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EDITED BY
Amelie Haugg,
Psychiatric University Hospital Zurich, Switzerland

REVIEWED BY
Lucas Murrins Marques,
Santa Casa de São Paulo School of Medical Sciences, Brazil
Juan Lorenzo Terrasa,
University of the Balearic Islands, Spain

*CORRESPONDENCE
Pierluigi Diotaiuti
✉ p.diotaiuti@unicas.it

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Evaluating the effectiveness of neurofeedback in chronic pain management: a narrative review

Pierluigi Diotaiuti[1]*, Stefano Corrado[1], Beatrice Tosti[1], Giuseppe Spica[1], Tommaso Di Libero[1], Anderson D'Oliveira[2], Alessandra Zanon[1], Angelo Rodio[1], Alexandro Andrade[2] and Stefania Mancone[1]

[1]Department of Human Sciences, Society and Health, University of Cassino and Southern Lazio, Cassino, Lazio, Italy, [2]Department of Physical Education, CEFID, Santa Catarina State University, Florianopolis, Santa Catarina, Brazil

The prevalence and impact of chronic pain in individuals worldwide necessitate effective management strategies. This narrative review specifically aims to assess the effectiveness of neurofeedback, an emerging non-pharmacological intervention, on the management of chronic pain. The methodology adopted for this review involves a meticulous search across various scientific databases. The search was designed to capture a broad range of studies related to neurofeedback and chronic pain management. To ensure the quality and relevance of the included studies, strict inclusion and exclusion criteria were applied. These criteria focused on the study design, population, intervention type, and reported outcomes. The review synthesizes the findings from a diverse array of studies, including randomized controlled trials, observational studies, and case reports. Key aspects evaluated include the types of neurofeedback used (such as EEG biofeedback), the various chronic pain conditions addressed (like fibromyalgia, neuropathic pain, and migraines), and the methodologies employed in these studies. The review highlights the underlying mechanisms by which neurofeedback may influence pain perception and management, exploring theories related to neural plasticity, pain modulation, and psychological factors. The results of the review reveal a positive correlation between neurofeedback interventions and improved pain management. Several studies report significant reductions on pain intensity, improved quality of life, and decreased reliance on medication following neurofeedback therapy. The review also notes variations in the effectiveness of different neurofeedback protocols and individual responses to treatment. Despite the promising results, the conclusion of the review emphasizes the need for further research. It calls for larger, well-designed clinical trials to validate the findings, to understand the long-term implications of neurofeedback therapy, and to optimize treatment protocols for individual patients.

KEYWORDS

neurofeedback, chronic pain, pain management, review, treatment effectiveness, pain reduction

1 Introduction

Chronic pain is a significant health issue affecting a substantial portion of the population globally. A study by Johannes et al. (2010) reported that chronic pain affects approximately 19% of European adults. The situation is similar in the United States, where Nahin (2015) found that over 25% of Americans suffer from chronic pain. Chronic pain can severely impact the quality of life of those affected. It is not just the physical discomfort but also the associated psychological and social issues. A review by Gatchel et al. (2007) highlighted that chronic pain could lead to significant functional impairment, disability, and a decrease in life satisfaction. The economic impact of chronic pain is substantial, too. According to Rice et al. (2016), chronic pain incurs high costs, both in terms of direct healthcare expenses and indirect costs due to lost productivity and work absence. Individuals with chronic pain often experience comorbid conditions such as depression, anxiety, and sleep disturbances. A study by Bair et al. (2003) demonstrated a strong association between chronic pain and depression, emphasizing the need for integrated treatment approaches. According to the research conducted by Turk and Okifuji (2002), individuals suffering from chronic pain have an increased susceptibility to developing anxiety, depression, and other mood disorders, which can worsen their experience of pain.

Before delving into the discussion on chronic pain treatments and the effectiveness of neurofeedback, it is crucial to establish a clear definition of what we mean by "chronic pain." According to the International Association for the Study of Pain (IASP), chronic pain is defined as pain that persists or recurs for more than 3 months (International Association for the Study of Pain, 2021). This pain can arise from a variety of medical conditions and traumas, or it may have an unknown origin. Unlike acute pain, which serves as the body's alarm system indicating injury or disease, chronic pain is often a complex and multifactorial condition that persists well beyond the normal healing process and can significantly impact an individual's quality of life, psychological well-being, and daily functioning.

The non-pharmacological approaches to chronic pain management have gained increasing recognition and importance in recent years. They encompass a wide range of techniques, including cognitive–behavioral therapy (CBT), physical therapy, mindfulness, acupuncture, and more (Andrade et al., 2017). Through various interventions such as CBT, physical therapy and exercise, mindfulness and meditation, and acupuncture and acupressure, individuals can develop effective strategies to cope with pain, improve functional abilities, and enhance their quality of life (Andrade et al., 2019; Sieczkowska et al., 2019, 2020a,b). These approaches aim to reduce pain, improve functionality, enhance psychological well-being, and empower individuals to actively participate in their own pain management (Gupta, 2023; Paroli and Galdino, 2023).

To fully understand the application of neurofeedback in the treatment of chronic pain, it is essential to first explore the concept of brain oscillations and their role in pain perception. Brain oscillations, or brain waves, refer to the rhythmic patterns of neuronal activity that emerge from the synchronous interaction of groups of neurons in the brain. These oscillations are commonly classified according to their frequency into different bands, such as delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (30–100 Hz), each of which is associated with specific cognitive states and neurophysiological processes.

Delta waves (0.5–4 Hz), for example, are typically associated with deep sleep and body repair, but abnormalities in this frequency band have been linked to chronic pain conditions. Theta waves (4–8 Hz) are linked to meditation, stress reduction and emotional processing; alterations in this band may reflect dysfunctions in pain modulation. Alpha waves (8–12 Hz) are associated with relaxation and inhibition of unnecessary cortical activity, and their modulation may influence pain perception. Finally, beta waves (12–30 Hz) are related to active attention and cognitive processes, while gamma waves (30–100 Hz) are associated with the integration of sensory information and may play a role in acute and chronic pain perception.

