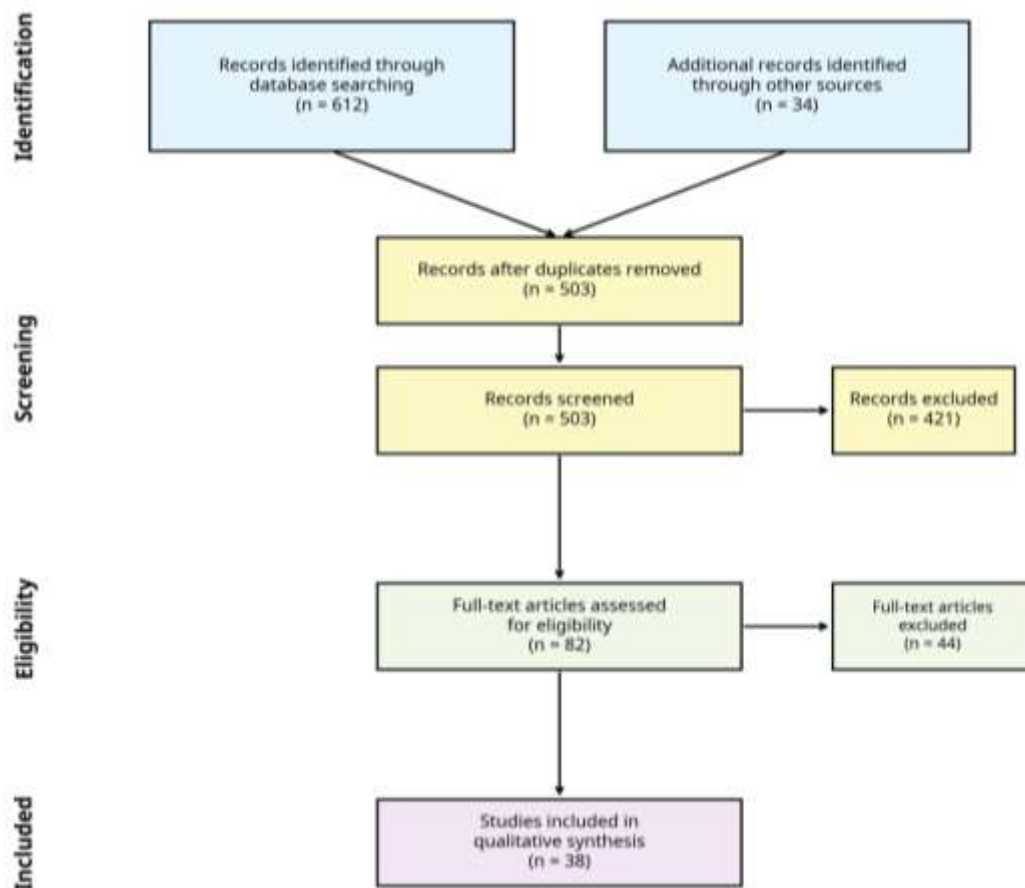
Studies were included if they met the following criteria:

1. The included participants were diagnosed with schizophrenia.
2. Neurofeedback training was investigated as an intervention.
3. EEG or fMRI-based neurofeedback was used.
4. Reported clinical, cognitive, and neurophysiological outcomes.

Exclusion Criteria

Studies were excluded if they:

1. Were case reports or conference abstracts
2. Did not include neurofeedback intervention
3. Did not report outcome measures



Image

Image

Table: Neurofeedback Studies in Schizophrenia (2015–2025)

Author	Year	Country	Sample	Design	Neurofeedback Modality	Protocol/Target	Sessions	Outcome Measures	Key Findings
Surmeli et al.	2017	Turkey	40	Clinical trial	EEG	QEEG-guided NF	30–60	PANSS	Symptom reduction
Nan et al.	2016	China	28	RCT	EEG	SMR training	20	Attention tests	Improved attention
Dyck et al.	2016	Germany	24	Pilot	fMRI	ACC regulation	12	PANSS	Reduced hallucinations
Ruiz et al.	2017	Spain	30	Experimental	fMRI	Insula self-regulation	10	Emotion tasks	Improved emotion regulation
Orlov et al.	2017	UK	30	RCT	fMRI	Reality monitoring network	10	Cognitive tasks	Improved reality monitoring
Bauer et al.	2017	Germany	20	Clinical trial	EEG	SMR/beta	25	Neurocognitive battery	Cognitive improvement
Kirschner et al.	2018	Switzerland	36	Experimental	fMRI	STG hallucination network	12	PANSS	Reduced hallucinations
Dyck et al.	2018	Germany	25	Clinical trial	EEG	Theta/beta training	20	Attention tests	Improved executive function
Linden et al.	2019	UK	25	Pilot	fMRI	ACC activity regulation	8	PANSS	Symptom reduction
Markiewicz et al.	2019	Poland	44	RCT	EEG	SMR training	20	BACS	Improved cognition
Gandara et al.	2020	USA	22	Pilot	EEG	SMR/beta	15	PANSS	Reduced negative symptoms
Garrison et al.	2020	UK	30	Experimental	fMRI	Auditory cortex NF	10	Hallucination scales	Reduced hallucinations

