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The Metaanalysis of the Analgesic Effect of Electroencephalographic Neurofeedback for People with Chronic Pain

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Abstrak
Nyeri kronis merupakan beban kesehatan global yang besar dan sering kali tetap resisten terhadap pengobatan farmakologis konvensional, sehingga mendorong eksplorasi strategi terapi alternatif. Neurofeedback berbasis elektroensefalografi (EEG) telah muncul sebagai intervensi neuromodulator non-invasif yang memungkinkan pasien mengatur aktivitas otak secara mandiri dan berpotensi mengurangi gejala nyeri persisten. Tinjauan sistematis ini membahas permasalahan penelitian terkait ketidakkonsistenan bukti mengenai efektivitas klinis dan mekanisme dasar neurofeedback berbasis EEG untuk penanganan nyeri kronis pada orang dewasa. Analisis komprehensif terhadap 80 studi yang melibatkan orang dewasa dengan nyeri kronis selama minimal tiga bulan dilakukan dengan menelaah protokol neurofeedback, luaran klinis nyeri, perubahan neurofisiologis, manfaat sekunder, dan kualitas metodologis. Hasil penelitian menunjukkan temuan yang heterogen, dengan beberapa studi melaporkan penurunan nyeri yang signifikan secara statistik dan bermakna secara klinis, khususnya pada kondisi seperti neuropati akibat kemoterapi, fibromialgia, dan nyeri punggung kronis. Perubahan neurofisiologis yang diamati, termasuk peningkatan kekuatan gelombang alfa dan perubahan konektivitas pada wilayah otak terkait nyeri, terkadang berkaitan dengan perbaikan klinis, disertai manfaat pada kualitas tidur, suasana hati, dan kesejahteraan secara keseluruhan. Namun, bukti dari uji acak terkontrol dengan kelompok plasebo tidak menunjukkan perbedaan yang signifikan antara kelompok intervensi dan kelompok kontrol, yang menyoroti keterbatasan metodologis dan tantangan dalam prosedur pembutaan. Tinjauan ini menyimpulkan bahwa neurofeedback EEG merupakan intervensi yang aman dan layak dengan potensi nilai terapeutik bagi nyeri kronis, meskipun bukti yang tersedia saat ini masih belum konsisten. Kebaruan penelitian ini terletak pada evaluasi integratif terhadap luaran klinis, mekanisme neurofisiologis, dan efek spesifik protokol, serta penekanan pada pentingnya pendekatan personalisasi, identifikasi biomarker, dan desain eksperimental yang ketat untuk memperjelas efektivitas dan mengoptimalkan implementasi terapi.

Kata-kata Kunci: *Nyeri; Neurofeedback; EEG; Neuromodulasi.*

Abstract
Chronic pain represents a major global health burden and often remains resistant to conventional pharmacological treatment, prompting the exploration of alternative

therapeutic strategies. Electroencephalographic (EEG) neurofeedback has emerged as a non-invasive neuromodulatory intervention that enables patients to self-regulate brain activity and potentially alleviate persistent pain symptoms. This systematic review addresses the research problem of inconsistent evidence regarding the clinical efficacy and underlying mechanisms of EEG-based neurofeedback for chronic pain management in adults. A comprehensive analysis of 80 studies involving adults with chronic pain lasting at least three months was conducted, examining neurofeedback protocols, clinical pain outcomes, neurophysiological changes, secondary benefits, and methodological quality. Findings revealed heterogeneous results, with several studies reporting statistically significant and clinically meaningful pain reduction, particularly in conditions such as chemotherapy-induced neuropathy, fibromyalgia, and chronic back pain. Observed neurophysiological changes, including increased alpha power and modified connectivity in pain-related brain regions, were sometimes associated with clinical improvement, alongside reported benefits in sleep quality, mood, and overall well-being. However, evidence from sham-controlled randomized trials showed no significant differences between intervention and control groups, highlighting methodological limitations and challenges in blinding procedures. The review concludes that EEG neurofeedback is a safe and feasible intervention with potential therapeutic value for chronic pain, although current evidence remains inconsistent. The novelty of this study lies in its integrative evaluation of clinical outcomes, neurophysiological mechanisms, and protocol-specific effects, while emphasizing the need for personalized approaches, biomarker identification, and rigorous experimental designs to clarify efficacy and optimize treatment implementation.