Recent literature has begun to reveal how specific brain oscillations are related to chronic pain. For example, studies have shown that neurofeedback aimed at modulating activity in the theta (4–8 Hz) and alpha bands (8–12 Hz) can lead to a reduction in pain perception in individuals with chronic pain (Maddison et al., 2022; Rustamov et al., 2022). These findings suggest that training in the modulation of specific brain oscillations via neurofeedback may alter pain-processing mechanisms in the brain, offering a potential therapeutic pathway for the treatment of chronic pain.

Incorporating this understanding of brain oscillations and their link to chronic pain, neurofeedback is proposed as a promising approach to modulate brain activity to positively influence pain perception.

Neurofeedback, or EEG biofeedback, is a non-invasive technique that teaches individuals to control their brain activity, with its theoretical basis in pain management rooted in the understanding of the brain's neuroplasticity and the central nervous system's role in pain perception. Neurofeedback entails the observation of brain activity using electroencephalography (EEG) and delivering immediate feedback to the individual. This feedback facilitates the individual's acquisition of the ability to consciously regulate distinct brainwave patterns. Sherlin et al. (2010) defined neurofeedback as a method by which individuals undergo brainwave training to enhance their brain function. The central nervous system (CNS) has a significant impact on the perception of pain. CNS has the ability to regulate the perception of pain, which is a fundamental idea in comprehending the application of neurofeedback for pain control. Flor and Turk (2011) emphasized the role of the CNS in the perception and modulation of pain. Neuroplasticity, the brain's ability to reorganize itself by forming new neural connections, plays a crucial role in neurofeedback. This adaptability allows for the potential modification of pain pathways. Chronic pain is not only merely a persistent sensory experience but also a complex condition with profound effects on the brain's structure and function. As highlighted by Apkarian et al. (2011), chronic pain can lead to significant changes within the brain, underscoring the condition's complexity beyond its initial physiological origins. This seminal work has demonstrated that individuals suffering from chronic pain exhibit alterations in brain gray matter density, particularly in regions associated with pain processing and modulation. Such changes include the prefrontal cortex and the thalamus, areas critically involved in the cognitive and emotional aspects of pain. These structural changes, likely a result of long-term pain and its management, suggest that chronic pain can fundamentally alter the neural architecture, impacting not only pain perception but also emotional and cognitive functions.

On the mechanism of action for neurofeedback, Mayaud et al. (2014) provided a compelling exploration of how this technique empowers individuals to modulate specific brain functions. Neurofeedback leverages the principle of operant conditioning, wherein individuals learn to alter their brain activity patterns in response to feedback. This process involves the real-time monitoring of brain waves using electroencephalography (EEG) and providing immediate feedback to the individual about specific brain activity. For instance, individuals can learn to increase or decrease the activity of certain brain oscillations associated with relaxation or alertness, respectively. This capability to self-regulate brain function opens new avenues for addressing chronic pain, by directly influencing the neural circuits involved in pain perception and processing. The training aims to normalize or modulate the dysfunctional patterns of brain activity associated with chronic pain, thereby offering a novel, non-pharmacological approach to pain management.

Together, these studies lay the foundation for understanding the bidirectional relationship between chronic pain and brain function. They not only highlight the profound impact of chronic pain on the brain but also illustrate the potential of neurofeedback as a powerful tool for modulating brain activity, offering new hope for individuals suffering from chronic pain conditions.

The most well-established and standard neurofeedback protocols include theta/beta (TBR), sensorimotor rhythm (SMR), and slow cortical potential (SCP) (Enriquez-Geppert et al., 2019). These protocols have shown efficacy and specificity in treating conditions such as ADHD and epilepsy (Coben et al., 2018). Additionally, neurofeedback treatment protocols mainly focus on specific brainwave frequencies such as alpha, beta, delta, theta, and gamma, or a combination of them, such as alpha/theta ratio and beta/theta ratio (Marzbani et al., 2016). However, it is important to note that the efficacy of neurofeedback training can vary widely among individuals, and certain populations may not benefit from it (Sakurada et al., 2022; Tosti et al., 2024).

Individualized neurofeedback protocols have been used to account for electrophysiological heterogeneity in conditions such as ADHD (Lansbergen et al., 2010). In the context of tinnitus treatment, studies have investigated the efficacy of individualized alpha/delta neurofeedback protocols, suggesting it as a suitable option for the treatment of chronic tinnitus (Güntensperger et al., 2019). Further research has investigated the application of neurofeedback in managing central neuropathic pain (CNP) in paraplegia, highlighting the necessity for controlled experiments to validate the effectiveness of particular neurofeedback protocols for pain therapy (Hassan et al., 2015).

Al-Taleb et al. (2019) presented groundbreaking evidence on the efficacy of neurofeedback in treating CNP among individuals with spinal cord injuries. Their study demonstrated that patients who engaged in a tailored neurofeedback training protocol experienced notable reductions in pain intensity, highlighting neurofeedback's potential as a significant modality in the realm of pain management. This research underscores the capability of neurofeedback to target and modulate the neural mechanisms underlying neuropathic pain, offering a promising non-pharmacological approach for patients grappling with this challenging condition.

Shimizu et al. (2022) further substantiated the value of neurofeedback in chronic pain treatment through their intervention study targeting alpha-wave neurofeedback training in individuals with chronic low back pain. They found that this specific neurofeedback protocol had a significant and clinically meaningful impact on reducing pain severity. This study not only confirms the therapeutic potential of neurofeedback but also emphasizes the importance of specific brain oscillations, like the alpha waves, in mediating pain perception and relief.

In a novel exploration of the learning processes involved in neurofeedback, Patel et al. (2021) investigated the utilization of EEG alpha states to understand how individuals learn to modulate their brain activity during alpha neurofeedback training for chronic pain. Their findings reveal that engagement with alpha neurofeedback can enhance individuals' ability to enter and maintain alpha states, a brain activity pattern associated with relaxation and reduced pain perception. This research highlights the interactive process between neurofeedback training and cognitive engagement, illustrating a pathway through which neurofeedback may exert its effects on chronic pain.