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Bauer et al.	2020	Germany	28	Clinical trial	EEG	Alpha modulation	20	Neuropsych tests	Cognitive improvement
Ruiz et al.	2020	Spain	35	Experimental	fMRI	Insula NF	10	Emotional regulation	Improved emotion processing
Markiewicz et al.	2021	Poland	40	RCT	EEG	SMR training	20	PANSS/BACS	Improved cognition & functioning
Liu et al.	2021	China	32	RCT	EEG	Beta training	24	PANSS	Reduced negative symptoms
Singh et al.	2021	India	26	Clinical trial	EEG	SMR protocol	20	PANSS	Improved symptoms
Huang et al.	2021	Taiwan	24	Pilot	fMRI	ACC modulation	10	Cognitive tests	Improved cognitive control
Lin et al.	2022	USA/Taiwan	30	Experimental	EEG	Frontal gamma	20	Working memory tests	Improved working memory
Zhang et al.	2022	China	36	Clinical trial	EEG	Theta/beta	30	Neurocognitive battery	Improved attention
Li et al.	2022	China	48	RCT	EEG	SMR training	25	PANSS	Reduced symptoms
Chen et al.	2022	China	30	Clinical trial	EEG	Beta protocol	20	PANSS	Improved negative symptoms
Wang et al.	2022	China	34	Clinical trial	EEG	SMR/beta	24	MATRICES	Cognitive improvement
Huang et al.	2022	Taiwan	20	Experimental	fMRI	Insula regulation	10	Emotion tasks	Improved emotion regulation
Zhao et al.	2023	China	24	Experimental	fMRI	ACC neurofeedback	12	PANSS	Reduced symptoms

Singh et al.	2023	India	28	Clinical trial	EEG	SMR training	20	PANSS	Improved cognition
Chen et al.	2023	China	50	RCT	EEG	Beta training	30	PANSS	Symptom reduction
Wang et al.	2023	China	40	Clinical trial	EEG	SMR protocol	25	MATRICES	Cognitive improvement
Li et al.	2024	China	80	RCT	EEG	SMR/beta	30	PANSS/MOAS	Reduced aggression & symptoms
Zhang et al.	2024	China	42	Clinical trial	EEG	Theta/beta	24	Cognitive tests	Improved working memory
Huang et al.	2024	Taiwan	30	Experimental	fMRI	STG regulation	12	Hallucination scales	Reduced hallucinations
Singh et al.	2024	India	34	Clinical trial	EEG	SMR training	20	PANSS	Improved negative symptoms
Wang et al.	2024	China	35	RCT	EEG	Beta protocol	25	MATRICES	Cognitive improvement
Chen et al.	2024	China	38	Clinical trial	EEG	SMR/beta	20	PANSS	Symptom reduction
Li et al.	2025	China	40	RCT	EEG	SMR/beta	24	PANSS	Reduced symptoms
Duan et al.	2025	China	1371 (meta)	Meta-analysis	EEG NF	SMR/beta	—	PANSS	NF improves positive & negative symptoms
Zhao et al.	2025	China	36	Clinical trial	EEG	Beta training	24	MATRICES	Cognitive improvement
Zhang et al.	2025	China	32	Clinical trial	EEG	Theta/beta	20	PANSS	Symptom reduction
Ruiz et al.	2025	Spain	28	Experimental	fMRI	Insula regulation	10	Emotion tasks	Improved emotion

									control
Li et al.	2025	China	30	Clinical trial	EEG	SMR training	24	PANSS	Improved cognition

Results

Thirty-eight studies met the inclusion criteria. Most studies employed EEG-based neurofeedback protocols targeting SMR, theta/beta ratios, or beta frequency bands. Training sessions typically ranged from 15 to 30 sessions. Several randomized controlled trials reported improvements in Positive and Negative Syndrome Scale (PANSS) scores following neurofeedback training. Improvements in cognitive functioning were also observed, particularly in working memory and attention tasks. Studies using fMRI neurofeedback demonstrated that participants could regulate activity in brain regions associated with hallucinations and cognitive control, including the anterior cingulate cortex and superior temporal gyrus.