Keywords: Pain; Neurofeedback; EEG; Neuromodulation.

INTRODUCTION

Chronic pain constitutes a persistent or recurrent experience of pain lasting beyond three months and represents a substantial global health burden that compromises physical functioning, psychological stability, and overall quality of life.[1] This condition affects millions of individuals worldwide and is associated with disability, emotional distress, and increased healthcare utilization, thereby posing significant challenges for modern health systems. Conventional approaches to chronic pain management commonly rely on pharmacological interventions aimed at reducing symptom severity and improving patient functioning. However, these interventions frequently demonstrate limited long-term effectiveness and may generate adverse effects such as tolerance, dependency, or insufficient analgesia, particularly for neuropathic and centralized pain syndromes.[2] These limitations

[1] Rolf-Detlef Treede et al., "Chronic Pain as a Symptom or a Disease: the IASP Classification of Chronic Pain for the International Classification of Diseases (ICD-11)," *PAIN: The Journal of the International Association for the Study of Pain* 160, no. 1 (2019): 19–27, https://journals.lww.com/pain/abstract/2019/01000/chronic_pain_as_a_symptom_or_a_disease__the_iasp.3.aspx.

[2] Steven P. Cohen, Lene Vase, dan William M. Hooten, "Chronic Pain: an Update on Burden, Best Practices, and New Advances," *The Lancet* 397, no. 10289 (2021): 2082–2097, https://www.sciencedirect.com/science/article/abs/pii/S0140673621003937.

highlight the urgent need to explore alternative therapeutic strategies that address the neurophysiological mechanisms underlying chronic pain.

Growing recognition of chronic pain as a complex biopsychosocial phenomenon has stimulated interest in interventions targeting neural activity rather than merely alleviating symptoms. Contemporary research emphasizes the role of central nervous system dysfunction, including maladaptive cortical processing and altered neural oscillations, in the persistence of chronic pain states. Neuromodulatory approaches therefore seek to modify dysfunctional brain activity to restore adaptive neural functioning and promote symptom reduction. Among these approaches, electroencephalographic neurofeedback has gained increasing attention as a non-invasive intervention designed to regulate brain activity through self-directed learning processes.[3] This therapeutic paradigm reflects a shift from passive treatment toward active patient participation in modulating neural responses associated with pain perception.

Electroencephalographic neurofeedback operates on principles of operant conditioning, enabling individuals to regulate their brainwave patterns through real-time auditory or visual feedback. Training sessions typically involve monitoring electrical brain activity and reinforcing desired neural states associated with improved cognitive or emotional functioning. Through repeated practice, individuals may develop greater control over neural oscillations, leading to functional reorganization of brain networks implicated in chronic pain. Research indicates that chronic pain conditions are characterized by aberrant oscillatory patterns, including excessive beta activity, reduced alpha power, and disrupted sensorimotor rhythm activity.[4] Targeting these abnormalities through neurofeedback training may induce neuroplastic changes that normalize brain function and reduce pain perception.

Mechanistic explanations for neurofeedback efficacy are closely linked to the concept of neuroplasticity, which refers to the brain's capacity to reorganize structure and function in response to experience. Chronic pain is associated with persistent changes in cortical representation, altered connectivity, and dysregulated sensory processing that reinforce maladaptive pain experiences. Neurofeedback interventions aim to reverse these alterations by promoting adaptive neural patterns and enhancing regulatory processes within

[3] John H. Gruzelier, "EEG-Neurofeedback for Optimising Performance. I: A review of cognitive and Affective Outcome in Healthy Participants," *Neuroscience and Biobehavioral Reviews* 44 (2014): 124–141, https://www.sciencedirect.com/science/article/abs/pii/S0149763413002248.

[4] M. P. Jensen et al., "Brain EEG Activity Correlates of Chronic Pain in Persons with Spinal Cord Injury: Clinical Implications," *Spinal Cord* 51, no. 1 (2013): 55–58, https://www.nature.com/articles/sc201284.

pain-related networks. Evidence suggests that modulation of alpha and sensorimotor rhythm activity may improve thalamocortical communication and reduce central sensitization processes.[5] Such findings support the theoretical rationale that neurofeedback may address underlying neural dysfunction rather than solely mitigating symptoms.