Elbogen et al. (2019) provided compelling evidence of neurofeedback's efficacy from a study with veterans suffering from chronic pain, traumatic brain injury, and PTSD. They discovered that after undergoing neurofeedback training, veterans were able to independently use mobile neurofeedback devices to manage their symptoms effectively. This independence in managing their condition marks a significant step forward in self-directed pain and trauma care, offering insights into the practical applications and benefits of neurofeedback outside a clinical setting.

Finally, Trullinger et al. (2017) highlighted the synergistic benefits of combining neurofeedback with physical therapy in managing chronic pain. By integrating these modalities, their proposed treatment approach not only addresses the physiological aspects of pain but also engages the brain's natural plasticity to alleviate pain. This holistic approach presents a compelling alternative to medication-dependent treatments, promising a more sustainable and empowering path for chronic pain management. Together, these studies illustrate a broad spectrum of neurofeedback's applicability and effectiveness in chronic pain management, from specific neural modulation and learning mechanisms to practical and integrative treatment approaches. The diversity and success of these applications underscore neurofeedback's potential as a versatile and powerful tool in the ongoing battle against chronic pain.

The objective of this review on the efficacy of neurofeedback in the treatment of chronic pain is to critically evaluate and synthesize current scientific evidence to determine the effectiveness of neurofeedback as a therapeutic intervention for individuals suffering from chronic pain. This includes as follows: (1) Evaluating the extent to which neurofeedback can reduce pain intensity, frequency, and duration in individuals with chronic pain conditions; (2) Exploring the underlying mechanisms by which neurofeedback influences pain perception and modulation in the brain, including changes in brainwave patterns and neural plasticity; (3) Comparing the efficacy of neurofeedback with other conventional and alternative pain management methods to understand its relative benefits and limitations; (4) Reviewing clinical studies and trials to determine the practical applications of neurofeedback in various chronic pain conditions, such as neuropathic pain, fibromyalgia, and chronic back pain; (5) Identifying the most effective neurofeedback protocols and techniques for pain management, including the types of neurofeedback (e.g., EEG biofeedback, fMRI-based neurofeedback) and treatment parameters (frequency, duration, and intensity); (6) Assessing the safety profile and tolerability of neurofeedback in the long-term management of chronic pain; (7) Focusing on patient-reported outcomes, including improvements in quality of life, functional capacity, and psychological well-being; and (8) Discussing the limitations of current research and proposing future research directions for advancing the understanding and application of neurofeedback in chronic pain management.

TABLE 1 Methodological approach for evaluating neurofeedback efficacy in chronic pain management.

Element	Description
Databases searched	PubMed, PsycINFO, Scopus, Web of Science, Google Scholar (including for grey literature).
Keywords used	Main Terms: "Neurofeedback," "EEG Biofeedback," "Chronic Pain"; Related Terms: "Pain Management," "Brainwave Training," "Neurotherapy"; Specific Conditions: "Neuropathic Pain," "Fibromyalgia," "Chronic Back Pain"; Outcome Terms: "Pain Reduction," "Quality of Life," "Functional Improvement."
Combination of keywords	Boolean operators ("AND," "OR") were used to combine keywords. For example, "Neurofeedback AND Chronic Pain," "EEG Biofeedback AND Pain Management."
Time frame of literature search	Spanning from 2010 to the present (22/01/2024) to balance foundational studies and recent advancements.
Inclusion criteria	Peer-reviewed articles, clinical trials, systematic reviews, and meta-analyses.
Exclusion criteria	Non-English articles, articles without full text available, non-peer-reviewed articles, and studies not specifically addressing the efficacy of neurofeedback in chronic pain.
Screening process	Initial screening based on titles and abstracts; full-text review for selected studies to assess relevance and quality, resulting in a selection of 17 studies.
Quality assessment	The methodological quality of the studies was evaluated using standardized tools such as the PRISMA guidelines for systematic reviews and the CONSORT checklist for clinical trials.
Data extraction and synthesis	Key data such as study design, sample size, intervention details, outcome measures, and results were extracted; then, the data were summarized to provide a comprehensive understanding of the efficacy of neurofeedback in chronic pain management.

The ultimate goal was to provide a comprehensive and evidence-based overview of neurofeedback's role in chronic pain management, aiding healthcare professionals, researchers, and patients in making informed decisions regarding its use as a therapeutic modality.

2 Methods

2.1 Narrative vs. systematic review

The choice to conduct a narrative review to assess the efficacy of neurofeedback in managing chronic pain was guided by key methodological considerations, reflecting the peculiarities and challenges of the current field of study. Research on neurofeedback applied to chronic pain presents a wide variety of study designs, ranging from randomized controlled trials (RCTs) and observational studies, to pilot studies and systematic reviews. This heterogeneity complicates the use of traditional systematic methodologies, which require homogeneity for direct comparison and effective meta-analysis. A narrative review, however, allows for a qualitative synthesis that embraces the diversity of approaches and outcomes, providing a comprehensive and critical overview of the field.

The included studies exhibit considerable variability in the neurofeedback protocols used, highlighting the ongoing exploration of best practices in this therapeutic area. This variability, from EEG biofeedback to real-time functional magnetic resonance imaging (rt-fMRI)-based neurofeedback, further complicates the systematic synthesis of data. Opting for a narrative review allows for a detailed discussion of each protocol, assessing its potential benefits and limitations based on available evidence.

Many reported studies have small or unspecified sample sizes, a factor that can limit the statistical power and generalizability of the results. The narrative review accommodates these studies, acknowledging their contribution to understanding the efficacy of neurofeedback in chronic pain treatment, while highlighting the need for further research on larger samples.

The frequent mention of the need for further research to validate current findings and optimize treatment protocols reflects the emerging state of research on neurofeedback and chronic pain. A narrative review facilitates discussion of these points, summarizing the current state of research, identifying gaps in existing literature, and suggesting future directions for in-depth investigations.

2.2 The methodological choice

The choice of a narrative review was determined by the complex nature and evolutionary stage of research on neurofeedback in chronic pain treatment. This methodological approach allows for a holistic and detailed understanding of the field, providing a solid foundation on which to build future inquiries. For a thorough literature search on the efficacy of neurofeedback in the treatment of chronic pain, the following Table 1 provides a systematic overview of the methodological path followed in the narrative review to assess the efficacy of neurofeedback in the management of chronic pain, outlining the search strategies, study selection criteria, and data synthesis techniques.