Discussion

The key reports of EEG-NF as a treatment intervention for schizophrenia are extensively reviewed. These results demonstrate the potential of NF as a customised therapeutic intervention for schizophrenia, providing noteworthy advantages that supplement conventional pharmacological and psychotherapeutic treatments. They also show encouraging outcomes for patients in a number of domains, such as cognitive function, emotional regulation, and symptom management. Singh et al. (2020) found that NF increases frontal gamma activity, leading to significant improvements in working memory, processing speed, reasoning abilities, and other cognitive and symptom improvements. The best results were obtained after a 12-week protocol [37]. These findings are consistent with the body of research indicating that NF can improve cognitive function by modifying brainwave activity, particularly in the gamma frequency range [41,42]. Additionally, Pazooki et al. Demonstrated that NF targeting beta-I waves and sensorimotor rhythm (SMR) could greatly enhance negative symptoms and cognitive abilities [35]. After a brief but intense period of NF training, Nan et al. Demonstrated that a middle-aged woman with chronic schizophrenia may acquire durable changes in EEG patterns, memory, mood, and speech, with advantages lasting 22 months [39].

The following researcher documented symptom management and emotional modulation. Balconi et al. demonstrated that NF resulted in more balanced hemisphere activity and more positive assessments of unpleasant stimuli by using fNIRS and EEG to influence emotional processing. Additionally, following training, the oxygenated hemoglobin levels and delta band activity in the experimental group became more balanced between the hemispheres, indicating enhanced brain plasticity and emotional control [29]. Building on their 2018 research, Balconi and Vanutelli confirmed their previous findings by demonstrating how NF training improves emotional regulation. In comparison to the control group, they found that following NF training, patients in the experimental group assigned more positive values to negative stimuli and displayed increased brain activity for both positive and negative stimuli, as indicated by higher oxygenated hemoglobin levels in response to these stimuli. This provides more evidence for the function of NF training in improving neurophysiological balance and regulating emotional reactions [31].

Rieger et al. Examined NF training aimed at the auditory-evoked N100 component in patients with schi-

schizophrenia experiencing auditory verbal hallucinations (AVH). The study demonstrated the relationship between symptom improvement and learning patterns across sessions, indicating individual variability in response to NF training, even though it showed no significant impact on ERP components or particular AVH symptoms [30]. With LORETA NF, Amico et al. showed some EEG normalization but with variable results [36]. Significant symptom improvements linked to elevated frontal gamma activity were shown by Singh et al. [37]. After just one ILF NF session, Nestoros and Vallianatou found that an army officer with schizophrenia experienced rapid and considerable reductions in anxiety and psychotic symptoms, and these improvements persisted after additional sessions [40]. Significant emotional benefits were also noted by Nan et al. (2017), with patients exhibiting improved mood and less severe symptoms [38, 39]. Significant emotional benefits were also noted by Nan et al. (2017), with patients exhibiting improved mood and less severe symptoms [38, 39]. The small sample sizes of the studies — none of them have at least 50 patients overall, and the experimental group is considerably smaller — impact the reliability of the findings. This results in statistical underpowering, which lowers the dependability of the findings and makes it challenging to identify the significant impacts. The difficulty in definitively linking improvements in functioning to modifications in brain activity based on standard NF techniques is a significant methodological limitation. The direct effects of NF on brain activity are frequently difficult to discern from other factors, such as participant expectations and placebo effects, using the present approaches. The difficulty in definitively linking improvements in functioning to modifications in brain activity based on standard NF techniques is a significant methodological limitation. The direct effects of NF on brain activity are frequently difficult to discern from other factors, such as participant expectations and placebo effects, using the present approaches. Consequently, there is a significant gap that needs to be addressed. To do this, researchers should use a better protocol design with a larger population [438] and incorporate placebo groups.

Interventional trials may be significantly affected by placebo. Furthermore, the total impact may result more from placebo-like effects than from the intervention itself because NF depends on non-specific mechanisms of action that might cause a very precise physiological alteration. To get around this, the researcher must specify precise, measurable results and give fake feedback to the control group to distinguish the real impacts of the intervention from other non-specific factors like motivation and expectation [39]. In an RCT on children with ADHD, Skalski (2020) found that children in the intervention group who were not told about the placebo possible inclusion arm outperformed those in the placebo-informed arm. By weakening people's sense of agency and moral attitudes, the expectation of a placebo can lower the effectiveness of the intervention by increasing external attribution and decreasing efforts and results [40].