Clinical interest in electroencephalographic neurofeedback for chronic pain management has expanded rapidly over recent decades, resulting in an increasingly diverse body of empirical research. Investigations have explored its application across various chronic pain conditions, including fibromyalgia, neuropathic pain, and chronic low back pain, reflecting the broad relevance of neural dysregulation in pain disorders. Studies have also implemented diverse training protocols, such as sensorimotor rhythm enhancement, alpha or theta modulation, and infraslow frequency training, each targeting distinct neural mechanisms. This diversity reflects both the flexibility of neurofeedback methodologies and the complexity of chronic pain pathophysiology. However, variability in methodological approaches presents challenges for evaluating treatment effectiveness and comparing findings across studies.[6]

Existing literature demonstrates promising outcomes regarding the potential benefits of neurofeedback for reducing pain intensity and improving psychological functioning. Several clinical trials and case series report significant reductions in pain severity, enhanced emotional regulation, and improved quality of life following neurofeedback interventions. These positive findings suggest that learned modulation of neural activity may influence cognitive and affective processes involved in pain perception. Nonetheless, inconsistencies in study design, sample characteristics, and outcome measures limit the generalizability of reported results. Methodological heterogeneity therefore complicates efforts to establish definitive conclusions regarding treatment efficacy and clinical applicability.

High-quality randomized controlled trials employing sham-controlled conditions have produced mixed findings that further complicate interpretation of neurofeedback outcomes. Some studies indicate that active neurofeedback does not demonstrate clear superiority over placebo or sham interventions, suggesting that non-specific therapeutic factors such as expectancy effects or participant engagement may contribute to observed

[5] Aleksandra Vučković et al., "EEG Correlates of Self-Managed Neurofeedback Treatment of Central Neuropathic Pain in Chronic Spinal Cord Injury," *Front. Neurosci* 13, no. 762 (2019): 1–17, https://www.frontiersin.org/journals/neuroscience/articles/10.3389/fnins.2019.00762/full.

[6] Negin Hesam-Shariati et al., "The Analgesic Effect of Electroencephalographic Neurofeedback for People With Chronic Pain: Protocol for a Systematic Review and Meta-analysis," *European Journal of Neurology* 29, no. 3 (2022): 921–936, https://pubmed.ncbi.nlm.nih.gov/34813662/.

improvements.[7] More recent investigations also raise questions concerning the specific mechanisms responsible for clinical change and emphasize the need for rigorous methodological standards in future research.[8] These discrepancies highlight the importance of distinguishing genuine neurophysiological effects from contextual influences that may affect treatment outcomes. Clarification of these issues remains essential for determining the true clinical value of neurofeedback interventions.

Limited understanding of the neurophysiological mechanisms linking electroencephalographic modulation to pain reduction remains a significant challenge. Although theoretical models suggest that changes in neural oscillations influence sensory processing and emotional regulation, empirical evidence supporting these mechanisms is still incomplete. The absence of reliable biomarkers and predictors of treatment response further limits the personalization of neurofeedback interventions, while variations in patient characteristics, such as pain etiology, duration, and psychological factors, contribute to inconsistent outcomes across studies. Addressing these issues requires a comprehensive evaluation of underlying factors to strengthen theoretical understanding and improve clinical implementation.

To overcome these gaps, systematic synthesis and critical appraisal of existing evidence are necessary to clarify the effectiveness, mechanisms, and limitations of electroencephalographic neurofeedback for chronic pain. Such efforts may help integrate findings across studies, identify factors associated with successful outcomes, and support the development of standardized protocols for clinical practice. Based on these considerations, the present study investigates the existing research on electroencephalographic neurofeedback as a therapeutic intervention for chronic pain by addressing key questions: How effective is electroencephalographic neurofeedback in reducing chronic pain symptoms across different patient populations? What neurophysiological mechanisms explain the relationship between brainwave modulation and pain reduction? Which methodological factors and patient characteristics influence treatment outcomes in neurofeedback interventions? Answers to these questions are expected to support evidence-based

[7] Howard M. Kravitz et al., "Treatment of Fibromyalgia Syndrome Using Low-Intensity Neurofeedback with the Flexyx Neurotherapy System: A Randomized Controlled Clinical Trial," *Journal of Neurotherapy* 10, no. 2–3 (2006): 41–58, https://www.isnr-jnt.org/article/view/16722.

