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Mapping Protocols and Evidence on Combined EEG Neurofeedback and Meditation: A Systematic Review

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Abstract

Background. The combination of meditation and EEG neurofeedback has gained attention as a nonpharmacological approach for emotion regulation, stress reduction, and cognitive enhancement. **Methods.** This systematic review, registered in PROSPERO (CRD42024554716) and conducted in accordance with PRISMA guidelines, aimed to map methodologies, protocols, and evidence on these combined interventions. Experimental or quasi-experimental empirical studies involving human participants across ages and contexts, published between 2015 and 2025, were included. Searches across six databases yielded 356 records; 45 met eligibility criteria. **Results.** Studies showed substantial methodological heterogeneity, with a predominance of randomized clinical trials (44%) and within-subject designs (33%). Focused attention and mindfulness meditations and auditory feedback prevailed; wearable devices were used in 35 studies. Intervention dose varied widely, from 1 to 50+ sessions, ranging from 1.5 to 80 min long. Primary outcomes consistently showed reductions in stress, anxiety, depression, and fatigue, alongside gains in well-being, attention, and resilience. Neurophysiological findings included increases in alpha and theta power. **Conclusions.** Combining meditation with EEG neurofeedback is a promising strategy, but the lack of protocol standardization, small sample sizes, and limited blinding reduce evidence robustness. Future research with rigorous methodology is needed to establish clinical efficacy and guide interventions.

Keywords: neurofeedback; meditation; mindfulness; electroencephalography; brain-computer interface

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Background

Meditation encompasses a broad set of practices aimed at enhancing physiological, behavioral, and cognitive self-regulation by inducing specific attentional states (Davidson & Goleman, 1977; Shapiro & Giber, 1978). Rooted in Buddhist and yogic traditions, it has been reframed by contemporary science as a technique capable of producing psychosomatic effects and promoting psychological well-being (Brandmeyer & Delorme, 2018; Fincham et al., 2023). Empirical studies associate meditation with reductions in stress- and anxiety-related symptoms (Brandmeyer & Delorme, 2018; Shapiro & Giber, 1978) and with improved cognitive functioning (Basso et al., 2019; Lodha & Gupta, 2022). Although modalities vary, such as concentrative practice and mindfulness, they share two core components: deliberate attention orienting and cognitive-emotional self-regulation (Goleman, 1988).

Meditation is increasingly recognized for its potential to induce measurable neurophysiological changes. Regular practice can alter the autonomic nervous system, increasing heart rate variability (HRV; Y.-H.

Lee et al., 2022), lowering cortisol (Aguilar-Raab et al., 2021), and regulating skin-conductance reactivity (Boxmeyer et al., 2023), indices commonly associated with reduced stress and anxiety. Electroencephalogram (EEG) studies also reveal consistent changes, mostly including increased alpha and theta activity which are linked to relaxation and sustained attention, respectively (Cahn & Polich, 2006). These findings suggest that meditation not only shapes cognitive-emotional states but also modulates brain activity in ways that can be measured and potentially trained.

Building on this principle of neurophysiological self-regulation, EEG neurofeedback is an expanding field at the interface of applied neuroscience and clinical psychology that provides a brain self-regulation technique based on real-time monitoring of cortical electrical activity (Bielas & Michalczyk, 2021; Cantor, 2009; Hampson et al., 2020). Registered neural signals are processed and delivered as visual and/or auditory feedback, enabling individuals to learn how to voluntarily modify their brain-activity patterns (Hammond, 2011). This approach has been widely studied as a therapeutic tool for attention-deficit/hyperactivity disorder (ADHD; Arns et al., 2020; Butnik, 2005; Van Doren et al., 2019), anxiety (Aristizabal et al., 2024; Chen et al., 2021; Christian et al., 2024), and depression (Patil et al., 2023; Takamura et al., 2020; S.-Y. Wang et al., 2019), as well as in performance optimization contexts (Faller et al., 2019; Mikicin et al., 2015).

Neurofeedback and meditation have been examined in isolation and in combination as nonpharmacological interventions to enhance psychological well-being and emotion regulation (Brandmeyer & Delorme, 2013; Tarrant, 2020). However, there is still a gap in the literature regarding how their integration has been explored and how to optimize such protocols. In fact, studies show substantial methodological heterogeneity, complicating comparability, limiting generalizability, and hindering evidence-based guidelines development.

Given this context, this systematic review aims to critically map the existing evidence, not only to identify trends and gaps, but also to inform more consistent and replicable future investigations. Therefore, we examine studies combining meditation and neurofeedback as interventions across different human conditions, focusing on methodological designs, implemented protocols, and clinical and nonclinical contexts. In addition to synthesizing reported outcomes, the review provides a critical appraisal of the risk of bias in the included studies.

Method

This systematic review was preregistered in PROSPERO (https://www.crd.york.ac.uk/PROSPERO/view/CRD42024554716; accessed June 4, 2024) under CRD42024554716 and conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

Search Strategy

The search was performed in six databases (EBSCO, PubMed, Web of Science, LILACS-BVS, *Periódicos* CAPES, and Scopus), using descriptors covering multiple denominations of the techniques. Key terms included *neurofeedback*, *EEG biofeedback*, *neural biofeedback*, *brain-computer interface* (BCI), *wearable devices*, *meditation*, *meditative state*, *mindfulness*, *relaxation*, *imagery*, and *breath focus meditation*. Terms were combined using the following Boolean expression: ("Neurofeedback" OR "EEG biofeedback" OR "biofeedback neural" OR "Brain Computer Interface" OR "BCI" OR "wearable devices") AND ("meditation" OR "meditative state" OR "mindfulness" OR "relaxation" OR "imagery" OR "breath focus meditation").

Selection Criteria and Process

Eligible studies were empirical with experimental or quasi-experimental designs evaluating combined neurofeedback and meditation interventions. Studies had to manipulate the variables of interest and report outcomes in mental health, cognition, behavior, or well-being using validated instruments. Articles published from 2015 to 2025 in English, Portuguese, or Spanish with human participants of any age and gender were eligible.

Exclusion criteria included theoretical papers, systematic reviews, meta-analyses; studies involving animals; and studies of other interventions (e.g., biofeedback, pharmacotherapy, psychotherapy) without a clear separation of effects attributable solely to neurofeedback and meditation. Titles and abstracts were screened independently by the two first authors; disagreements were resolved by a third reviewer. In the second stage, each full text was read by at least two researchers, with collective discussion for final inclusion.

Data Extraction and Analysis

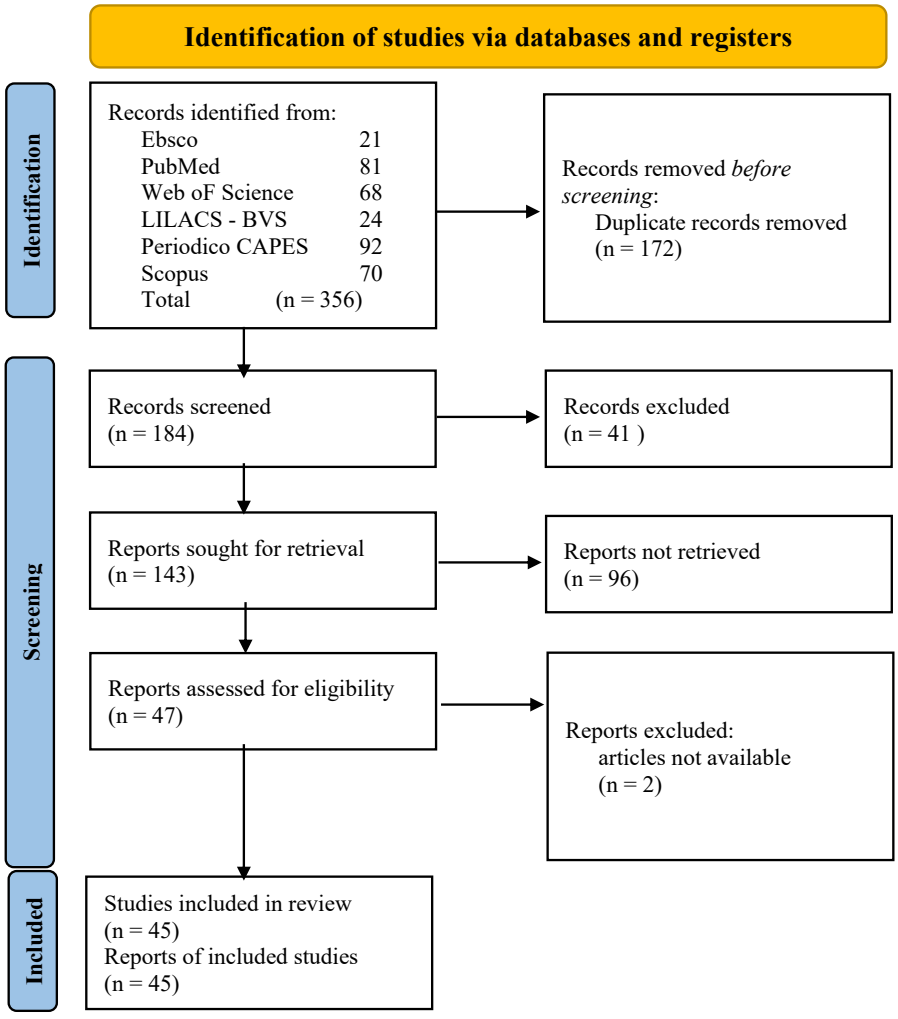
Data were extracted independently by the first four authors and organized in Microsoft Excel 2019 to present, clearly and systematically, methodological characteristics and intervention protocol details, following the PICOS strategy (Population, Intervention, Comparator, Outcomes, Study design), as recommended by the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins et al., 2022) and the PRISMA checklist (Page et al., 2021).

Key information targeted herein included methodological characteristics and intervention protocol specifics (please see Tables 3 and 5, respectively, in the Results section). Outcome-based analyses within each of these dimensions were subsequently conducted, generating graphs and descriptive statistics (means, percentages, trends, distribution patterns) to provide an integrated view of the current literature. Additionally, a risk-of-bias assessment was conducted for the included studies (please see Table 6 and Figure 7 in the Results section).

Results

The initial search identified 356 records; after screening and exclusions, 47 studies remained for eligibility assessment. Two lacked full-text availability, resulting in 45 studies included in the review. Figure 1 displays the flow diagram for the search, screening, and exclusion process according to the predefined criteria.

Figure 1. *Flowchart Study Selection.*



After the selection stage, the first four authors independently read the articles in full and extracted relevant data. The collected information was organized into two main tables (Tables 3 and 5).

General Characteristics

The analyzed data show a gradual increase is evident over 2015–2024, with a more pronounced rise from 2019 onward, as can be seen in Figure 2.

Moreover, Figure 3 and Table 1 present the geographic distribution of publications, with the United States accounting for 17 of 45 studies, underscoring its leading role in the field. The analysis identifies both high-producing countries and underrepresented regions, such as Latin America, where a notable gap indicates opportunities for local development and implementation of the interventions.