3 Results

The types of neurofeedback used in the studies considered include electroencephalographic (EEG) neurofeedback, infra-low frequency (ILF) neurofeedback, volitional limbic neuromodulation, SMR-based neurofeedback, alpha-wave neurofeedback, and rt-fMRI neurofeedback (Jensen et al., 2013; Guan et al., 2015; Hassan et al., 2015; Goldway et al., 2019; Terrasa et al., 2020; Arina et al., 2022; Demarest et al., 2024). These studies have shown promising results, with notable reductions in non-pain-related symptoms and pain relief in patients with chronic pain (Terrasa et al., 2020; Barbosa-Torres and Delgado, 2021; Shimizu et al., 2022) and with a significant impact on pain intensity in the immediate period (Hesam-Shariati et al., 2022).

Some studies have investigated the potential mechanisms of neurofeedback training for chronic pain, specifically targeting the modulation of EEG activity in brain regions associated with pain processing (Jensen et al., 2013; Hassan et al., 2015). Additionally, rt-fMRI neurofeedback has been suggested as a potential treatment for chronic pain, showing beneficial effects in patients with chronic pain (Guan et al., 2015). While the evidence is promising, it is important to note that the field of neurofeedback for chronic pain is still evolving, and there is a need for further research to establish its efficacy and mechanisms of action (Jensen et al., 2014; Hesam-Shariati et al., 2020).

The manipulation of pain perception using cognitive techniques such as placebo, distraction, or alterations in expectation likely utilizes comparable brain mechanisms, indicating the participation of multiple brain regions in pain modulation (Zeidan et al., 2012; Diotaiuti et al., 2021, 2022a,b, 2023; Vilarino et al., 2022). Research has shown that neurofeedback training can result in both immediate and long-term decrease in CNP, along with measurable adjustments in cortical activity over short and long periods of time (Hassan et al., 2015). Moreover, neurofeedback has demonstrated the ability to facilitate intentional control of brain activity for the treatment of neurological conditions, such as CNP (Vuckovic et al., 2019).

Individual variations in alpha neurofeedback training have been linked to the efficacy of neurofeedback training in pain regulation. Individuals who exhibited positive responses to neurofeedback training experienced a reduction in pain and an augmentation in the regulation of SMR intensity, along with improved functional communication between motor and somatosensory regions (Peng et al., 2020). Research has shown that the use of neurofeedback to modulate neural activity voluntarily could be a possible therapy for chronic conditions characterized by dysregulation of both peripheral and central neural systems, such as fibromyalgia (Goldway et al., 2019).

3.1 Applying NFT to specific pain conditions

Neurofeedback has been explored in the context of specific pain conditions, such as CNP in chronic spinal cord injury, where it was found to produce immediate and longer-term reduction of pain accompanied by measurable cortical activity modulation (Vuckovic et al., 2019). rt-fMRI neurofeedback studies have shown that individuals can gain voluntary control over activation in brain regions involved in pain processing, leading to control over pain perception (Guan et al., 2015). The modulation of brain activity in the anterior cingulate cortex using rt-fMRI neurofeedback resulted in a decrease in pain intensity ratings, indicating the potential of neurofeedback in pain management (Emmert et al., 2014).

The studies considered in this review have explored its application in conditions such as fibromyalgia, tension-type headache (TTH), chronic low back pain, complex regional pain syndrome (CRPS), CNP in paraplegia, and cancer pain. Table 2 provides a detailed overview of all studies mentioned in the section, organized by each specified pain condition, and includes the type of neurofeedback considered and an indication of the effectiveness level based on the document's reporting.

The ensemble of studies outlined in Table 2 offers a comprehensive examination of neurofeedback's application across various chronic pain conditions. This diverse collection of research underscores the versatility of neurofeedback techniques and their potential effectiveness in pain management. A significant focus on fibromyalgia is evident, with studies demonstrating the effectiveness of EEG biofeedback and Low Energy Neurofeedback System (LENS) in reducing symptoms. The inclusion of various research designs, from randomized controlled trials to observational studies, provides a robust framework for understanding neurofeedback's impact on this condition.

The examination of neurofeedback's role in managing TTHs through ILF neurofeedback and QEEG-guided neurofeedback highlights its promise as a preventative and therapeutic intervention. These studies suggest that neurofeedback can effectively reduce headache frequency, offering a non-pharmacological alternative for sufferers.

The exploration of alpha-wave neurofeedback's clinical significance in treating chronic low back pain indicates its potential as an adjunctive therapy. By combining neurofeedback with conventional treatments, there's an indication of a clinically meaningful effect on pain intensity in the short term.

The inclusion of studies on CRPS showcases neurofeedback's capacity to induce short-term improvements in pain relief and associated symptoms. This suggests a promising avenue for further research into neurofeedback's utility in managing CRPS.

Investigations into neurofeedback's effectiveness for CNP in paraplegia reveal its potential to produce immediate and longer-term reductions in pain. These studies focus on EEG-based neurofeedback's role in modulating brain activity associated with pain, offering hope for individuals with spinal cord injuries.

Although evidence is limited regarding neurofeedback's efficacy in cancer pain management, the inclusion of systematic reviews suggests varied effectiveness across different studies. This highlights the need for further research to establish neurofeedback's role in cancer pain management.

Collectively, these studies provide a nuanced understanding of neurofeedback's potential across a spectrum of chronic pain conditions. The diversity of neurofeedback techniques, from EEG biofeedback to rt-fMRI neurofeedback, underscores the field's complexity and the importance of personalized treatment approaches. The varying levels of effectiveness observed across studies emphasize the need for further research to refine neurofeedback protocols and understand its mechanisms fully. This burgeoning field holds promise for non-pharmacological pain management, offering new hope for individuals seeking alternatives to traditional pain treatments.