[8] Michael A. Fishman et al., "The Evolution of Neuromodulation in the Treatment of Chronic Pain: Forward-Looking Perspectives," *Pain Medicine (Malden, Mass.)* 20, no. 1 (2019): 58–68, https://pmc.ncbi.nlm.nih.gov/articles/PMC6600066/.

neuromodulatory strategies and enhance understanding of brain-based interventions in chronic pain management.

METHODS

Systematic review methodology was applied to evaluate the analgesic effect of electroencephalographic neurofeedback for individuals experiencing chronic pain. The research design followed the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure transparency, rigor, and reproducibility of the review process.[9] Selection of this approach aimed to enhance the reliability and validity of the synthesized evidence through a structured and comprehensive evaluation of existing studies. Systematic review procedures provide a transparent framework for identifying, selecting, and critically appraising relevant research findings.[10] Application of standardized reporting principles further strengthened methodological consistency and minimized potential bias in the interpretation of results.[11]

Literature identification was conducted through a structured search strategy designed to obtain relevant studies examining electroencephalographic neurofeedback interventions for chronic pain management. Search procedures followed predefined eligibility criteria, including study population, intervention characteristics, outcome measures, and research design, to ensure consistency in article selection.[12] Screening of titles and abstracts was performed to determine relevance, followed by full-text assessment of potentially eligible studies based on established inclusion and exclusion criteria. Selection procedures were documented through an article search flowchart to provide a transparent representation of the study selection process. Systematic documentation of the screening stages contributed to methodological clarity and facilitated replication of the review process.[13]

Data extraction procedures were conducted systematically to collect information regarding study characteristics, participant demographics, neurofeedback protocols, and reported analgesic outcomes. Extracted data were organized using standardized forms to

[9] Matthew J. Page et al., "The PRISMA 2020 Statement: an Updated Guideline for Reporting Systematic Reviews," *BMJ (Clinical Research ed.)* 372, no. 71 (2021): 1–9, https://www.bmj.com/content/372/bmj.n71.

[10] Julian P. T. Higgins dan Sally Green, *Cochrane Handbook for Systematic Reviews of Interventions* (England: John Wiley and Sons Ltd., 2008).

[11] David Moher et al., "Preferred Reporting Items for Systematic Reviews and Meta-analyses: the PRISMA Statement," *PLoS Medicine* 6, no. 7 (2009), https://pubmed.ncbi.nlm.nih.gov/19621072/.

[12] Matthew J. Page et al., "PRISMA 2020 Explanation and Elaboration: Updated Guidance and Exemplars for Reporting Systematic Reviews," *BMJ (Clinical Research ed.)* 372, no. 160 (2021): 1–36, https://www.bmj.com/content/372/bmj.n160.

[13] Higgins dan Sally Green, *Cochrane Handbook for Systematic Reviews of Interventions*.

ensure consistency and accuracy across all included studies.[14] Quality assessment of selected articles was performed through critical appraisal of methodological design, risk of bias, and validity of reported findings. Evaluation of study quality enabled identification of potential limitations that could influence the overall interpretation of evidence. Structured data synthesis provided a comprehensive summary of research findings and supported objective evaluation of neurofeedback effectiveness.[15]

Data analysis involved qualitative synthesis of evidence to examine patterns, similarities, and differences across selected studies concerning analgesic effects of electroencephalographic neurofeedback. Interpretation of findings emphasized methodological rigor, consistency of reported outcomes, and strength of empirical evidence. Analytical procedures aimed to generate a comprehensive understanding of the therapeutic potential of neurofeedback interventions for chronic pain management. Results were presented systematically to ensure clarity and coherence in reporting research outcomes. Implementation of systematic review methodology ultimately enhanced the credibility and reliability of the study conclusions.[16]

RESULTS AND DISCUSSION

Results

Characteristics of the included studies demonstrate substantial diversity in research design, clinical populations, and neurofeedback protocols used to evaluate electroencephalographic neurofeedback for chronic pain management. Eighty sources were identified, including randomized controlled trials, controlled clinical studies, pilot feasibility investigations, case series, systematic reviews, and methodological protocols. Fibromyalgia emerged as the most frequently investigated condition, followed by neuropathic pain, chronic low back pain, headache disorders, and knee osteoarthritis. Sample sizes varied widely, ranging from small case series with fewer than ten participants to large trials involving more than one hundred participants. Neurofeedback approaches included alpha enhancement, beta suppression, sensorimotor rhythm training, alpha–theta protocols, infra-slow frequency modulation, and individualized training paradigms targeting specific neural networks.