Figure 2. *Selected Publications by Year.*

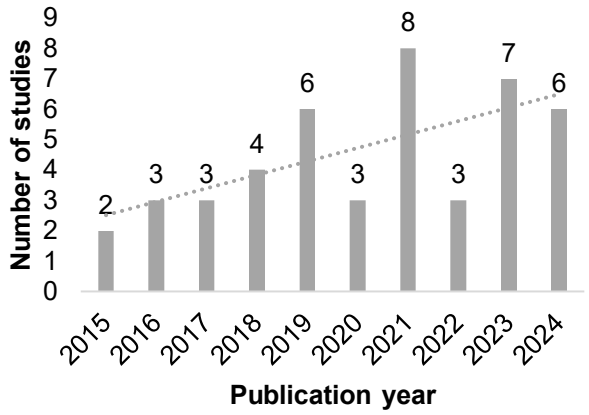


Figure 3. *Geographical Distribution of Studies*.

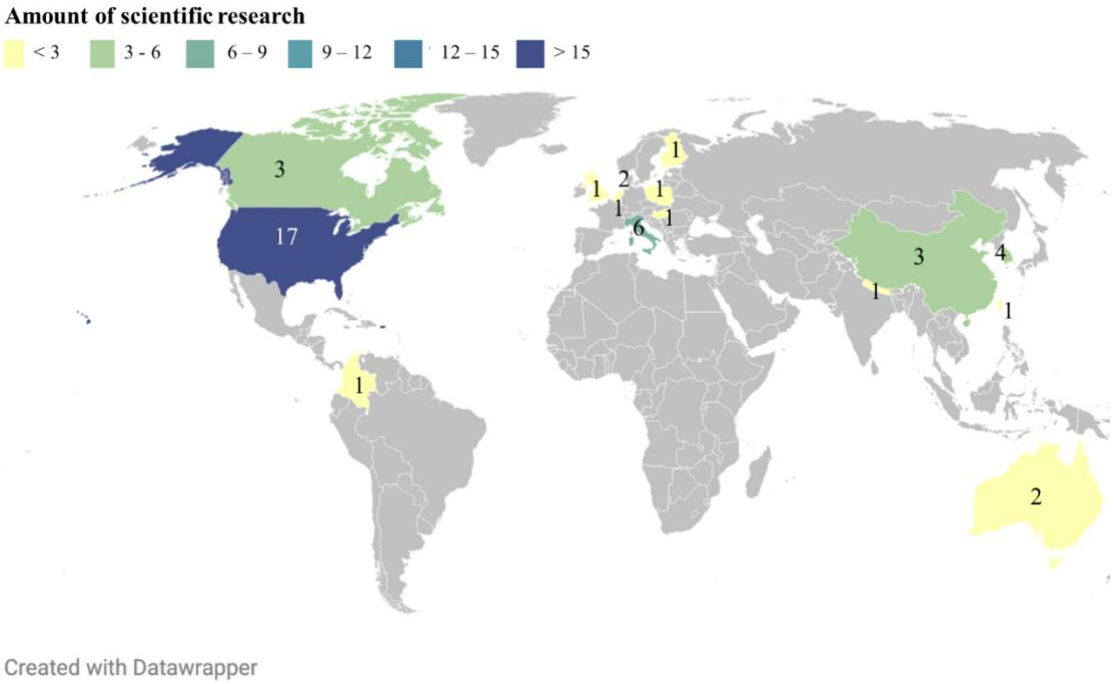


Table 1
Studies' Distribution Worldwide

Country	Amount of Scientific Research
United States of America	17
Italy	6
South Korea	4
Canada	3
China	3
Australia	2
Netherlands	2
Belgium	1
Colombia	1
Finland	1
Hungary	1
Nepal	1
Poland	1
Taiwan	1
United Kingdom	1

Regarding sample size and age, the mean sample size of the selected studies was 39.6 participants with substantial variability (*SD* = 28.6), indicating wide differences across studies. This range spans from case reports, such as Tarrant and Cope (2018) with firefighters, to larger samples, such as P. Wang et al. (2023) with 120 participants. Such heterogeneity reflects diverse methodological approaches, from exploratory and pilot studies to more structured clinical trials. Further, there was a predominance of female participants, averaging 60.1% (*SD* = 22.7). Summary of sample size, age and sex can be seen in Table 2.

Table 2
Population Characteristics

	N	**% Female**	**Mean Age (Years)**
Mean (*SD*)	39.6 (28.6)	60.1 (22.7)	34.3 (14.2)

In turn, the mean participant age was 34.3 years (*SD* = 14.2), indicating that young and middle-aged adults were the primary target population. Figure 4 depicts the distribution of mean-age intervals. A predominance of studies enrolled participants aged 20–30 years (*n* = 14). Only one study included children aged 0–10 years (Vekety et al., 2022) and another included older adults aged 70–80 years (P. Wang et al., 2023), highlighting a gap in the application of these interventions to extreme age ranges.

Notably, seven studies did not explicitly report mean age (Antle et al., 2018; Balconi et al., 2017; Choi et al., 2024; Martinez & Zhao, 2018; McMahon et al., 2021; Mikicin et al., 2015; Nieto-Vallejo et al., 2021), and six did not report gender (Balconi et al., 2017; Chen et al., 2021; Crivelli, Fronda, & Balconi, 2019; Crivelli, Fronda, Venturella, et al., 2019b; Hawley et al., 2021; Nieto-Vallejo et al., 2021). This omission constitutes a relevant methodological limitation, as the absence of these basic data hampers assessment of sample representativeness and the generalizability of results.

Finally, based on clinical and functional similarities, the investigated conditions were grouped into seven broad categories, synthesizing the diversity of therapeutic goals and application contexts of the interventions.

As can be seen in Figure 5, a predominance of research focuses on anxiety, mood, and stress disorders, represented in 19 of the 45 articles analyzed. This category ranges from isolated manifestations of anxiety or stress, as in Balconi et al. (2019), to complex constellations of symptoms, including burnout, depression, emotional exhaustion, and resilience, as in the study conducted by Ghosh et al. (2023). The emphasis on these clinical presentations underscores their relevance to contemporary mental health and points to the therapeutic potential of combining the techniques as strategies for regulating affect and psychophysiological stress.

The second most frequent category concerns cognitive performance and attentional regulation, covered in eight studies. These investigations examine interventions aimed at enhancing executive functions such as attentional control (Hunkin et al., 2021a; Vekety et al., 2022), impulsivity (van der Schoot et al., 2024), and performance on specific cognitive tasks, including working memory and reaction time (Brandmeyer & Delorme, 2020).

Figure 4. *Mean Ages Distribution.*

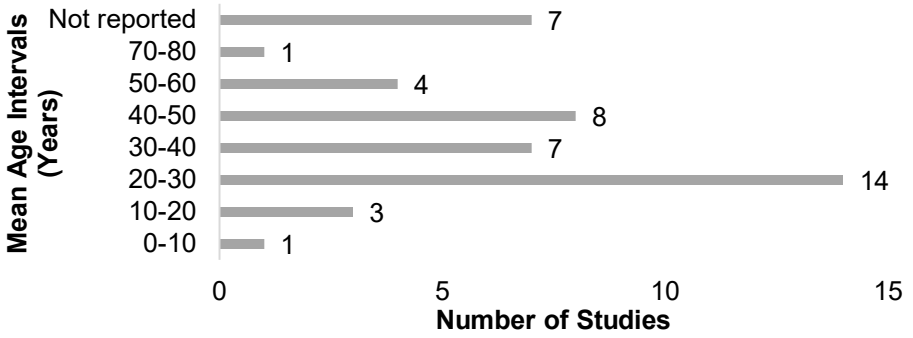


Figure 5. *Distribution of Conditions by Category.*

The presence of this category indicates interest in applications that increase performance in healthy populations or in high cognitive-demand settings.

Other less represented yet relevant categories include specific neurological and medical conditions, such as multiple sclerosis (Motolese et al., 2023), cancer (Millstine et al., 2019; Rolbiecki et al., 2023), atrial fibrillation (He et al., 2023), and poststroke sequelae (P. Wang et al., 2023), as well as traumatic brain injury (Polich et al., 2020). Additional studies addressed specific psychiatric disorders, including obsessive-compulsive disorder (Hawley et al., 2021), posttraumatic stress disorder (Choi et al., 2024; Schuurmans et al., 2021), and substance use disorders (Chiu et al., 2024).

Furthermore, interventions focused on the effects of the techniques on meditative states and mindfulness experiences were identified. These studies evaluated participants' ability to attain meditative states (Hunkin et al., 2021b; Sas & Chopra, 2015), the depth of these states (Kosunen et al., 2016), and the development of skills related to mindfulness and relaxation (Salminen et al., 2024; van Lutterveld et al., 2017). Unlike investigations centered on specific conditions such as anxiety or depression, these works primarily examined how combined use of the techniques facilitated induction of meditative states and improved meditation quality.

This thematic diversity demonstrates the breadth of contexts in which neurofeedback and meditation are applied, while also reinforcing clinical and methodological heterogeneity across studies that should be considered when interpreting results.

Methodological Characteristics

Table 3 synthesizes the methodological characteristics, accompanied by figures and summary analyses.

Table 3
Methodological Characteristics of the Included Studies

Participants' Characteristics					Study Design				
Authors (Year)	*N*	% Female	Population Type	Mean Age (*SD*)	Condition	Study Design	Control Condition	Randomization	Blinding
Acabchuk et al. (2021)	53	73.10	Healthy university students, novice meditators	20.52 (2.76)	Depression, anxiety, stress	RCT	AC	Yes	No
Antle et al. (2018)	21	100	Girls in poverty with trauma history	5–11*	Anxiety and attention	Mixed-methods field experiment with control and repeated measures	PC (waitlist)	Yes	No
Balconi et al. (2017)	40	NR	University students	NR	Mild to moderate stress	RCT	AC	Yes	No
Balconi et al. (2019)	55	69	Healthy university adults	23.2 (1.8)	Mild stress	RCT with pre/post measures	AC	Yes	No
Bhayee et al. (2016)	26	46	Adults with moderate/high stress	Exp: 33.3 (4.7) Control: 32.0 (4.9)	Stress	RCT with repeated measures	AC	Yes	Allocation blinding
Brandmeyer & Delorme (2020)	24	50	Young healthy adults	25 (3)	Cognitive enhancement (working memory, reaction time)	Double-blind sham-controlled RCT	Sham control group	Yes, and counterbalanced	Double-blind
Chen et al. (2021)	34	NR	Adults with/without anxiety symptoms	Anxious: 37 (7.61) Healthy: 24.4 (1.49)	Anxiety	Mixed design: between-subjects (control) and within-subjects (repeated measures)	Condition comparison	NA	No
Chiu et al. (2024)	110	18.20	Adults with substance use disorder (SUD)	37.77	Substance use disorder (SUD)	Multicenter quasi-experimental within-subjects	Pre/post	No	No
Choi et al. (2024)	58	86.20	Adults with trauma history	18–45*	Posttraumatic stress disorder (PTSD)	RCT	PC (waitlist)	Yes	Data analysts
Christian et al. (2024)	5	40	High-achieving adolescents with anxiety	16.4 (0.55)	Anxiety and high performance	Single-case design (A-B-A), within-subjects, with follow-up	A1, B1, A2	NA	No