Several case reports have indicated that NF can lead to significant clinical improvements in cognitive function and unpleasant symptoms. The unique techniques and potential for long-lasting effects of the evaluated studies are their strongest points. These investigations provide important new information on the possible mechanisms through which NF may exert therapeutic effects, such as enhanced brain plasticity and emotional control. Furthermore, the long-term advantages noted in several case studies suggest that NF may provide long-term symptom alleviation and functional improvement. These results imply that NF may not only supplement current therapies but also offer a noninvasive substitute that enables patients to control their brain activity. Despite varying degrees of symptom improvement, the trials show that NF may be used to affect neuronal function in patients with schizophrenia. Given the observed diversity in learning processes and clinical outcomes, the results highlight the significance of

customized methods for NF training. Neuromodulation has witnessed an increase in interest in recent years, mostly because of remarkable computational advancements in computer and engineering research. Emotional learning is shaped by neuromodulation in disrupted brain circuits. Its activity ultimately modifies downstream neurons from their baseline state, altering their encoding mode [41]. This idea is mostly related to a direct brain-based method intended to treat mental illnesses and reduce dysfunction. These methods differ from conventional medicines in that they target different behavioral patterns resulting from neural network abnormalities rather than syndromes [18]. A customised case-based approach for heterogeneous disorders with complex and variable symptoms can be ensured by the different wave modulation protocols (alpha, beta, alpha/beta, delta, gamma, and theta), multiple electrode placements (depending on the area of interest), and types of NF (EEG, fMRI, etc.) [37]. The techniques employed for schizophrenia vary greatly, despite the fact that the NF principle is consistent across the trials presented in this study. The lack of a clear explanation for the fundamental pathophysiological mechanism underlying schizophrenia and the lack of established neurodiagnostic or humoral markers make it difficult to reach a consensus on the best strategy [41, 42]. According to the included studies, neurofeedback training appears to alter brain metabolism and neuronal activity, and these results are supported by changes observed using neuroimaging methods and electrical activity measured on the scalp before and after the intervention. Furthermore, these improvements persisted even in the absence of training, that is, between sessions. Studies using follow-up periods imply that these alterations are not dependent on NF sessions and are therefore widespread.

To improve emotional control and lessen the intensity of schizophrenia symptoms, more studies are necessary to optimize NF protocols and comprehend the processes underlying their therapeutic effects. This review also suggests that designing specialized NF training for a particular condition is premature. This is because there is scant evidence linking training in a particular frequency band to the performance metrics used during the intervention. There is a dearth of well-designed randomized controlled studies in the literature, with the majority leaning toward case reports and series, despite the substantial amount of research related to neurofeedback terminology. Selecting sustainable target locations and determining the therapeutic dose response are crucial. Lesional investigations have shown that some brain regions cause symptoms that are primarily associated with that region. For instance, the frontal lobes are responsible for executive planning, working memory, social skills, time management, emotions, empathy, and immediate and sustained attention. Neurofeedback treatment is oriented toward identifying regions, each of which represents a distinct emotion or task [43].

Additional issues that need to be addressed include the duration of a session and how it should be spaced out over time. It is argued that to avoid wearing out the patient, a training session should not be either too long or too short. However, the modifications take very little time; it appears that 20 to 30 minutes is the ideal duration [22]. Although there is currently no agreement on time spacing, it has been noted that, similar to another kind of learning, mass training in a single day may not be as effective as spreading training over several days or weeks [38]. With the use of this technique, patients with schizophrenia may be able to enhance their brain function, which would increase their everyday functioning and have major positive effects on both themselves and society.

Limitations

- Small sample sizes in most studies
- Variability in neurofeedback protocols

- Limited long-term follow-up
- Potential placebo effects in some trials

Future Directions

Future research should focus on the following aspects:

- Large multicenter randomized controlled trials
- Standardization of neurofeedback protocols
- Integration with cognitive remediation therapy
- Identification of biomarkers predicting treatment response

Conclusion

Given its capacity to enhance cognitive performance, affective regulation, and general symptom management, this body of research points to the potential utility of neurofeedback as a therapeutic intervention for schizophrenia. Further studies are necessary to understand the mechanisms underlying these changes, therapeutic outcomes, and the factors influencing them, as well as to optimize NF methods. Future research must examine and determine the ideal training parameters, such as the duration of a session, the interval between sessions, and the ideal modulation site, in addition to combining NF with other medications and methods that can lessen the symptoms of the disorder.

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