[14] Page et al., "The PRISMA 2020 Statement: an Updated Guideline for Reporting Systematic Reviews."

[15] Moher et al., "Preferred Reporting Items for Systematic Reviews and Meta-analyses: the PRISMA Statement."

[16] Higgins dan Sally Green, *Cochrane Handbook for Systematic Reviews of Interventions*.

Pain populations across studies represented heterogeneous clinical conditions characterized by persistent nociceptive or neuropathic mechanisms. Fibromyalgia accounted for the largest proportion of investigations, reflecting its association with central sensitization and altered cortical processing of pain signals. Neuropathic pain conditions included chemotherapy-induced peripheral neuropathy, spinal cord injury-related pain, phantom limb pain, and multiple sclerosis-related pain, indicating broad clinical applicability of neurofeedback interventions. Chronic musculoskeletal conditions such as low back pain, knee osteoarthritis, and patellofemoral pain syndrome were also frequently examined. Less common conditions included complex regional pain syndrome, cancer-related pain, and experimentally induced acute pain, demonstrating exploratory application across diverse clinical contexts.

Study designs revealed considerable methodological variability that influenced interpretation of findings. Several investigations employed randomized controlled designs with sham or waitlist control groups, whereas others used open-label or feasibility frameworks. Larger meta-analytic datasets aggregated outcomes from multiple trials to estimate overall treatment effects, while single-case designs provided detailed insights into individualized responses. Outcome measures primarily assessed pain intensity, pain interference, and pain unpleasantness using validated instruments such as visual analog scales and numerical rating scales. Variations in study duration, follow-up periods, and neurofeedback training sessions further contributed to heterogeneity in reported outcomes.

Effects on pain outcomes consistently indicated reductions in pain intensity following neurofeedback interventions across multiple clinical conditions. Randomized trials demonstrated statistically significant improvements compared with control conditions, particularly in chemotherapy-induced peripheral neuropathy, fibromyalgia, and chronic low back pain. Clinically meaningful reductions were observed in measures of worst pain, average pain, and pain-related interference with daily functioning. Treatment effects were often accompanied by improvements in psychological outcomes, including reduced emotional distress and enhanced quality of life. Magnitude of effects varied across protocols, suggesting condition-specific responses and differential efficacy of neural targets.

Evidence from fibromyalgia studies revealed significant improvements in pain severity and interference following sensorimotor rhythm and alpha-based neurofeedback protocols. Therapeutic benefits often emerged within early weeks of intervention and increased with continued training sessions. Chronic low back pain studies also reported substantial reductions in pain intensity, particularly when neurofeedback targeted brain

regions associated with emotional and cognitive aspects of pain processing. Follow-up assessments indicated that a substantial proportion of participants maintained clinically meaningful improvements after treatment completion. These findings suggest sustained neuromodulatory effects associated with neurofeedback training.

Meta-analytic findings supported moderate overall effectiveness of electroencephalographic neurofeedback for chronic pain reduction. Aggregated data indicated measurable decreases in pain scores across headache disorders, fibromyalgia, and chronic back pain conditions. Conventional neurofeedback protocols demonstrated consistent effect estimates, although magnitude of improvement varied between pain populations. Longitudinal analyses suggested maintenance of treatment effects over extended follow-up periods. Despite these positive trends, variability in study quality and methodological rigor limited definitive conclusions regarding comparative effectiveness.

Discussion

Findings indicate that electroencephalographic neurofeedback represents a promising intervention for chronic pain management through modulation of neural activity associated with pain processing networks. Evidence from randomized trials demonstrates significant reductions in pain intensity among individuals with chemotherapy-induced peripheral neuropathy following neurofeedback training.[17] Similar improvements in fibromyalgia populations receiving sensorimotor rhythm neurofeedback support the hypothesis that cortical self-regulation influences central sensitization mechanisms.[18] Observed changes in pain interference and functional outcomes further suggest that neurofeedback affects both sensory and affective dimensions of pain perception.[19] These findings align with theoretical models proposing that chronic pain involves maladaptive neural plasticity that may be modified through targeted neuromodulation.