Table 3

Methodological Characteristics of the Included Studies

Participants' Characteristics					Study Design				
Authors (Year)	***N***	**% Female**	**Population Type**	**Mean Age (*SD*)**	**Condition**	**Study Design**	**Control Condition**	**Randomization**	**Blinding**
Crivelli, Fronda, & Balconi (2019)	50	NR	Healthy adults, athletes/non-athletes	22.94 (2.22)	Attention, perceived stress, anxiety, psychological well-being	Three-group experimental design (athletic, non-athletic, AC) with pre/post evaluation	AC	Yes	No
Crivelli, Fronda, Venturella, et al. (2019a)	16	50	Executive professionals	44.38 (6.22)	Stress management and neurocognitive efficiency	Quasi-experimental within-subjects	Pre/post	No	No
Crivelli, Fronda, Venturella, et al. (2019b)	40	NR	Adults with mild stress	23.47 (2.33)	Mild stress symptoms	RCT	AC	Yes	No
Dunham et al. (2019)	Exp 57 Ctrl 191	80.7	Trauma center healthcare providers	36.5 (11.8)	Stress, emotional exhaustion, burnout risk	Non-randomized quasi-experimental	PC	No	No
Ghosh et al. (2023)	40	85	Pandemic frontline healthcare workers	41.3 (11.0)	Stress, burnout, depression, resilience, cognition	Pilot quasi-experimental within-subjects	Pre/post	No	No
Gu & Frasson (2017)	6	33	Healthy adults	29.67 (4.84)	Mild symptoms of stress, anxiety, and depression	Quasi-experimental within-subjects	Pre/post	NA	No
Hawley et al. (2021)	71	NR	Adults with OCD	26 (4.61)	OCD	RCT	PC (waitlist)	Yes	Data analysts
He et al. (2023)	80	39	Patients with atrial fibrillation	59 (11)	Atrial fibrillation (post ablation)	RCT	AC	Yes	Data analysts
Hunkin et al. (2021a)	35	58.82	Healthy university students	22.66 (7.35)	Mindfulness state and meditative experience	Within-subjects crossover experimental design	Condition comparison	Condition	No

Table 3
Methodological Characteristics of the Included Studies

Participants' Characteristics					Study Design				
Authors (Year)	***N***	**% Female**	**Population Type**	**Mean Age (*SD*)**	**Condition**	**Study Design**	**Control Condition**	**Randomization**	**Blinding**
Hunkin et al. (2021b)	68	59	Healthy adults	22.66 (7.35)	Attention regulation and cognition	Observational study (within- and between-subjects analysis)	Condition comparison	NA	No
Hwang et al. (2017)	24	75	University students	Male: 23.32 Female: 22.22	Psychological /emotional well-being and psychosocial flourishing	RCT	PC + AC	Yes	No
Kosunen et al. (2016)	43	60	Healthy university students	28.7	Meditative depth and presence	2×2 factorial within-subjects repeated measures design	Condition comparison and pre/post	Yes	No
E. Lee et al. (2024)	38	68.40	Adults with stress, depression, and/or sleep disorders	49.1 (12.15)	Stress, depression, sleep disorders	RCT	AC	Yes	Double-blind
Martinez & Zhao (2018)	19	58	Adolescents with disciplinary issues	NR	School disciplinary difficulties	Matched quasi-experimental	PC	No	No
McMahon et al. (2021)	5	40	Students with mild/moderate intellectual and developmental disabilities (IDD)	18–25*	Cognitive/adaptive deficits (IDD)	Single-case design (A-B-A-B), within-subjects	A1, B1, A2, B2	NA	No
Mikicin et al. (2015)	35	42.86	Healthy semi-professional university athletes	18–25*	High sports performance	Quasi-experimental	PC	NR	No
Millstine et al. (2019)	28	100	Women with recent breast cancer diagnosis	55.85 (10.8?)	Breast cancer (stress, fatigue, quality of life)	RCT with follow-up	PC	Yes	No

Table 3
Methodological Characteristics of the Included Studies

Participants' Characteristics					Study Design				
Authors (Year)	***N***	**% Female**	**Population Type**	**Mean Age (*SD*)**	**Condition**	**Study Design**	**Control Condition**	**Randomization**	**Blinding**
Min et al. (2023)	92	90	Adults with high stress	38.67 (10,82)	Stress	RCT with three parallel arms	AC + PC	Yes	No
Motolese et al. (2023)	27	69	Adults with multiple sclerosis	46.1 (8.7)	Multiple sclerosis: mood, cognition, QoL, fatigue	Quasi-experimental within-subjects	Pre/post	No	No
Nieto-Vallejo et al. (2021)	9	NR	Young healthy adults	20–35*	Attention and relaxation	Quasi-experimental within-subjects	Pre/post	No	No
P. Wang et al. (2023)	120	23.3	Stroke patients with hemiplegia	77.7 (7.44)	Poststroke hemiplegia	RCT	AC	Yes	Data analysts
Polich et al. (2020)	20	85	Adults with mild/moderate traumatic brain injury (TBI)	45.4 (3.0)	Chronic mood /cognitive symptoms post-TBI	Pilot RCT	AC	Yes	No
Rolbiecki et al. (2023)	15	53	Adults with cancer	52.4 (11.8)	Cancer-related pain and anxiety	Exploratory single-group quasi-experimental mixed-methods	Pre/post	No	No
Salminen et al. (2024)	43	60.50	Healthy university adults	28.7 (age range 20–48)	Meditative state, concentration, relaxation	Within-subjects mixed factorial design	AC + PC	Condition	No
Sas & Chopra (2015)	16	62.50	Healthy adults, novice /experienced meditators	41 (age range 20–60)	Mindfulness state and meditative experience	Quasi-experimental mixed design (within-subjects: control/monaural /binaural; between-subjects: expertise level)	Condition comparison and pre/post	Yes	No
Schuurmans et al. (2021)	77	40.30	Institutionalized adolescents	15.25 (1.79)	Posttraumatic stress disorder (PTSD)	RCT	AC	Yes	No
Smarinsky et al. (2023)	13	62	High school students with anxiety	17.1 (0.61)	Anxiety and introspection	Quasi-experimental time-series within-subjects	Pre/post	NA	No

Table 3

Methodological Characteristics of the Included Studies

Participants' Characteristics					Study Design				
Authors (Year)	***N***	**% Female**	**Population Type**	**Mean Age (*SD*)**	**Condition**	**Study Design**	**Control Condition**	**Randomization**	**Blinding**
Soriano et al. (2024)	31	81	Healthy adults	23.16 (age range 18–30)	*Alpha* power self-regulation	Within-subjects experimental design	Condition comparison and pre/post	Yes, and counterbalanced	Condition blinded
Svetlov et al. (2019)	S1: 99 S2: 46	77	University and general population	18–72*	Stress	S1: Within-subjects RCT; S2: Between-subjects RCT	S1: Condition comparison S2: AC	Yes	No
Tarrant & Cope (2018)	4	0	Firefighters	39.5 (5.6)	Mood and gamma patterns	Within-subject case study	Pre/post	No	No
Tarrant et al. (2022)	100	91	COVID-19 frontline healthcare workers	Control: 40.9 (13.9) Exp: 42.6 (14.4)	Positive/negative mood states	Between-subjects RCT with repeated measures (pre/post)	AC	No	No
van der Schoot et al. (2024)	8	75	Forensic outpatients with impulse control issues	40.88 (12.28)	Impulse control	Pilot quasi-experimental within-subject mixed-methods	Pre/post	NA	No
van Lutterveld et al. (2017)	32	34	Healthy adults, novice /experienced meditators	Novices: 51 (14) Expert: 53 (12)	Meditative state, concentration, relaxation	Double-blind randomized within-subjects experiment with feedback manipulation	Condition comparison and pre/post	Yes	Double-blind
Vekety et al. (2022)	31	51	Elementary school children	9.92 (4.35)	Attention	Pilot RCT	PC	Yes	No
Viczko et al. (2021)	41	68.29	Adults with moderate /severe anxiety or depression	35.4 (11.6)	Anxiety and depression	RCT	AC	Yes	Participant allocation

Note. AC = active control; PC = passive control; NR = not reported; NA = not applicable; RCT = randomized controlled trial; OCD = obsessive-compulsive disorder. *Age-range reported when mean age and standard error are not available in the original paper.

Firstly, the selected studies were classified into six broad categories and their percentage distribution presented in Figure 6.

The data indicate that randomized controlled trials (RCTs) were the most frequent design, representing 44% (*n* = 20) of the total sample. Within-subject designs were the second most common, accounting for 24% (*n* = 11). This design is particularly useful in exploratory studies or when participant selection is constrained by specific clinical conditions such as cancer (Rolbiecki et al., 2023), multiple sclerosis (Motolese et al., 2023), or substance use disorders (Chiu et al., 2024).

Quasi-experimental designs ranked third, comprising 18% of studies (*n* = 8). These studies assigned participants to conditions without random assignment.

The remaining categories were less represented and deviated and often adopted more individualized or integrative approaches, differing from traditional group-based experimental designs. Although less prevalent, these formats provide valuable contributions, particularly for exploring complex contexts, generating hypotheses, or deepening understanding of specific phenomena. For example, the case studies by Christian et al. (2024) and McMahon et al. (2021), which used an A–B–A design, enabled detailed analysis of interventions in individual cases. In this type of experimental design, an initial baseline phase (A) is followed by an intervention phase (B) and then a return to the baseline (A) without intervention. This sequence allows researchers to observe changes in the target behavior during and after the intervention, strengthening causal inferences by showing whether effects disappear or reappear when the intervention is withdrawn. Mixed-methods studies, such as those by Antle et al. (2018) and Rolbiecki et al. (2023), integrated quantitative and qualitative data, broadening understanding of both effects and processes involved. Finally, observational studies also yielded important descriptive evidence, exemplified by Hunkin et al. (2021b), which applied an observational design with within- and between-subjects analyses.

Furthermore, control strategies, randomization, and blinding were assessed and are summarized in Table 4.