3.1.1 Fibromyalgia

Promising results have been recorded by utilizing neurofeedback, particularly EEG biofeedback, to alleviate fibromyalgia symptoms. For instance, a randomized, rater-blind clinical trial demonstrated the efficacy of EEG biofeedback in reducing pain in fibromyalgia syndrome (Kayiran et al., 2010). Additionally, neurofeedback targeting specific brain regions, such as the anterior cingulate cortex and supplementary motor area, has shown preliminary success in alleviating chronic pain in fibromyalgia patients (Linden, 2012). A systematic review reported that biofeedback and LENS were more effective than sham/placebo biofeedback in reducing fibromyalgia pain (Lee et al., 2014). Terrasa et al. (2020) reported significant improvements in functional connectivity of somatomotor cortices and

TABLE 2 Overview of neurofeedback studies on chronic pain management: types and effectiveness.

Pain condition	Study	Design	Main details	Neurofeedback type	Effectiveness level
Fibromyalgia	Kayiran et al. (2010)	Randomized controlled trial (RCT)	Effectiveness of EEG biofeedback in reducing pain in fibromyalgia syndrome.	EEG biofeedback	Promising
	Linden (2012)	Pilot study	Preliminary success of neurofeedback targeting specific brain regions in fibromyalgia.	Targeted neurofeedback	Preliminary success
	Lee et al. (2014) and Terrasa et al. (2020)	RCT, systematic review	Biofeedback and LENS more effective than sham/placebo in reducing fibromyalgia pain.	EEG biofeedback, LENS	More effective than sham
	Fuentes-García et al. (2019)	Observational study	Evidence on the utility of neurofeedback in improving psychological symptoms, quality of life, and pain in fibromyalgia.	EEG biofeedback	Effective
Tension-type headache	Arina et al. (2022)	Cross-over sham-controlled study	Cross-over sham-controlled study on the efficacy of neurofeedback in prevention.	Infra-low frequency neurofeedback	Promising
	Stokes and Lappin (2010) and Walker (2011)	RCT	Efficiency of QEEG-guided neurofeedback in reducing headache frequency.	QEEG-guided neurofeedback	Effective
	Bentivegna et al. (2021)	Review	Highlights the importance of personalized approaches in TTH management.	Personalized neurofeedback	Suggested improvement
Chronic low back pain	Shimizu et al. (2022)	Intervention study	Intervention study combining alpha-wave neurofeedback training with conventional treatments.	Alpha-wave neurofeedback	Clinically meaningful effect
	Roy et al. (2020)	Observational study	Emphasizes the potential of neurofeedback in pain management, linking neurophysiological abnormalities to pain.	General neurofeedback	Potential
Complex regional pain syndrome (CRPS)	Hassan et al. (2015)	Pilot study	Neurofeedback training leads to short-term improvements in pain relief and non-pain-associated symptoms.	General neurofeedback	Short-term improvements
Central neuropathic pain in paraplegia	Vuckovic et al. (2019)	Experimental study	Investigating the potential mechanism of neurofeedback training on central neuropathic pain and its brain signatures.	EEG-based neurofeedback	Promising
	Anil et al. (2022)	Observational study	Importance of self-efficacy and negative affect for neurofeedback success for central neuropathic pain post-SCI.	EEG-based neurofeedback	Key factor for success
	Hasan et al. (2016)	Longitudinal study	Long-term neurofeedback reduces CNP and cortical overactivity in painful paraplegia.	EEG-based neurofeedback	Effective
Cancer pain	Hesam-Shariati et al. (2022)	Systematic review and meta-analysis	Focus on studies examining the impact of neurofeedback on chronic pain, including fibromyalgia and cancer-related pain.	EEG neurofeedback	Varied effectiveness
	Luctkar-Flude and Groll (2015) and Luctkar-Flude et al. (2019)	Systematic review	Discussion on insufficient evidence of neurofeedback efficacy in relieving symptoms like fatigue and cognitive disorders in cancer survivors.	Neurofeedback	Insufficient evidence

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a reduction in pain among fibromyalgia patients. However, the outcomes of neurofeedback interventions in fibromyalgia patients have shown variability, as indicated by Villafaina et al. (2019). Despite this, there is evidence supporting the utility of neurofeedback in improving psychological symptoms, quality of life, and pain in fibromyalgia patients (Fuentes-García et al., 2019).

3.1.2 Tension-type headache

Neurofeedback has been a subject of interest in the management of TTHs. Results of a cross-over sham-controlled study were reported in a study that examined the effectiveness of neurofeedback in the preventive treatment of TTH (Arina et al., 2022). Previous studies by Stokes and Lappin (2010) and Walker (2011) demonstrated the effectiveness of QEEG-guided neurofeedback in reducing headache frequency in patients with recurrent migraine, suggesting the potential applicability of neurofeedback in headache management. While the potential of neurofeedback in managing TTH is evident, the literature also emphasizes the need for more controlled studies in this area (Stokes and Lappin, 2010). Additionally, the genetic predisposition to TTH suggests the importance of personalized approaches in its management (Bentivegna et al., 2021). Therefore, future research could focus on integrating neurofeedback with genetic insights to develop personalized interventions for TTH.

3.1.3 Low back pain

Neurofeedback has gained attention as a potential treatment for chronic low back pain. Shimizu et al. (2022) conducted an intervention study combining alpha-wave neurofeedback training with conventional treatments for chronic low back pain, reporting a clinically meaningful effect on pain intensity in the short term. Roy et al. (2020) emphasized the potential of neurofeedback in pain management, highlighting the association of neurophysiological abnormalities with pain and the rationale for treatments targeting these factors. These studies collectively suggest that neurofeedback holds promise as an adjunctive therapy for chronic low back pain. While there is growing evidence supporting the potential of neurofeedback as a treatment modality for chronic low back pain, further research is warranted to elucidate its specific mechanisms of action and long-term efficacy.

3.1.4 Complex regional pain syndrome

Neurofeedback has been increasingly explored as a potential treatment for chronic pain conditions such as CRPS (Hassan et al., 2015). Studies have shown that neurofeedback training can lead to short-term improvements in pain relief and non-pain-associated symptoms in patients with CRPS (Terrasa et al., 2020). Previous research indicates that neurofeedback has the potential to be an effective and comprehensive method for managing chronic pain, specifically in cases of CRPS. However, further well-designed studies with larger sample sizes are needed to establish its efficacy and clinical utility in the treatment of CRPS.