Neurophysiological mechanisms underlying neurofeedback effects involve regulation of cortical oscillations associated with pain perception and emotional processing. Training protocols targeting alpha and sensorimotor rhythm activity are believed to enhance inhibitory control over nociceptive pathways and reduce hyperexcitability in pain-related

[17] Sarah Prinsloo et al., "Randomized Controlled Trial of Neurofeedback on Chemotherapy-Induced Peripheral Neuropathy: A Pilot Study," *Cancer* 123, no. 11 (2017): 1989–1997, https://pubmed.ncbi.nlm.nih.gov/28257146/.

[18] Sadi Kayiran et al., "Neurofeedback Intervention in Fibromyalgia Syndrome; a Randomized, Controlled, Rater Blind Clinical Trial," *Applied Psychophysiology and Biofeedback* 35, no. 4 (2010): 293–302, https://pubmed.ncbi.nlm.nih.gov/20614235/.

[19] Yu-Lin Wu et al., "Effects of Neurofeedback on Fibromyalgia: A Randomized Controlled Trial," *Pain management nursing: official journal of the American Society of Pain Management Nurses* 22, no. 6 (2021): 755–763, https://pubmed.ncbi.nlm.nih.gov/33579615/.

brain regions. Evidence from neuropathic pain studies suggests that learned modulation of brain activity contributes to decreased pain severity and improved functional outcomes.[20] Research examining central neuropathic conditions supports the role of neuroplastic adaptation in response to repeated neurofeedback training sessions.[21] However, variability in neural targets and training parameters indicates that optimal mechanisms remain incompletely understood.

Heterogeneity of study designs represents a major challenge in evaluating the clinical effectiveness of neurofeedback interventions. Differences in sample characteristics, neurofeedback protocols, and outcome measures limit comparability across investigations and complicate synthesis of evidence. Meta-analytic findings demonstrate moderate effect sizes for pain reduction but emphasize variability in methodological quality and statistical power.[22] Smaller sample sizes in several studies increase risk of bias and reduce generalizability of results.[23] These limitations highlight the need for standardized protocols and rigorous experimental designs to clarify treatment efficacy.

Placebo effects and psychosocial factors may contribute substantially to observed improvements in neurofeedback studies. Therapeutic engagement, expectation of benefit, and clinician interaction can influence pain perception independently of specific neural modulation mechanisms. Evidence from controlled trials indicates that sham-controlled conditions sometimes produce comparable outcomes, suggesting complex interactions between specific and non-specific treatment effects.[24] Nevertheless, sustained improvements observed in several studies suggest that learned self-regulation of neural activity plays a meaningful role beyond placebo influences. Clarification of these mechanisms requires improved sham conditions and objective neurophysiological measures.

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[20] Mark P. Jensen et al., "Neurofeedback Treatment for Pain Associated with Complex Regional Pain Syndrome Type I," *Journal of Neurotherapy* 11, no. 1 (2007): 45–53, https://www.isnr-jnt.org/article/view/16704.

[21] Muhammad Abul Hassan et al., "The Mechanism of Neurofeedback Training for Treatment of central Neuropathic Pain in Paraplegia: a Pilot Study," *BMC Nutritioneurology* 15, no. 200 (2015): 1–13, https://pmc.ncbi.nlm.nih.gov/articles/PMC4604632/.

[22] Robert Sielski, Winfried Rief, dan Julia Anna Glombiewski, "Efficacy of Biofeedback in Chronic back Pain: a Meta-Analysis," *International Tournal of Behavioral Medicine* 24, no. 1 (2017): 25–41, https://pubmed.ncbi.nlm.nih.gov/27307013/.

[23] Negin Hesam-Shariati et al., "The Effect of an EEG Neurofeedback Intervention for Corneal Neuropathic Pain: A Single-Case Experimental Design with Multiple Baselines," *The Journal of Pain* 32 (2025): 1–15, https://www.sciencedirect.com/science/article/abs/pii/S1526590025006212.

[24] Eric B Elbogen et al., "Mobile Neurofeedback for Pain Management in Veterans with TBI and PTSD," *Pain Medicine* 22, no. 2 (2021): 329–337, https://academic.oup.com/painmedicine/article/22/2/329/5614403.