Figure 6. *General Categories of Study Designs.*

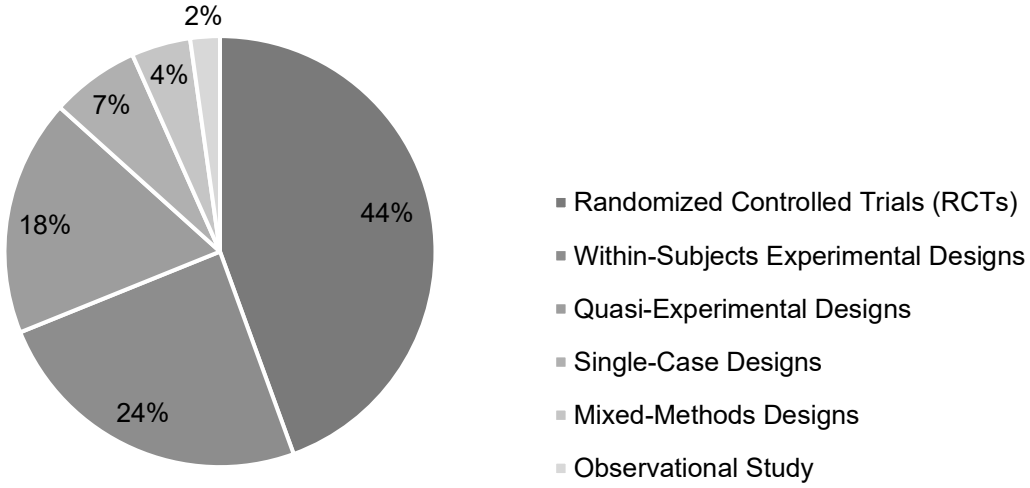


Table 4
Control Strategy, Randomization, and Blinding

Control Strategy	Number of Studies	Percentage
Active control	14	31.11%
Passive control	8	17.78%
Pre/post measures (within-subjects)	10	22.22%
Condition comparison	9	20.00%
Sham/placebo control	1	2.22%
Active + Passive control	3	6.67%
Randomization	**Number of Studies**	**Percentage**
Yes (randomized)	27	60%
No (not randomized)	10	22%
Not applicable	7	16%
Not reported/unclear	1	2%
Blinding	**Number of Studies**	**Percentage**
No blinding	35	77.78%
Blinded data analysts	4	8.89%
Double-blind	3	6.67%
Allocation blinding	2	4.44%
Condition blinding	1	2.22%

Building on these methodological features, we next detail the neurofeedback protocols implemented and the outcomes reported across studies. Table 5 provides a summary of key intervention features across the included studies, including equipment type, feedback modalities, neurofeedback protocols, meditation approaches, session number and duration, assessment strategies, and outcomes, which are subsequently described in detail.

The interventions were characterized primarily by the use of wearable devices to deliver neurofeedback, reported in 35 of the 45 included studies (78%). Their widespread adoption likely reflects accessibility, portability, and ease of use (Peake et al., 2018), which facilitate deployment in settings with lower technical demands and for practical, low-cost protocols. Only 10 studies employed conventional EEG equipment, typically used in laboratory or clinical contexts (Sharma & Meena, 2024).

As regards to feedback, most studies (60%) used auditory feedback, usually delivered either as simple sounds, such as pure tones, or as more complex soundscapes modulated in real time by the user's brain activity. Modulation occurred continuously, for example through gradual volume changes, or discontinuously, characterized by the presence or complete absence of the auditory stimulus. For example, the Muse Headband uses bird vocalizations to signal calm and focus, as well as modulated ambient sounds (e.g., ocean waves) that soften as the user attains greater relaxation.

Second most used was visual feedback, employed in 27% of studies. In this modality, visual stimuli varied either continuously or discretely. In continuous feedback, parameters such as screen brightness or object size were adjusted in real time, increasing or decreasing with participant performance. In discrete feedback, information was delivered at specific events; for example, a video paused or advanced depending on whether the training target was being met. In Tarrant et al. (2022), using the BrainLink Lite EEG, a luminous dragonfly signaled relaxation or focus, while the virtual environment adapted under distraction, stress, or anxiety. Finally, among the included studies, only Nieto-Vallejo et al. (2021) employed olfactory stimuli. The unimodal or multimodal sensory feedback modalities employed in the analyzed studies is depicted in Figure 7.

Table 5
Characteristics of the Interventions

Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
Acabchuk et al. (2021)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	28 s (7×/week for 4 weeks)	10	FA on breath and bodily sensations	↓ DASS-21; ↑ MINDSENS (both groups), $p < .0001$	No significant EEG modulation (Muse); ↓ Calm time (App group)
Antle et al. (2018)	Visual	Alpha/theta ratio ↑ Beta	FP1	24 s (3–4×/week for 6 weeks)	15	FA on breath and bodily sensations	↑ Relaxation, attention during gameplay; ↑ Calm, attention (experimental > control, post test)	No pre-test differences in calm or attention
Balconi et al. (2017)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	28 s (estimated: 7×/week for 4 weeks)	10	FA on breath	↓ PSS (16%); ↑ focus (↑ N2 ERP); ↑ relaxation (↑ alpha/beta); ↑ subjective well-being	No effects in control group
Balconi et al. (2019)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	28 s/daily	10–20	FA on breath	↓ Perceived stress, anxiety, fatigue; ↑ vigor, HRV (rest & Stroop)	No change in HR, HRV (eyes closed), or mood (tension, anger, depression, confusion)
Bhayee et al. (2016)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	Minimum of 32 s	10	FA	↓ Stroop RT, somatization (BSI); ↑ calmness, body awareness	No significant effects in depression /anxiety (BSI), affect (PANAS), QoL (WHOQOL), Mindfulness (FMI), attention (d2, Digit Span), personality (BFI)
Brandmeyer & Delorme (2020)	Visual	↑ Theta (FMθ)	Fpz, Fz, F7/8, Cz, P7/8, and Oz	8 s over 2 weeks	30	FA on breath	↑ FMθ; ↓ RT (N-back); ↑ gamma; sustained effects	No effects in SART, local–global tasks, sham group
Chen et al. (2021)	Visual	Frontal alpha asymmetry	FP1/2, F7/8, F3/4	1 s with 3 experimental conditions	18	Mindfulness	↑ Alpha/theta/gamma after mindfulness-NFB in anxiety patients ($p < .05$)	Healthy controls also ↑ Alpha/theta /gamma, but nonsignificant

Table 5
Characteristics of the Interventions

Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
Chiu et al. (2024)	NR	↑ Beta and SMR	Not specified	12 mindfulness + 12 NF s (total: 24)	NF 50 Mindfulness 60	Mindfulness-based relapse prevention therapy	↓ Addiction, anxiety (BAI), depression (BDI); ↑ QoL (multiple domains), $p < .01$	WHOQOL physical domain improvement non-significant ($p = .509$)
Choi et al. (2024)	Auditory	↑ Alpha	Not specified (uses two-channel EEG headset)	≥12 s (≥3× /week for 4 weeks)	50	Not specified; described as meditation with alpha wave and binaural beat feedback	↑ Psychological well-being, emotional stability; ↓ symptoms (SCL-47-R), $p < .01$	↓ PTSD (PDS) and anti-stress index (left) not significant ($p > .05$)
Christian et al. (2024)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	A1: 9 (baseline), B: 15 (intervention, A2: 9 (post)	5	FA on breath	60% reported ↓ anxiety at follow-up; stronger effects in low-income and minority participants	Isolated ↑ or stable anxiety in 2 participants; no sustained effect
Crivelli, Fronda, & Balconi (2019)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	14 s (1×/day for 2 weeks)	10–20	FA on breath	↓ Stress (PSS), RT, false responses; ↑ non-judgment (FFMQ), N2 amplitude	No effects in other FFMQ domains, STAI, cognitive tasks
Crivelli, Fronda, Venturella, et al. (2019a)	Auditory	Proprietary alg.	Inion, T3/4	14 s	10–20	FA on breath	↓ Stress, anxiety, anger, fatigue, RT; ↑ HRV, alpha-beta ratio, alpha blocking (frontal/parietal)	No significant cognitive /electrophysiological modulation
Crivelli, Fronda, Venturella, et al. (2019b)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	28 s	10–20	FA on breath	↓ Complex RT; ↑ alpha/beta ratio, alpha blocking, N2 (Fz, Cz)	ERP (Pz), cognitive tasks: $p > .05$

Table 5
Characteristics of the Interventions

Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
Dunham et al. (2019)	Visual	Bispectral index: ↑ 11–20 Hz intermediate ↓ 30–47 Hz high	Frontal /temporal	8 s over 4 days	12	Mindfulness focused on expanded attention, conscious relaxation, and peripheral visual awareness	↓ Bispectral Index; ↑ relaxation, well-being (77% improved)	23% no improvement; smaller change in positive affect vs. nonstress scores
Ghosh et al. (2023)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	23.8 s on average	5.8 (2.2)	FA on breath and bodily sensations	↓ Stress, burnout; ↑ resilience, cognitive performance, QoL, $p < .01$	No effects in feature match, grammatical reasoning
Gu & Frasson (2017)	Visual	Proprietary alg.	AF3/4, F7/8, F3/4, FC5/6, T7/8, P7/8, O1/2	8 s	15	Sophrology (self-training in physical and mental relaxation)	↓ HADS-Anxiety/depression, time to relaxation; ↑ meditation score	TItR unchanged in low-threshold group
Hawley et al. (2021)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	56 s (1×/day for 8 weeks)	20	FA on breath and bodily sensations	↓ YBOCS; ↑ Alpha, Beta, non-reactivity (FFMQ); Alpha/Beta correlated with ↓ symptoms	No significant change in delta and theta bands
He et al. (2023)	Auditory and visual	Proprietary alg.	Frontal	Single session in a cardiac catheterization lab	35	Guided mindfulness (including body scan and visualization)	↓ Pain, anxiety, fatigue, opioid use ($p < .01$)	No effects in HR, BP, SpO_2, medication use
Hunkin et al. (2021a)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	Single lab session (with and without feedback) + 14 days home practice	10	FA on breath	↑ Mindfulness, mind wandering, ↑ perceived control (home practice)	↓ Calm/relaxation; feedback aversive to some participants ($p < .01$)

Table 5
Characteristics of the Interventions

Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
Hunkin et al. (2021b)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	14 s home-based for 29 participants	10	FA on breath	Muse recoveries predicted ↓ mind wandering; explained variance in mindfulness/attention	Mind wandering differences (experienced vs. novice meditators); ICCs low (mind wandering = .27; recoveries = .17)
Hwang et al. (2017)	Visual	↑ Alpha and theta; ↓ Beta	Fp1/2	10 s	30–45	FA meditation and visualization	↑ FS, SPANE-N; large effect for SPANE-P (NFB group)	SPANE-P NS (mPPT); small control group effect
Kosunen et al. (2016)	Visual	↑ Alpha and theta	F3/4, C3/4, P3/4	1 s with 6 different conditions	10 x Cond.	FA on breath and bodily sensations	↑ Relaxation, presence, meditation depth; ↓ boredom (VR + NFB)	MEDEQ (e.g., relaxation, transpersonal states): NS
E. Lee et al. (2024)	Auditory	↑ Theta and alpha; ↓ High beta	Fp1/2	28 s (2×/day for 2 weeks)	12	Mindfulness: breath-focused and relaxation-based	↓ Stress, state anxiety, depression, insomnia; ↑ satisfaction (experimental group)	No intergroup qEEG or biomarker (BDNF, cortisol, ACTH, IL-6, TNF-α) differences
Martinez & Zhao (2018)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	20 s (1×/week from Oct 2016 to Mar 2017)	3	FA on breath	↓ Disciplinary referrals; ↑ Muse scores	↑ Control group disciplinary referrals
McMahon et al. (2021)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	20 s (10 with NF, 10 without)	5	FA on breath	↑ Mindfulness, attention to breath, affect (post session); high acceptability	No consistent Mindfulness/ attention (*n* = 2) /affect changes (*n* = 1)
Mikicin et al. (2015)	Auditory and visual	↑ SMR and Beta1 ↓ Theta and Beta2	C3/4	20 s over 4 months	30	Autogenic relaxation with green light and 7–13 Hz sound stimulation	↑ Alpha and beta1 (eyes closed), Kraepelin performance; ↓ RT	SMR and oscillation index NS
Millstine et al. (2019)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	Median of 29 s (range: 0–116)	≥3	FA on breath	↓ Emotional fatigue, stress; ↑ vigor, emotional well-being ($p < .01$)	No between-group differences