3.1.5 Central neuropathic pain

Neurofeedback has emerged as a potential treatment for CNP in paraplegia, offering a novel approach to pain management. CNP, often associated with spinal cord injury (SCI), poses a significant challenge due to its complex pathophysiology (Scholz et al., 2019). Conditions of CNP include pain caused by spinal cord or brain injury, post-stroke pain, and pain associated with multiple sclerosis. While chronic peripheral neuropathic pain is caused by diseases of the peripheral somatosensory nervous system, chronic CNP is attributed to damage or diseases of the central somatosensory nervous system, including spinal cord injury and brain injury (Liu et al., 2020). Research has demonstrated that neurofeedback, particularly EEG-based neurofeedback, holds promise in relieving CNP after SCI by enabling voluntary self-modulation of brain activity (Anil et al., 2022). In patients with chronic paraplegia, a pilot study sought to investigate the potential mechanism of neurofeedback training on CNP and its underlying brain signatures (Hassan et al., 2015). Additionally, EEG correlates of self-managed neurofeedback treatment for CNP in chronic SCI have been examined, shedding light on the neuromodulatory technique's potential in treating CNP (Vuckovic et al., 2019). Long-term neurofeedback treatment has been found to reduce CNP and cortical overactivity in painful paraplegia, particularly during imagined movements of painful and paralyzed legs (Hasan et al., 2016).

The emerging body of research suggests that neurofeedback holds promise as a non-invasive and potentially effective approach for managing CNP in paraplegia. By enabling voluntary modulation of brain activity, particularly in the context of chronic SCI, neurofeedback presents a novel avenue for addressing the complex nature of CNP. However, further rigorous studies are warranted to establish its efficacy, safety, and long-term effects in this specific population.

3.1.6 Cancer pain

Neurofeedback has also been proposed as a potential method for managing chronic pain in cancer patients. Several studies have explored the use of neurofeedback for pain management in various patient populations, including cancer survivors. Marzbani et al. (2016) recommended the use of biofeedback/neurofeedback for pain management. Nevertheless, Luctkar-Flude and Groll (2015) proposed that there is presently inadequate evidence to substantiate the efficacy of neurofeedback in alleviating symptoms such as fatigue and cognition disorders in individuals who have survived cancer. However, they do acknowledge the encouraging outcomes that justify the necessity for additional investigation in this specific group of patients. Hesam-Shariati et al. (2022) emphasized that previous studies examining the impact of EEG neurofeedback on chronic pain have primarily concentrated on particular pain conditions, such as fibromyalgia and pain associated with cancer. Rolbiecki et al. (2023) suggested the usefulness of complementary and alternative medicine approaches, such as neurofeedback and virtual reality, for the management of cancer-related pain and mood. While some promising evidence supports the use of neurofeedback for managing chronic pain in cancer patients, further research is needed to establish its effectiveness in this specific population.

3.2 Duration and frequency of neurofeedback sessions

Neurofeedback has been investigated as a potential treatment for chronic pain with varying durations and frequencies of sessions reported in the literature. For instance, studies have employed 40 or more weekly neurofeedback training sessions for fibromyalgia patients

(Jensen et al., 2007) and 10 sessions for TTH patients (Arina et al., 2022). Additionally, a study on fibromyalgia patients utilized biweekly neurofeedback sessions for a total duration of five consecutive weeks (Goldway et al., 2019).

The duration of a single neurofeedback session has been reported to range from 8.5 min Zweerings et al. (2018) to 30–45 min (Patel et al., 2020), with some studies mentioning sessions lasting 20–40 min (Son et al., 2020). Additionally, a study on the analgesic effect of EEG neurofeedback for chronic pain reported that sessions tend to be 30–40 min long, with patients offered 20–40 sessions (Patel et al., 2020). It is important to note that the duration and frequency of neurofeedback sessions can vary based on the specific condition being treated and the neurofeedback protocol being used.

3.3 Efficacy findings

Hesam-Shariati et al. (2022) found a medium effect size favoring neurofeedback treatments for chronic pain compared to control groups. Studies have demonstrated that neurofeedback training can potentially alleviate pain and other pain-related symptoms in individuals suffering from chronic pain (Terrasa et al., 2020). Moreover, Barbosa-Torres and Delgado (2021) revealed substantial enhancements in pain alleviation and other symptoms unrelated to pain in individuals with chronic fibromyalgia who underwent neurofeedback training based on SMR. These findings are consistent with Jacobs and Jensen (2015), who reported the potential for neurofeedback to alleviate suffering and improve related symptoms and problems in individuals with chronic pain.

However, it is important to note that the efficacy of neurofeedback in reducing chronic pain is still under investigation. While some evidence suggests its effectiveness, questions remain regarding the specific mechanisms through which neurofeedback produces these benefits (Jensen et al., 2014). There are still too few studies evaluating the efficacy of neurofeedback in young people with chronic pain to draw firm conclusions regarding its effectiveness (Miró et al., 2016). Furthermore, the use of functional magnetic resonance imaging-based neurofeedback in chronic pain interventions has limited evidence due to associated difficulties and expenses (Patel et al., 2020).

3.4 Adverse effects

While some studies have reported positive outcomes in reducing pain intensity (Jensen et al., 2007; Shimizu et al., 2022), others have highlighted potential adverse effects such as transient exacerbation of symptoms like fatigue and pain (Luctkar-Flude and Groll, 2015). It has also been observed that neurofeedback treatment can occasionally be linked to temporary side effects and more severe adverse effects (Hammond, 2009; Rogel et al., 2015). However, it is important to note that the reported symptoms are often seen in these conditions irrespective of the provision of neurofeedback therapy (Patel et al., 2020). A recent systematic review found a medium effect size of pain reduction favoring neurofeedback treatments for chronic pain compared to control groups (Hesam-Shariati et al., 2022). This suggests that while there may be potential adverse effects, neurofeedback could still offer benefits in managing chronic pain. It is important to note that the combination of physical therapy and neurofeedback could be a viable alternative for managing chronic pain. This approach reduces the need for medication and lowers long-term expenses (Trullinger et al., 2017).