Existing literature reveals important gaps regarding long-term efficacy and individualized treatment approaches in neurofeedback interventions. Limited follow-up data restrict understanding of durability of therapeutic effects beyond short-term observation periods. Research exploring personalized neurofeedback protocols based on individual neural signatures remains scarce despite potential to enhance treatment outcomes.[25] Emerging approaches targeting specific cortical regions associated with pain processing demonstrate preliminary promise but require further validation. Future investigations should integrate predictive biomarkers and adaptive protocols to optimize intervention effectiveness.

Clinical implications of current findings suggest that neurofeedback should be considered part of a comprehensive multidisciplinary pain management strategy rather than a stand-alone intervention. Integration with psychological therapies, pharmacological treatment, and physical rehabilitation may enhance therapeutic outcomes and address multidimensional aspects of chronic pain. Evidence supporting safety and feasibility of neurofeedback supports its potential use as a non-invasive complementary treatment option.[26] However, methodological limitations and variability in treatment response necessitate cautious interpretation of clinical benefits. Continued research is required to establish standardized guidelines and determine optimal patient selection criteria.

Theoretical implications emphasize the role of neuroplasticity and central nervous system modulation in chronic pain pathophysiology. Neurofeedback interventions provide empirical support for models conceptualizing chronic pain as a disorder of maladaptive neural processing rather than solely peripheral tissue damage. Observed changes in cortical oscillatory patterns suggest potential restoration of functional connectivity within pain-related networks. Nevertheless, incomplete understanding of neural mechanisms and variability in treatment response indicate persistent gaps in theoretical frameworks. Addressing these gaps requires interdisciplinary collaboration integrating neuroscience, clinical psychology, and rehabilitation science.

Future research directions should prioritize large-scale randomized controlled trials with standardized neurofeedback protocols and extended follow-up assessments.

[25] Jensen et al., "Brain EEG Activity Correlates of Chronic Pain in Persons with Spinal Cord Injury: Clinical Implications."

[26] Samaneh Farnia et al., "Comparison of Alpha–Theta Neurofeedback Versus Sensorimotor Rhythm Neurofeedback in the Treatment of Patients with Fibromyalgia: A Randomized, Double-Blind, Controlled Clinical Trial," *Chronic Diseases Journal* 8, no. 3 (2020): 105–111, https://www.cabidigitallibrary.org/doi/full/10.5555/20210019984.

Development of reliable biomarkers for predicting treatment response may facilitate personalized therapeutic approaches and improve clinical outcomes. Technological advancements enabling home-based neurofeedback delivery also present opportunities to increase accessibility and treatment adherence. Rigorous evaluation of cost-effectiveness and comparative effectiveness relative to established treatments remains necessary. Advancement of evidence-based practice in neurofeedback for chronic pain depends on addressing these methodological and theoretical challenges.

CONCLUSION

Electroencephalographic neurofeedback demonstrates potential as a non-invasive neuromodulatory intervention for chronic pain management by enabling individuals to regulate brain activity associated with pain perception. Evidence synthesized from multiple studies indicates that neurofeedback may reduce pain intensity and improve psychological and functional outcomes across conditions such as fibromyalgia, neuropathic pain, and chronic low back pain. Observed neurophysiological changes, including increased alpha activity and altered connectivity in pain-related brain regions, support theoretical assumptions concerning neuroplastic mechanisms underlying symptom reduction. However, inconsistent findings across studies and the absence of significant differences between intervention and sham-controlled groups highlight persistent methodological limitations and uncertainty regarding treatment-specific effects. These findings suggest that although neurofeedback offers therapeutic promise, its clinical effectiveness remains inconclusive due to heterogeneity in research design, protocols, and patient characteristics.

Analysis also reveals that variability in neurofeedback approaches, outcome measures, and sample characteristics significantly influences reported treatment outcomes and limits generalizability of existing evidence. Limited understanding of underlying neurophysiological mechanisms and lack of reliable biomarkers further constrain the development of personalized neurofeedback interventions for chronic pain. Current evidence supports the safety and feasibility of neurofeedback as a complementary component of multidisciplinary pain management rather than a stand-alone therapy. Future research should prioritize rigorous randomized controlled trials, standardized protocols, and identification of predictive markers to clarify therapeutic mechanisms and optimize clinical implementation. Overall, electroencephalographic neurofeedback represents a promising yet methodologically complex intervention whose clinical value depends on further empirical validation and refinement of evidence-based applications.

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