Table 5
Characteristics of the Interventions

Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
Min et al. (2023)	Auditory	↑ Alpha /beta ratio (≥ 2.775)	FP1/2	28 s (2×/day for 4 weeks)	30	Mindfulness meditation with awareness training, abdominal breathing, and body scan	↓ Stress, depression, insomnia, emotional labor; ↑ resilience, relaxation index (NFB group)	No improvement in K-MAAS, KOSS, or PSS
Motolese et al. (2023)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	56 s (7×/week for 8 weeks)	30–45	FA on breath and bodily sensations	↓ RRS; ↑ Digit Span; ↓ beta power (scalp-wide)	HADS, SF-12, PSS, VAS, GSE, MFIS: NS
Nieto-Vallejo et al. (2021)	Visual, auditory, and olfactory	Proprietary alg. Attention /relaxation score (0–100); freq. not detailed	1 (single frontal sensor (Neurosky headset)	4 s (1 without feedback + 3 with different sensory feedbacks)	10	Trataka (open-eyed meditation focusing on an object)	↑ Attention (78%), relaxation (44.4%), subjective well-being (mood)	Olfactory stimulus ↓ relaxation (88.9%) and attention (66.6%)
P. Wang et al. (2023)	Visual and motor	ERD via motor imagery detection; freq. not specified	Primary motor and premotor area	40 s (5×/week for 8 weeks)	20 (BCI) + 80 weekly mindfulness	Mindfulness-based stress reduction	↑ Motor function, daily activity, mindfulness, sleep quality, QoL ($p < .001$)	MBI NS at 3-month
Polich et al. (2020)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	Up to 42 s (1×/day for 6 weeks)	12	FA on breath	↓ NSI, anxiety (BAI), depression (BDI-II); ↑ well-being (combined practice)	No cognitive performance or Calm% improvement
Rolbiecki et al. (2023)	Visual	Proprietary alg.	BrainLink device: prefrontal	1 s	22	Mindfulness	↓ Pain, fatigue; trend for anxiety and depression	↓ Anxiety ($p = .13$), depression ($p = .56$); sleepiness, nausea, shortness of breath, appetite NS
Salminen et al. (2024)	Visual	↑ Theta and alpha	F3/4, C3/4, P3/4	6 consecutive s	10	FA with external focal point and body scan	↑ Meditation depth (HMD + NFB); ↑ theta, gamma ($p < .05$)	No alpha modulation (NFB); presence unchanged (body scan vs. focal)

Table 5
Characteristics of the Interventions

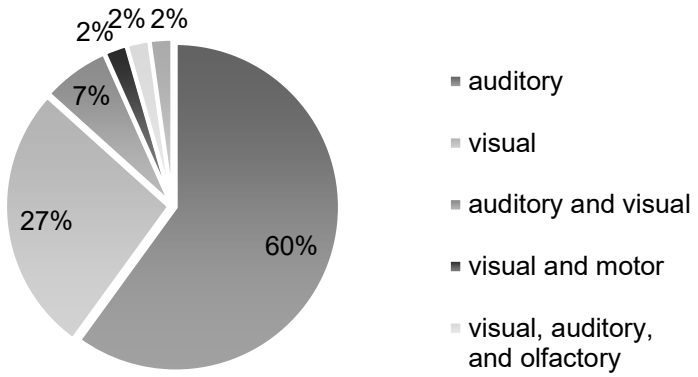
Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
Sas & Chopra (2015)	Auditory	Proprietary alg.	AF3/4, F3/4, FC5/6, F7/8, T7/8, P7/8, O1/2	3 consecutive s (control, monaural, binaural)	10	Mindfulness with emphasis on attention self-regulation	↑ Meditation depth, benefit for beginners, subjective quietness duration; binaural more effective than monaural ($p < .05$)	Main effect of expertise on subjective rating; no interaction in self-assessment
Schuurmans et al. (2021)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	12 s	15–20	FA on breath	↓ Traumatic stress (CRIES-13), anxiety (SCAS), cortisol; ↑ Mindfulness (CAMM)	HR/cortisol unchanged (session 1)
Smarinsky et al. (2023)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	33 s (3×/week for 11 weeks)	5	FA on breath	↑ Correlation self-report & NFB (intervention/post); gender × introspection interaction	SR–NFB correlation NS ($r = −0.02$); no male introspection
Soriano et al. (2024)	Auditory	↑/↓ Alpha	Global analysis with 19 electrodes; emphasis on O1, O2, T5, T6 (greater power)	1 s with 4 training blocks (2 ↑ and 2 ↓ training)	6 x block	FA	↑ Alpha (up-training); ↓ Alpha (downtraining), $p < .05$	No significant differences in subjective reports or resting state transfer effect (pre/post × condition)
Svetlov et al. (2019)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	1 s (2 conditions)	7 x Cond.	FA on breath	↑ HRV, Calm%; ↓ EDA, effort perception (Calm%)	HRV, EDA, sAA, Calm% NS (Muse-assisted vs. unassisted)
Tarrant & Cope (2018)	Auditory and visual	Frontal gamma asymmetry	AF7/8	1 s	4–5	Open Heart meditation: gratitude or cultivation of positive emotions	↑ Left frontal gamma asymmetry, possitive affect PANAS, and STCI; ↓ negative mood	One participant ↓ left asymmetry (shifted to right); ↓ joviality (STCI); no change in negative mood
Tarrant et al. (2022)	Visual	↓ High beta	FP1/2	1 s	5	Progressive body-scan/relaxation mindfulness meditation	↑ Happiness, calm; ↓ confusion, fatigue, depression, tension, anger (experimental and control)	↓ Vigor (experimental); no changes in happiness, calm, fatigue (control)

Table 5
Characteristics of the Interventions

Authors (Year)	Type of Feedback	NF Protocol	Location	Number of Sessions	Duration (min)	Meditation Type	Significant Results	Nonsignificant Results
van der Schoot et al. (2024)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	8 s (2×/week for 4 weeks)	6	FA on breath and bodily sensations	↓ Impulsivity, aggression, tension; "↑ relaxation, body awareness, inhibitory control, Muse Calm%	AVL-AV anger, MOAS: no aggression reduction
van Lutterveld et al. (2017)	Visual	↑/↓ Low gamma– (condition-based)	PCC	1 s with multiple experimental combinations	1.5–7 (total ~45 per participant)	Effortless awareness-based meditation	94% linked ↓ PCC to effortless awareness; ↑ volitional signal control ($p < .001$)	No voluntary PCC control; no EO/EC difference
Vekety et al. (2022)	Auditory	Proprietary alg.	AF7/8, TP9/10, Fpz	8 s	1–4	FA on breath	↑ Stroop accuracy, alpha and theta (rest), calm states; ↓ errors (Hearts/Flowers)	Theta and alpha (EC) and Stroop RT: NS
Viczko et al. (2021)	Visual	Frontal gamma asymmetry	AF7/8	1 s	5	Compassion meditation (Open Heart)	↑ Happiness, calm, alpha and beta (frontal, midline, parietal), engagement; ↓ tension, depression	No significant group differences; ↓ frontal gamma in both (↑ trend in experimental only); vigilance changes not significant ($p = .096$)

Note. NR = not reported; MINDSENS = Mindfulness Sensitivity Index; DASS-21 = Depression, Anxiety and Stress Scale – 21 Items; PSS = Perceived Stress Scale; ERP = event-related potential; HRV = heart rate variability; Stroop RT = Stroop Task Reaction Time; BSI = brief symptom inventory; PANAS = positive and negative affect schedule; WHOQOL-BREF = World Health Organization Quality of Life – Brief; FMI = Freiburg Mindfulness Inventory; d2 = d2 Test of Attention; BFI = Big Five Inventory; FMθ = frontal midline theta; RT = reaction time; SART = sustained attention to response task; BAI = Beck Anxiety Inventory; BDI = Beck Depression Inventory; QoL = quality of life; PDS = Posttraumatic Diagnostic Scale; SCL-47-R = Symptom Checklist-47 Revised; STAI = State-Trait Anxiety Inventory; FFMQ = Five Facet Mindfulness Questionnaire; HADS = Hospital Anxiety and Depression Scale; TItR = time interval to relaxation; YBOCS = Yale-Brown Obsessive Compulsive Scale; HR = heart rate; BP = blood pressure; SpO_2 = oxygen saturation; ICCs = intraclass correlation coefficients; FS = Flourishing Scale; SPANE-N/P = Scale of Positive and Negative Experience – Negative/Positive Affect Subscale; mPPT = modified positive psychotherapy; MEDEQ = Meditation Depth Questionnaire; BDNF = brain-derived neurotrophic factor; ACTH = adrenocorticotropic hormone; IL-6 = Interleukin-6; TNF-α = Tumor Necrosis Factor Alpha; K-MAAS = Korean version of the Mindful Attention Awareness Scale; KOSS = Korean Occupational Stress Scale; RRS = Ruminative Response Scale; SF-12 = 12-Item Short Form Health Survey; VAS = Visual Analogue Scale; GSE = General Self-Efficacy Scale; MFIS = Modified Fatigue Impact Scale; MBI = Modified Barthel Index; CRIES-13 = Children's Revised Impact of Event Scale – 13 items; SCAS = Spence Children's Anxiety Scale; CAMM = Child and Adolescent Mindfulness Measure; EDA = electrodermal activity; STCI = State-Trait Cheerfulness Inventory; MOAS = Modified Overt Aggression Scale; AVL-AV = Aggression Questionnaire – Agressievragenlijst – Short Version; FA = focus attention meditation; Proprietary alg. = proprietary, undisclosed algorithm in wearable devices.

Figure 7. *Feedback Modalities Distribution.*



Concerning the EEG-based oscillations targeted or generating the feedback across the included studies, the most frequently trained frequency ranges comprised the theta band (4–7.5 Hz), the alpha band (8–12 Hz), the sensorimotor rhythm (SMR, 12–15 Hz), and the beta band (13–30 Hz). These frequency ranges served as the basis for both single- and multiband training protocols. In addition to single-band approaches (18%), an equivalent proportion of studies (18%) employed combined training of multiple bands, a common clinical and research practice aimed at achieving broader neuromodulatory effects.