4 Discussion

The efficacy of neurofeedback in managing chronic pain, as highlighted in various studies, demonstrates its potential as a non-pharmacological therapy. Neurofeedback, involving self-regulation of brain functions, has been shown to influence areas of the brain involved in pain processing and perception, potentially leading to the reduction or elimination of pain and associated symptoms like depression or anxiety.

NFT has been effective in various chronic pain conditions, notably in decreasing headache intensity and in managing migraine and fibromyalgia pain. Its role in post-operative and cancer pain management has also been noted. This therapy modulates the emotional component of pain and alters the connectivity between brain regions, affecting neuronal networks altered by chronic pain (Kubik and Biedroń, 2013).

Statistically, neurofeedback therapy's effectiveness varies: significant results are often observed after 30–60 training sessions, with some studies reporting up to a 50% reduction in headache symptoms. However, children with TTHs may require periodic reminder therapy (Kubik and Biedroń, 2013).

Despite positive outcomes, the quality of evidence supporting neurofeedback's use in chronic pain is largely considered low. High-quality, double-blinded, randomized sham-controlled trials are necessary to further explore this therapy's potential and to determine the most efficacious delivery methods (Hesam-Shariati et al., 2022).

Nevertheless, NFT is emerging as a promising integrative approach for chronic pain management, particularly for patients whose pain is refractory to pharmacological treatments. As methods and protocols continue to evolve, its significance in pain management is expected to grow.

4.1 Comparison with other treatments

Comparing the efficacy of neurofeedback with other chronic pain treatments involves examining several factors, such as the type of pain, the specific treatment methods, and individual patient characteristics:

Pharmacological Treatments: Traditional pain management often uses medications like NSAIDs, opioids, and anticonvulsants. These can be effective but come with side effects and risks, including gastrointestinal issues or addiction. Neurofeedback, as a non-pharmacological approach, avoids these side effects and is beneficial for those intolerant and concerned about long-term drug use (Chou et al., 2016).

Physical Therapy: Physical therapy focuses on improving mobility, strength, and function in chronic pain conditions, especially musculoskeletal issues. Neurofeedback, conversely, targets the brain's pain-processing mechanisms. These therapies can be complementary (Geneen et al., 2017).

Cognitive–Behavioral Therapy: CBT helps patients understand the relationship between thoughts, emotions, and pain. Neurofeedback also has a psychological component, as it can alter pain perception and processing in the brain. Both can be combined for comprehensive pain management (Williams et al., 2012).

Acupuncture: Acupuncture is believed to release endorphins and affect the nervous system. Neurofeedback directly targets brain function and may be more beneficial for pain influenced by neurological factors (Vickers et al., 2018).

Surgery: Surgery is considered for chronic pain with a clear anatomical cause but carries risks. Neurofeedback is non-invasive and can be an option before surgical interventions (Kumar et al., 2007).

Biofeedback and Relaxation Techniques: These techniques focus on the mind–body connection. Neurofeedback is a specific form of biofeedback targeting brainwave activity. It provides a targeted approach for modulating brain activity related to pain (Nestoriuc et al., 2008).

Summarizing, neurofeedback is a promising tool in chronic pain management, often most effective as part of a multidisciplinary approach. Treatment choice should be tailored to the individual's specific condition, needs, and preferences. Neurofeedback has emerged as a potential treatment for chronic pain, with studies indicating its efficacy in reducing pain intensity and related symptoms (Prinsloo et al., 2013). The mechanism of action of neurofeedback in chronic pain management is not yet fully understood, with questions remaining about whether it reduces pain-specific brain oscillations or increases comfort-related oscillations (Jensen et al., 2014). However, evidence suggests that neurofeedback has the ability to control atypical brain function linked to persistent pain, offering an analgesic effect (Hesam-Shariati et al., 2022). Studies have shown that neurofeedback training may reduce pain and other pain-related symptoms in chronic pain patients, including those with fibromyalgia and TTHs (Terrasa et al., 2020; Arina et al., 2022). Additionally, neurofeedback has been used to treat CNP conditions such as chronic spinal cord injury and CRPS (Jensen et al., 2007; Vuckovic et al., 2019; Roy et al., 2020). Furthermore, it has been reported that cancer survivors are using neurofeedback to alleviate symptoms such as pain, fatigue, and cognitive impairment, with few transient side effects (Luctkar-Flude et al., 2019). These findings suggest that neurofeedback holds promise as a non-invasive and holistic approach to managing chronic pain (Patel et al., 2020).

Neurofeedback therapy has emerged as a promising approach for managing chronic pain, with potential future advancements in this field. Neuroimaging-based therapeutics, such as transcranial magnetic stimulation and real-time functional magnetic resonance imaging neurofeedback, hold promise for providing additional benefits in clinical practice (Martucci and Mackey, 2018). Research has indicated that neurofeedback may play a part in the treatment of persistent pain, although the current level of evidence is of low quality (Schuurman et al., 2023). ILF neurofeedback and virtual reality neurofeedback therapy can be effective in improving CNS functionality and providing sustained analgesia in centralized pain syndromes (Alemanno et al., 2019; Orakpo et al., 2021, 2022). Studies on SMR-based neurofeedback training have demonstrated significant improvements in pain relief and other non-pain-associated symptoms in chronic pain patients, including those with fibromyalgia and CRPS (Terrasa et al., 2020; Barbosa-Torres and Delgado, 2021). Moreover, neurofeedback has been explored as a potential treatment for CNP in paraplegia, with promising results in modulating abnormal brain activity associated with chronic pain (Hassan et al., 2015; Hesam-Shariati et al., 2022).

Neurofeedback therapy for chronic pain is progressing quickly, with a growing emphasis on using EEG neurofeedback and brain–computer interface technology to address abnormal brain activity that contributes to chronic pain (Hesam-Shariati et al., 2020; Patel et al., 2020). Furthermore, neurofeedback has been recommended for pain management, and its potential benefits in combination with physical therapy for chronic pain have been highlighted (Marzbani et al., 2016; Trullinger et al., 2017). Additionally, studies have suggested that neurofeedback may offer an alternative treatment regimen for chronic pain management, reducing reliance on medication and long-term costs (Trullinger et al., 2017). It has been employed to modulate atypical brain function linked to persistent pain, suggesting its potential as a supplementary treatment for the management of chronic pain (Askovic et al., 2017; Hesam-Shariati et al., 2022).