Approximately 20% of the studies implemented combined protocols that trained alpha and theta concurrently, a configuration often selected due to its association with relaxation and internal attention (Dobrakowski et al., 2020). For instance, Salminen et al. (2024) applied a protocol that simultaneously increased alpha and theta activity, which was associated with enhanced deep relaxation and introspection. Similarly, E. Lee et al. (2024) adopted a protocol that increased alpha and theta power while inhibiting high beta activity (21–30 Hz), aiming to reduce cortical hyperactivity—a phenomenon frequently linked to anxiety, stress, and mental agitation (Lin et al., 2021). In contrast to these multiband designs, other studies focused on the modulation of a single oscillatory band to examine more specific neural mechanisms. For example, Choi et al. (2024) and Soriano et al. (2024) investigated isolated modulation of alpha activity, whereas Brandmeyer and Delorme (2020) targeted frontal midline theta.

SMR and beta protocols were identified in 11% of studies, particularly in applications related to attention and performance enhancement. Mikicin et al. (2015), for example, applied SMR- and beta-based training to optimize cognitive and physical performance in athletes, while Gadea et al. (2020) reported improvements in sustained attention, reductions in anxiety, and benefits for sleep quality.

Notably, A large majority of the analyzed studies (78%) used wearable devices with proprietary algorithms, such as Muse, Emotiv, and other commercial headsets. These systems provide feedback based on automated classifications of mental states (e.g., attention, relaxation, meditation) without explicitly reporting the brain frequencies involved in signal processing. This lack of transparency regarding the targeted frequency bands limits comparability across studies and obscures understanding of the underlying neural mechanisms being trained.

Alongside the neurofeedback parameters, the included studies also varied in the meditation practices implemented, with a majority focusing on breath-focused attention practices (62%), either in isolation or combined with awareness of bodily sensations. Some of these protocols also incorporated guided imagery (Hwang et al., 2017) or fixation on external points (Salminen et al., 2024).

Mindfulness-based practices were also highly represented (22%), generally defined as cultivating nonreactive awareness of the present moment. (Zhang et al., 2021). Within this category, interventions frequently drew upon standardized clinical frameworks, including mindfulness-based stress reduction (MBSR; P. Wang et al., 2023) and mindfulness-based relapse prevention (MBRP) for relapse prevention (Chiu et al., 2024). The body scan technique was another recurring component

across multiple studies. (He et al., 2023; Salminen et al., 2024; Tarrant et al., 2022).

Less common but theoretically relevant approaches together accounted for 11% of the protocols. Among them were compassion-based meditations, such as Open Heart meditation (Tarrant & Cope, 2018; Viczko et al., 2021), as well as specific traditional techniques like Trataka (Nieto-Vallejo et al., 2021), and Sophrology (Gu & Frasson, 2017).

Across the included studies, both the number and duration of neurofeedback and meditation sessions varied substantially. On average, intervention protocols comprised 16.5 sessions, with a mean session duration of 17.9 min. Protocols range was wide, extending from single-session protocols to programs comprising more than 50 sessions. Session durations also show heterogeneity, varying from 1.5 to 80 min. As illustrated in Figure 8, single-session protocols were the most common (*n* = 13). Longer interventions were less frequent, with only two studies reporting between 30 and 40 sessions: Bhayee et al. (2016), which implemented a minimum of 32 sessions, and Smarinsky et al. (2023), which applied 33 sessions. Four studies reported more than 40 sessions, namely Hawley et al. (2021) and Motolese et al. (2023), both with 56 sessions; P. Wang et al. (2023) with 40 sessions; and Polich et al. (2020) with 42 sessions. Notably, among these longer interventions, the only study that did not employ home-based wearable devices was P. Wang et al. (2023). All other studies in this group allowed participants to complete sessions within their own environments using wearable devices.

Figure 9 illustrates the distribution of sessions lengths across studies. The majority of protocols employed short sessions within 1–10 min (*n* = 15) and 10–20 min (*n* = 18) range. These data indicate a predominant trend toward short-duration protocols in the literature.

To evaluate the effects of these combined meditation and neurofeedback interventions, the included studies employed a range of assessment instruments encompassing psychological, cognitive, physiological, and qualitative measures.

A clear predominance of standardized psychometric measures targeting stress, anxiety, depression, and mindfulness was identified. Frequently used scales included the Perceived Stress Scale (PSS; Cohen et al., 1983), State–Trait Anxiety Inventory (STAI; Spielberger et al., 1983), Beck Depression Inventory (BDI; Beck et al., 1988), Beck Anxiety Inventory (BAI; Beck et al., 1988) and Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006), indicating primary evaluation goals centered on reducing psychological distress and enhancing emotional self-regulation.

Many studies incorporated complementary measures of attention, cognitive performance, and physiological variables, including the Stroop Task (Stroop, 1935), Digit Span (Wechsler, 2008), and the Continuous Performance Test (Conners, 1995). Additional neurophysiological assessments included heart rate variability (HRV) and electroencephalography (EEG), in traditional EEG, quantitative EEG (qEEG), and standardized low-resolution electromagnetic tomography (sLORETA) modalities.

Figure 8. *Session Counts of Included Studies.*

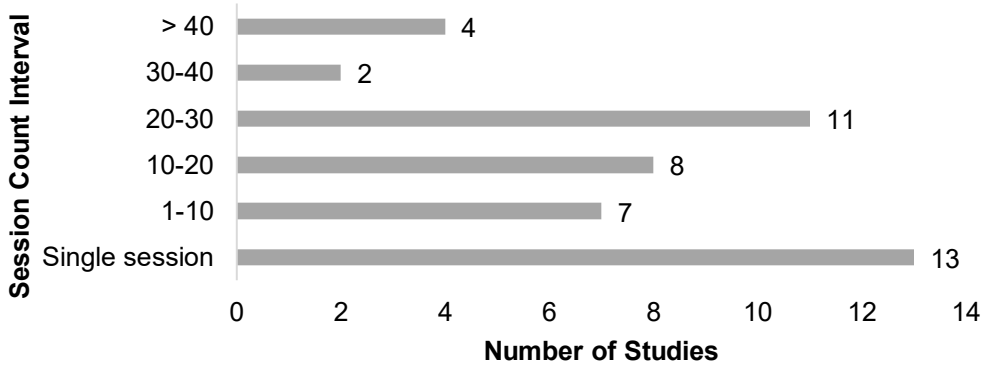
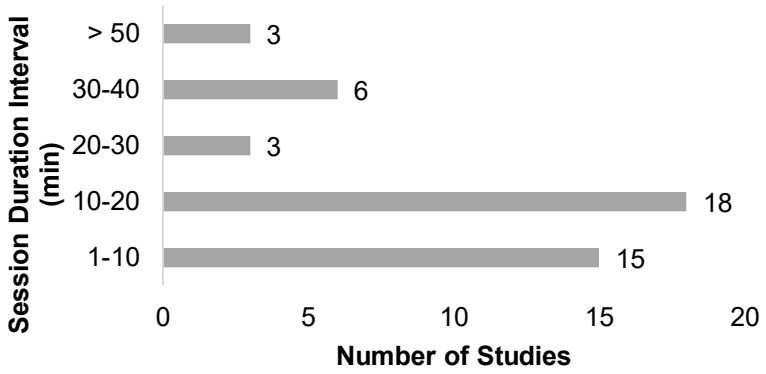


Figure 9. *Session Duration of Included Studies.*



Qualitative instruments such as interviews, diaries, and observations were used to capture subjective experience. For example, Antle et al. (2018) applied mixed methods to examine combined techniques among girls living in poverty and with trauma histories.

Most studies using wearable neurofeedback devices employed them for both intervention and outcome assessment. The Muse headset (InteraXon Inc.) was most frequent (*n* = 23), with metrics such as percent calm (%Calm) used as indicators of meditation or neurofeedback effects (Acabchuk et al., 2021; Balconi et al., 2019; Bhayee et al., 2016). Muse represented only one option, alongside devices with proprietary parameters and algorithms, including Neuroharmony M (Neuroharmony Ltda., Brazil) used by Choi et al. (2024), Emotiv EPOC (Emotiv Inc., San Francisco, CA, USA) used by Gu & Frasson (2017), and MindWave (NeuroSky Inc., San Jose, CA, USA) used by Nieto-Vallejo et al. (2021). Despite advantages of portability, accessibility, and easy integration in clinical and home settings, these devices raise methodological and epistemological concerns due to algorithmic opacity and limited specification and control of electrophysiological parameters (Acabchuk et al., 2021).

Only 10 studies conducted EEG analyses with traditional high-density systems using 32, 64, or 128 channels (Brandmeyer & Delorme, 2020; Chen et al., 2021; Soriano et al., 2024; van Lutterveld et al., 2017), which allow rigorous control of variables such as impedance, signal-extraction parameters, and filtering (Sharma & Meena, 2024). These capabilities exceed the simplified metrics of wearables devices and support more robust inferences about neurobiological mechanisms underlying the interventions (Cahn & Polich, 2006).

Taken together, these methodological choices reveal an emphasis on psychometric and neurophysiological assessments aimed at capturing both subjective and objective indicators of the effects of meditation combined to neurofeedback. However, the diversity of instruments and analytical approaches complicates direct comparisons across studies.

To provide an overview of the general findings across the 45 studies included in this systematic review, and to contextualize how these measures translate into empirical evidence, we present below a synthesis of the main results observed, together with illustrative examples drawn from a selection of representative studies. The summarized outcomes were organized into three categories, specifically, according to emotional–mood, cognitive, and meditative domains.

The emotional and mood outcomes include anxiety, fatigue, depression, somatic symptoms, and emotional reactivity. The cognitive outcomes focus on attention, memory, and executive functions. The indicators of the meditative domain include quality, depth, and engagement of practice. These categories synthesize most findings; comprehensive details for all included articles can be consulted in Table 5.

As noted in Figure 5, among the 45 studies included, 19 primarily assessed emotional and mood outcomes. Overall, combined techniques showed potential to improve these domains, although effects varied according to the protocol and participant

profile. For illustration, some representative studies are described below.

Consistent with Acabchuk et al. (2021), both the Muse (n = 25) and app-only (n = 27) groups showed significant improvements in mental health (DASS-21; d = 0.78 and 0.74, p < .001) and mindfulness (MINDSENS; d = 0.83, p < .001). EEG measures ("bird count" and "percent time calm") showed no change in the Muse group but decreased in the App group (bird count: d = −0.60, p < .001; percent time calm: d = −0.36, p < .01). EEG scores were strongly intercorrelated (r = 0.90, p < .01) but unrelated to mindfulness or mental health. Similarly, Bhayee et al. (2016) reported that neurofeedback-assisted mindfulness training (N-tsMT) led to specific improvements compared to the control group, including faster Stroop reaction times (Z = 3.29, p < .001, r = 0.65) and reduced somatic symptoms on the BSI (Z = 2.81, p = .004, r = 0.55), although no significant changes were detected in depression or anxiety factors. Attention gains correlated with symptom reductions, $r(24)$ = 0.44, p = .024; and higher neuroticism predicted greater improvement, $r(11)$ = −0.70, p = .007. The N-tsMT group also reported feeling calmer, $t(36)$ = 2.16, p = .04; and greater body awareness, $t(36)$ = 2.03, p < .05.