4.2 Future directions

Potential advancements in neurofeedback therapy for chronic pain are focused on enhancing the efficacy, specificity, and accessibility of this treatment. Here could be some key areas of development:

1 Integration with Advanced Neuroimaging: Integrating neurofeedback with advanced neuroimaging techniques like fMRI and real-time brain imaging can enhance the specificity of neurofeedback training. This approach can allow for more targeted interventions, where patients can learn to modulate specific brain areas associated with their pain symptoms.
2 Personalized Neurofeedback Protocols: Developing personalized neurofeedback protocols based on individual brain patterns can significantly increase the efficacy of treatment. Tailoring neurofeedback to the specific neural correlates of pain in each patient could lead to more effective and faster treatment outcomes.
3 Combining Neurofeedback with Other Therapies: Research into combining neurofeedback with other therapies, such as CBT, physical therapy, or pharmacological treatments, could offer a more holistic approach to pain management. This multimodal approach might address not only the neurological aspects of pain but also the psychological and physical components.
4 Longitudinal Studies and Follow-up Research: Long-term studies are needed to understand the sustainability of the benefits of neurofeedback. Research focusing on the long-term effects and potential lasting changes in brain function due to neurofeedback can provide insights into its role as a chronic pain management tool.
5 Wireless and Wearable Neurofeedback Devices: The development of portable and user-friendly neurofeedback devices could make this therapy more accessible to a wider population. Wearable technology can facilitate at-home neurofeedback sessions, making the treatment more convenient and cost-effective.
6 Machine Learning and Artificial Intelligence: Incorporating AI and machine learning algorithms can improve the analysis of EEG data and the customization of neurofeedback protocols. These technologies can help to identify the most effective training patterns and adapt the sessions in real time based on the patient's response.

7 Exploring Different Neurofeedback Modalities: Research into various forms of neurofeedback, such as ILF neurofeedback, SMR training, and others, can expand the options available for treating different types of chronic pain.
8 Clinical Trials and Standardization of Protocols: Conducting more rigorous clinical trials to establish standardized protocols and validate the effectiveness of neurofeedback in diverse chronic pain conditions is crucial. This will help to integrate neurofeedback into mainstream pain management practices.
9 Understanding Mechanisms of Action: Further research is needed to unravel the underlying mechanisms by which neurofeedback affects chronic pain. This understanding can guide the development of more effective treatment strategies and contribute to the field of pain neuroscience.
10 Ethical and Regulatory Considerations: As neurofeedback advances, addressing ethical and regulatory considerations will be important to ensure patient safety and the responsible use of this technology.

4.3 Limitations

Such a narrative review on the use of neurofeedback to treat chronic pain may have potential biases and gaps in the literature. While narrative reviews provide a comprehensive overview of the existing evidence, they may be susceptible to selection bias, as they often rely on non-randomized studies and may not include all available evidence. Additionally, the literature on neuromodulatory treatments for chronic pain, including neurofeedback, may have limitations in terms of study designs and sample sizes, potentially leading to biased conclusions. The effectiveness of neurofeedback in specific patient groups, such as cancer patients, post-cancer survivors, and adolescents with separation anxiety disorder, remains understudied, highlighting gaps in the literature. The limited evidence for the potential efficacy of neurofeedback procedures in the treatment of chronic pain emphasizes the need for further research to address these gaps.

While this narrative review could provide valuable insights into the use of neurofeedback for chronic pain, it is essential indeed to acknowledge potential biases and gaps in the literature, emphasizing the need for high-quality, randomized controlled trials and systematic reviews to strengthen the evidence base for the use of neurofeedback in chronic pain management.

5 Conclusion

The utilization of neurofeedback as a treatment for chronic pain has garnered attention for its potential to alleviate conditions like fibromyalgia, migraine, and other pain syndromes. This therapeutic approach is believed to achieve its effects by modulating brain areas that are crucial in the perception and regulation of pain, thus offering a non-pharmacological alternative to traditional pain management strategies. Notably, neurofeedback therapy has also been associated with improvements in symptoms that frequently accompany chronic pain, such as sleep disturbances, mood disorders, and fatigue, further underscoring its potential as a comprehensive treatment option.

As the field advances, there is a shift toward developing personalized neurofeedback protocols, which are designed based on the unique brain patterns and responses of each individual. This tailored approach is expected to enhance the treatment's efficacy and patient responsiveness, presenting a promising avenue for future research and application. Despite the encouraging outcomes observed thus far, the necessity for additional high-quality, controlled studies is evident. Such research is crucial for establishing standardized treatment protocols, understanding the long-term effects of neurofeedback, and conclusively determining its overall efficacy in managing chronic pain.

Technological advancements in neuroimaging and the development of portable neurofeedback devices are anticipated to make this therapy more accessible and effective, broadening its applicability to a wider patient demographic. Additionally, integrating neurofeedback with other therapeutic modalities, including CBT and physical therapy, could provide a more holistic approach to chronic pain management. This integration aims to address both the physical and psychological components of pain, offering a more comprehensive treatment strategy.

In conclusion, neurofeedback presents a promising, non-invasive, and customizable method for chronic pain management. However, its effectiveness and long-term benefits necessitate further investigation through detailed research. The preliminary findings suggest that neurofeedback has the potential to play a significant role in a multifaceted approach to chronic pain management, complementing existing treatments and therapies. As the field evolves, the integration of neurofeedback into broader pain management practices holds the promise of offering relief and improved quality of life for individuals suffering from chronic pain.

Author contributions

PD: Writing – original draft, Supervision, Methodology. SC: Writing – original draft, Investigation, Data curation. BT: Writing – original draft, Investigation, Data curation. GS: Writing – original draft, Investigation, Data curation. TD: Writing – review & editing, Investigation. AD: Writing – review & editing, Data curation. AZ: Writing – review & editing, Data curation. AR: Writing – review & editing, Methodology. AA: Writing - review & editing, Supervision. SM: Writing – original draft, Supervision, Methodology, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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