Chen et al. (2021) found that clinical status influenced participants' responses to the frontal alpha asymmetry protocol. After the intervention, a significant increase in mean power of alpha, theta, and gamma waves was observed across all participants. For anxious subjects, the results were $F(1, 338) = 127.65$, $p = 2.50 \times 10^{-25}$ (alpha); $F(1, 338) = 110.84$, $p = 1.31 \times 10^{-22}$ (theta); and $F(1, 338) = 633.73$, $p = 1.66 \times 10^{-79}$ (gamma). For healthy subjects, the corresponding values were $F(1, 338) = 9.93$, $p = 0.0017$; $F(1, 338) = 9.78$, $p = 0.0019$; and $F(1, 338) = 77.13$, $p = 8.13 \times 10^{-17}$, respectively. In the randomized controlled trial by E. Lee et al. (2024), the experimental group showed a significant reduction in stress (PSS: M = 25.85, SD = 4.97 to M = 19.40, SD = 4.56; p < .001), while the control group changed from M = 24.22, SD = 5.17 to M = 21.22, SD = 4.60 (p = .037 between groups). State anxiety decreased more in the experimental group (M = 11.95, SD = 10.46 vs. M = 6.50, SD = 7.69; p = .078). Both groups improved in depression, insomnia, trait anxiety, sleep quality, and quality of life (p < .05), with no significant between-group differences. No significant changes were observed in physiological indicators, and only the alpha band in qEEG showed a significant effect ($\chi^2 = 10.64$, p = .031).

In the study by Viczko et al. (2021), both experimental and control groups showed an increase in positive mood and a reduction in negative mood, with significant effects for happiness (p < .001), calmness (p < .001), depression (p < .001), tension (p < .001), and fatigue (p = .013). EEG analysis revealed increased frontal alpha activity (p = .008) and decreased gamma activity (p = .029), as well as elevated alpha and beta power in midline and parietal regions (p < .01).

Several studies focused on cognitive functions, exploring combined techniques to enhance attention, working memory, and cognitive regulation. In general, the evidence suggests beneficial but variable effects across cognitive domains. To illustrate these tendencies, a few examples are presented below. Results generally indicated improvements in cognitive performance and neurophysiological modulation, although not all domains showed significant effects. In Brandmeyer and Delorme (2020), the neurofeedback group showed a significant increase in FMθ power (44.62 dB) compared to the control group (44.35 dB), with a significant session correlation (r^2 = 0.49, p = .05) that became stronger after excluding nonresponders (r^2 = 0.85, p = .001). Significant effects were observed in the FMθ (3.5–6.5 Hz), low alpha (9–10 Hz), and beta (12–18 Hz) bands (p < .05). In the n-back task, the neurofeedback group demonstrated faster reaction times and increased gamma power over frontal midline and left temporoparietal regions (p < .01), effects not observed in the control group. Additionally, the association between neurofeedback and reduced mind-wandering was highlighted by Hunkin et al. (2021b), who found that the "Muse mind-wandering index" showed high internal consistency (Cronbach's α = 0.95) and was sensitive to attentional lapses within participants during the breath-counting task, with significant differences between correct, incorrect, and reset counts (miscounts: B = 2.84, p = .003; resets: B = 4.73, p < .001; δW = 0.56). Across participants, mean "Muse mind-wandering" was negatively correlated with the proportion of correct counts (r = −0.50, p = .002) and positively correlated with resets (r = 0.47, p = .004). The association with self-reported mind-wandering was minimal (rw = .01; rb = .11).

In elementary school children, Vekety et al. (2022) observed that the mindfulness + NF group showed significant differences in executive functions and brain activity compared to the control group. Specifically, improvements were observed in Stroop task accuracy, $F(1, 21) = 5.43$, p < .05; reductions in

errors on the Hearts and Flowers task, $F(1, 23) = 5.35$, $p < .05$; and increased theta and alpha power during eyes-open resting-state conditions with theta: $F(1, 18) = 7.09$, $p < .05$; and alpha: $F(1, 18) = 5.80$, $p < .05$). A positive correlation was found between changes in theta activity and reaction time ($r = 0.54$, $p = .03$). Additionally, there was a linear increase in calm/focused brain states, $F(1, 14) = 5.67$, $p = .03$; and in recovery from mind-wandering episodes, $F(1, 14) = 52.07$, $p < .001$.

Studies examining effects on meditation quality generally indicated potential to enhance attentional states, meditative depth, and neural pattern regulation, albeit with some limitations. To illustrate these general trends, selected studies are summarized below. Hunkin et al. (2021a) found that neurofeedback during the breath-counting meditation task was associated with greater attentional focus and reduced mind-wandering. Specifically, auditory feedback was associated with a 15% higher rate of correct breath counts ($RR = 1.15$, $p = .056$), a 41% lower rate of count resets ($RR = 0.59$, $p < .001$), and a 4.15-unit reduction in device-measured mind-wandering ($d = −0.22$, $p = .006$), with no significant correlation observed for recovery measures ($d = −0.11$, $p = .270$). Auditory feedback was also correlated with reduced subjective reports of calmness ($d = −0.83$, $p = .008$) and sleepiness ($d = −0.49$, $p = .016$).

Kosunen et al. (2016) observed that the combined use of a head-mounted display (HMD) and neurofeedback resulted in higher scores for relaxation, meditative depth, and sense of presence compared to the control condition (screen without feedback). In the Meditation Depth Questionnaire (MEDEQ), significant differences were observed for the factors Hindrances ($p < .01$), Relaxation ($p < .05$), Personal Self ($p < .01$), Transpersonal Qualities ($p < .01$), and Transpersonal Self ($p < .05$). No statistically significant differences were found between the HMD condition with and without neurofeedback ($p > .05$). In the same direction, Salminen et al. (2024) found that use of the HMD resulted in a significantly higher sense of presence compared to the computer screen ($p < .001$), and the neurofeedback condition further increased this effect ($p = .011$). Meditation depth was greater when using the HMD ($p < .001$). Frontal theta (4–6 Hz) power was higher with neurofeedback on than off ($p = .048$), while no significant differences were found for whole-head alpha (8–13 Hz) activity. Gamma (30–45 Hz) activity was significantly higher during HMD use ($p < .001$) and with neurofeedback activated ($p = .001$). The point-focus meditation condition elicited greater frontal theta activation ($p = .004$), whereas the body-scan meditation condition produced higher whole-head gamma activity ($p = .005$).

Soriano et al. (2024) revealed a significant main effect of training condition on absolute alpha power (8–14 Hz), $F(1, 30) = 10.49$, $p < .001$, $\eta^2 = 0.001$, with higher alpha power during the upregulation condition ($M = 4.14 \times 10^6$ μV², $SD = 2.25 \times 10^5$) compared to the downregulation condition ($M = 3.96 \times 10^6$ μV², $SD = 2.32 \times 10^5$). Regardless of training type (up- or downregulation), a general posttraining decrease in alpha power was observed (pre: $M = 4.63 \times 10^6$ μV²; post: $M = 4.17 \times 10^6$ μV²), $F(1, 30) = 6.70$, $p = .01$. These findings, together with the broader set of studies included in the review, suggest consistent yet context-dependent effects of combined mindfulness and neurofeedback interventions, with the full set of results detailed in Table 5.

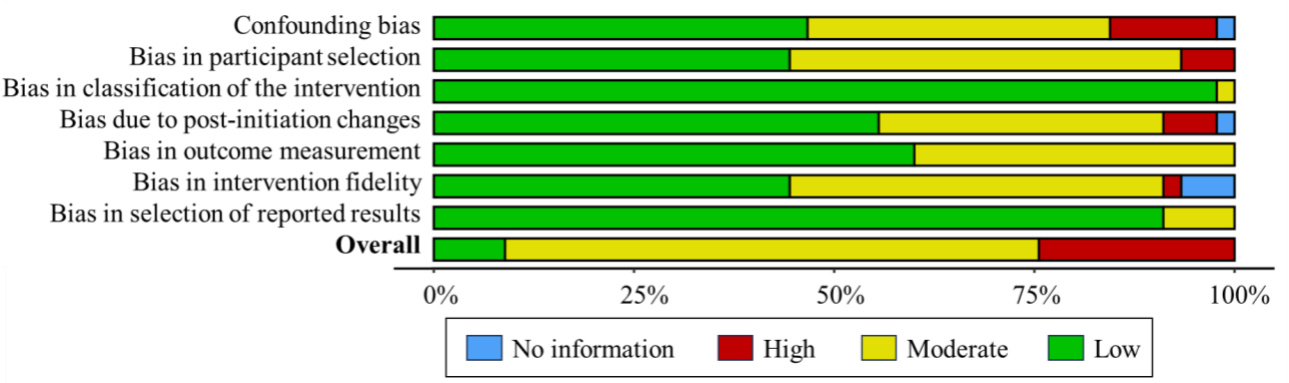
Risk of Bias

Risk of bias was assessed in accordance with PRISMA (Page et al., 2021) and guided by the Cochrane Handbook chapter “Assessing risk of bias in a nonrandomized study” (Sterne & Higgins, 2023). The first four authors independently evaluated the risk of bias across seven domains: (D1) bias due to confounding; (D2) bias in participant selection; (D3) bias in classification of the intervention/exposure; (D4) bias due to post initiation changes; (D5) bias in outcome measurement; (D6) bias in intervention fidelity; and (D7) bias in selection of reported results.

To facilitate visualization, the risk of bias across the seven assessed domains is summarized in Figure 10. The figure presents ratings for each domain as low risk (green), moderate risk (yellow), high risk (red), or no information available (blue). Visualizations were generated using the Risk-of-Bias VISualization tool (robvis; McGuinness & Higgins, 2021). Any discrepancies were resolved by consensus following discussion among the authors.

For bias in classification of the intervention (D3), most studies provided detailed descriptions of procedures and techniques, ensuring clear intervention characterization. With rare exceptions, protocols were explicitly reported, supporting comprehension and replicability (Bhayee et al., 2016; Brandmeyer & Delorme, 2020; Ghosh et al., 2023). Similarly, for bias in selection of reported results (D7), studies generally reported prespecified outcomes, with no clear indications of practices such as p-hacking, thereby maintaining transparency and

Figure 10. *Summary of Risk of Bias.*



integrity in reporting (E. Lee et al., 2024; Schuurmans et al., 2021).

By contrast, bias in selection of participants (D2) emerged as a critical issue. In some studies, inclusion and exclusion criteria were not clearly defined (Kosunen et al., 2016; Salminen et al., 2024), and convenience sampling frequently prevailed without robust justification, thereby limiting external validity (Smarinsky et al., 2023; Tarrant & Cope, 2018). A similar pattern was observed for bias due to confounding (D1), where key limitations included incomplete information on clinical history (Antle et al., 2018; Bhayee et al., 2016; Mikicin et al., 2015) and prior meditation experience (Smarinsky et al., 2023; Vekety et al., 2022; P. Wang et al., 2023), both fundamental to interpretation and generalization.

For bias in outcome measurement (D5), the principal weakness was the absence of blinded assessment procedures. As previously noted (Table 4), only 10 of 45 studies implemented any blinding, potentially compromising measurement objectivity. Additionally, the recurrent use of wearable devices as the primary evaluation method may introduce inaccuracies in quantifying observed effects.

Finally, for bias related to intervention fidelity (D6), there was limited standardization and insufficient monitoring of practice quality (Polich et al., 2020; Rolbiecki et al., 2023; van der Schoot et al., 2024). The predominance of home-based interventions using wearable devices, while increasing participant autonomy, introduces confounding variables outside experimental control. Some studies employed follow-up strategies, such as logging sessions via device-integrated apps; nonetheless, gaps persisted in controlling the practice environment. Scarce information on provider training or qualifications in technique delivery may also directly affect intervention consistency and efficacy (Soriano et al., 2024; Svetlov et al., 2019; Vekety et al., 2022; Viczko et al., 2021).

Discussion

This systematic review provides a comprehensive overview of the current literature on combining meditative practices and neurofeedback. Overall, the field is expanding but remains methodologically immature. A major challenge remains the marked heterogeneity in designs, protocols, and measurement instruments, which compromises comparability across studies and hinders the consolidation of robust empirical evidence.

Across the reviewed literature, several convergent themes emerge, such as methodological limitations, thematic focus, diversity of meditation types and neurofeedback protocols, and the observed spectrum of effects. Rather than treating these as separate blocks, the following synthesis integrates them to highlight cross-cutting patterns and research gaps.

Methodological and Sampling Constraints

A recurring challenge is the predominance of studies conducted in high income countries in the Northern Hemisphere, which restricts external validity and overlooks cultural variation that shapes both meditation practice (Buric et al., 2022) and response to neurofeedback (Wood & Kober, 2018). This pattern exemplifies the critique of Western, Educated, Industrialized, Rich, Democratic (WEIRD) samples described by Henrich et al. (2010). The scarcity of research in Latin American contexts is particularly critical, as social inequality, cultural

diversity, and heterogeneous economic conditions decisively influence adherence and protocol effectiveness (Migeot et al., 2024; Nagy et al., 2022). Progress in this matter requires not only greater international collaboration but also the cultural adaptation of both intervention and assessment methods.

Three methodological limitations stand out. First, the predominance of active controls, though informative, complicates the identification of specific versus nonspecific intervention effects (Kober et al., 2018). Second, blinding strategies are scarce: only 10 of 45 studies implemented any blinding, exposing results to expectation bias (Patel et al., 2020; Voigt et al., 2024). Third, placebo conditions are rarely used, with Brandmeyer and Delorme (2020) providing the only randomized double-blind trial with a sham condition. Studies combining active and sham conditions (e.g., Min et al., 2023) offer a more promising avenue, as they help to disentangle the contribution of each element.

Another critical issue is the mismatch between intervention length and the nature of the techniques. Given that both meditation (Basso et al., 2019; Brandmeyer et al., 2019) and neurofeedback (Domingos et al., 2021; Esteves et al., 2021) demand gradual training and sustained engagement, short or single-session protocols risk reducing ecological validity and underestimating the interventions' potential.

Thematic analysis indicated a concentration on anxiety, mood, and stress disorders, addressed in 19 of 45 articles. Within this category, studies range from daily stress to more complex conditions such as burnout and depression (Balconi et al., 2019; Ghosh et al., 2023). Other investigations examined cognitive performance and attention regulation, including executive functions such as attentional control, impulsivity, and working memory (Brandmeyer & Delorme, 2020; Hunkin et al., 2021b; van der Schoot et al., 2024; Vekety et al., 2022). Less frequently, research explored neurological conditions, specific psychiatric disorders, meditative states, adaptive needs, and sports performance (Choi et al., 2024; Kosunen et al., 2016; McMahon et al., 2021; Mikicin et al., 2015; Motolese et al., 2023). This diversity underscores the heterogeneity of applications in the field.

The variety of meditation practices further complicates synthesis, as they have distinct goals and specific neurophysiological effects. Focused attention practices typically increase alpha and beta activity, aiming to strengthen attentional regulation and cognitive control (Salminen et al., 2024; Zhang et al., 2021), while deeper or open-monitoring practices engage theta oscillations associated with relaxation and affective integration (Hwang et al., 2017; Tarrant et al., 2022). Likewise, mindfulness and body scan, which emphasize full awareness and interoceptive perception, display neurophysiological profiles that differ from compassion-based approaches such as Open Heart meditation or from visual practices such as Trataka (Gu & Frasson, 2017; Nieto-Vallejo et al., 2021; Viczko et al., 2021). Such diversity enriches the field but reinforces the need for clear conceptual distinctions and standardized outcome definitions to compare effects across modalities.

Similarly, neurofeedback protocols targeted distinct frequency bands, most often targeted theta 4–8 Hz, alpha 8–12 Hz, sensorimotor rhythm (SMR) 12–15 Hz, and beta 13–30 Hz because of their links to attention, emotional regulation, and self-regulation (Brandmeyer et al., 2019; Cahn & Polich, 2006; Dobrakowski et al., 2020). For example, protocols that increase alpha or theta aim to modulate relaxation or attentional focus (Choi et al., 2024; Soriano et al., 2024). In turn, combined approaches, such as increasing theta and reducing high beta, appear particularly effective for stress and mood modulation (E. Lee et al., 2024; Salminen et al., 2024); while SMR and beta training appear relevant to cognitive performance, emotional regulation, and sleep improvement (Chiu et al., 2024; Gadea et al., 2020; Mikicin et al., 2015).

A notable trend is the widespread use of commercial devices such as Muse and Emotiv (Chiu et al., 2024; Dobrakowski et al., 2020). Although these devices expand access to neurofeedback training and facilitate data collection in nonlaboratory settings, they raise concerns about transparency and scientific rigor (Acabchuk et al., 2021). Their proprietary architectures typically restrict access to raw EEG data and rely on closed-source algorithms that infer mental states such as relaxation or attention through internal classifications that are seldom disclosed. This opacity limits the reproducibility of findings and hinders precise interpretation of the underlying neurophysiological mechanisms (Flanagan & Saikia, 2023). In contrast, multichannel systems with full control of training parameters and complete metric access enable more accurate control of artifact removal, impedance levels and frequency-band targeting while also providing higher spatial resolution, supporting fine-

grained topographic and functional analyses of cortical activity (Sharma & Meena, 2024).

Importantly, neurofeedback protocol design should consider not only trained frequency bands but also be aligned with the meditation technique employed, ensuring that trained frequency bands correspond to the attentional, emotional, and interoceptive processes cultivated in practice. Thus, not merely combining meditation and neurofeedback but integrating them within a synergistic framework of self-regulation and awareness.

Observed Effects and Future Perspectives

Across studies, effects clustered around three outcome axes: emotional, cognitive, and meditative. Emotional outcomes were most consistent, showing reductions in anxiety, stress, and depression, especially in vulnerable populations (Acabchuk et al., 2021; Antle et al., 2018; Chen et al., 2021; E. Lee et al., 2024). Cognitive improvements included enhanced working memory, attention, and inhibitory control (Brandmeyer & Delorme, 2020; Hunkin et al., 2021b; Vekety et al., 2022), often accompanied by increases in frontal theta and gamma power. Meditative outcomes reflected deepened meditative experience associated with modulations in alpha, theta and beta bands (Hunkin et al., 2021a; Kosunen et al., 2016; Salminen et al., 2024).

The results indicate that the most consistent benefits were observed in emotional outcomes, particularly among participants with higher baseline vulnerability (Chen et al., 2021; E. Lee et al., 2024). Protocols that increased alpha and theta activity and reduced high beta were associated with decreases in stress, anxiety, depression, and insomnia, as well as higher satisfaction with the interventions (E. Lee et al., 2024). Nonetheless, the lack of intergroup changes in biomarkers and electrophysiological parameters suggests that improvements may have been primarily reflected in subjective and behavioral measures. This trend aligns with the general pattern observed across studies, in which emotional and self-reported indicators showed more stable improvement than physiological markers.

Across the reviewed literature, studies combining meditation and neurofeedback reported positive changes in emotional, cognitive, and neurophysiological variables, although effect sizes and consistency varied depending on protocol characteristics and participant profiles (Acabchuk et al., 2021; Bhayee et al., 2016; Brandmeyer & Delorme, 2020; Vekety et al., 2022; Viczko et al., 2021). Reductions in stress, anxiety, fatigue, and depression were accompanied by improvements in attention, executive functioning, and body awareness. EEG findings commonly showed increased alpha and theta activity, patterns related to relaxation and calmness, and decreases in gamma power, associated with alertness (Salminen et al., 2024; Viczko et al., 2021). Despite these convergences, results regarding physiological and mindfulness-related measures were not uniform, as indicated by the absence of transfer effects in some studies (Soriano et al., 2024). However, results varied according to task, context, and participant profile, limiting comparability and generalization of findings. Moreover, the scarcity of follow-up assessments and the limited evidence of transfer to everyday contexts further constrain the ecological validity of the observed effects.

Risk of bias assessment indicated modest progress in transparency of intervention and results, but persistent weaknesses in sampling, control conditions and blinding, reducing validity and objectivity. Low standardization and insufficient monitoring of interventions further compromise result consistency.

Final Considerations

To strengthen evidence quality, future studies should adopt randomized controlled trials with sham control (placebo) and blinding of participants and or assessors, accompanied by preregistration and a priori sample size estimation. Protocols must report, in verifiable detail, both the procedure and the neural target (e.g., alpha uptraining at the right parietal region P4), specify the feedback type, and describe artifact handling procedures, in accordance with the neurofeedback best practice checklist (Ros et al., 2020). Whenever possible, multichannel systems that allow access to raw EEG signals should be prioritized. When consumer devices are used, studies must rely on devices already validated against well-established laboratory equipment and clearly document the algorithms employed and the quality of the acquired signals. Only under these conditions can effects on underlying neurophysiological mechanisms be inferred with greater precision.

Studies should state the meditation modality employed (e.g., focused attention, open monitoring, compassion, or body scan) and align neurophysiological hypotheses with training objectives, since effects can vary substantially across techniques (Cahn & Polich, 2006).

Regarding samples and outcomes, larger multicenter studies incorporating geographic and cultural diversity are recommended, avoiding exclusive reliance on western, educated, urban populations. Cultural adaptation of materials should be ensured, along with detailed reporting of age, gender, and contextual variables. Outcomes should integrate emotional, cognitive, and meditation practice indicators together with neurophysiological markers. In addition, mediator and moderator analyses (e.g., adherence, motivation, prior experience) should be prespecified. Finally, longitudinal investigations with higher ecological applicability are needed to assess effect durability and transfer to everyday life.

Author Declaration

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