

Bibliometric analysis of neurofeedback research from 2000 to 2022

Siti Atiyah Ali ^{1,2,*}, Mazira Mohamad Ghazali ³, Nurfaizatul Aisyah Ab Aziz ³ and Humaira Nisar ^{1,2}

¹ Centre for Healthcare Science and Technology, Universiti Tunku Abdul Rahman, Bandar Sungai Long, 43000 Kajang, Malaysia.

² Department of Electronic Engineering, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman, 31900, Perak, Malaysia.

³ Department of Neuroscience & Brain & Behaviour Cluster, Universiti Sains Malaysia, 16150, Kelantan, Malaysia.

* Correspondence: atiyahali90@yahoo.com.my; Tel.: +6013-3153685

Received: 14 June 2023; **Accepted:** 19 December 2023; **Published:** 16 March 2024

Edited by: Indranath Chatterjee (Tongmyong University, South Korea)

Reviewed by: Ahmed Alsharif (Universiti Teknologi Malaysia, Malaysia);

Panlekha Rungruang (Mahidol University, Thailand)

<https://doi.org/10.31117/neuroscirn.v7i1.265>

ABSTRACT: The application of neurofeedback is gaining increasing interest among neuroscientists as a potential neurorehabilitation approach in cases of various neuro-related functional abnormalities. Discovering the current state of research and identifying gaps in the field of neurofeedback is an essential step in planning and mapping out future research efforts. This bibliometric analysis paper aims to identify the publications and research in neurofeedback from 2000 to 2022. A comprehensive Scopus database search was conducted using the keyword "neurofeedback" and relevant publications from 2000 to 2022 were retrieved. Bibliometric analyses were performed using the Harzing's Publish or Perish and VOSviewer software programmes. The number of retrieved documents was 1835. The number of publications has shown a steadily increasing trend since 2000, with a prominent spike in publications in 2014–2015, indicating a sudden interest in neurofeedback. Among the retrieved documents, 50.3% were related to neuroscience, 23.7% related to medicine, and 13.1% related to psychology. The main contributors to this research come from the United States (24.7%), Germany (13.7%), the United Kingdom (9.4%), and Switzerland (4.9%). Based on the network visualisation of author keywords, the most frequently occurring keywords were neurofeedback, real-time functional magnetic resonance imaging (fMRI), brain-computer interface (BCI), neuromodulation, and neurofeedback training. This bibliometric analysis presents the current status, knowledge base, and future neurofeedback study directions. These findings will benefit future researchers interested in applying neurofeedback as a potential neurorehabilitation approach for a wider population.

Keywords: Neurofeedback; Neurorehabilitation; Neuroscience

©2024 Ali *et al.* for use and distribution according to the Creative Commons Attribution (CC BY-NC 4.0) license (<https://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.

1.0 INTRODUCTION

The regulation of brainwaves is not new to the world of neuroscience. It is believed that abnormal brainwave patterns can be normalised back through training. Neurofeedback is a non-invasive neurotherapy that measures brainwave activity and provides a real-time feedback signal ([Marzbani et al., 2016](#)). Neurofeedback was introduced in the early 1940s, with researchers using classical conditioning methods to induce changes in EEG readings, specifically alpha-blocking responses. These findings led to the hypothesis that specific conditioning could elicit changes in brain activity ([Arns et al., 2014](#)).

In the last 20 years, research on the topic of neurofeedback has gradually gained attention among clinicians as a potential neurotherapy in improving specific symptoms associated with cognitive and behavioural abnormalities. The neurofeedback mechanism performs feedback training to correct the abnormal brainwave patterns and return them to normalcy. There are five different brainwaves, and each of them has specific frequencies: delta (1 – 3 Hz), theta (4 – 7 Hz), alpha (8 – 12 Hz), beta (13 – 30 Hz), and gamma (> 30 Hz). Each brainwave represents a different state of brain activity. Delta is dominant when the mind is unconscious or deep asleep, while theta is most commonly found during dreamless sleep, inattention, trance meditation, or drowsiness. In a state of relaxation, your brain exhibits alpha brainwaves, while when you're alert or focused, your brain generates beta brainwaves. Gamma is dominant during learning and concentration. However, some neurological issues related to cognitive or neurodevelopmental disorders may lead to abnormal dominance of brain activity. For instance, attention-deficit hyperactivity disorder (ADHD) is associated with an elevated theta and beta ratio, while schizophrenia is linked to reduced alpha with enhanced beta. Alzheimer's disease is characterised by an improved delta/theta ratio with a reduced alpha/beta ratio ([Adamou et al., 2020](#); [Itil, 1977](#); [Newson & Thiagarajan, 2019](#); [Picken et al., 2020](#)).

However, each brain brainwave's dominance is not unique to a specific neurological disorder, as there may be cross-similarities in brainwave dominance across different disorders. Given that neural maturity varies throughout adulthood or ageing, it is not ascertained that the dominance of brainwaves remains the same. In this regard, neurofeedback is a neurotherapy method that uses a certain brainwave as a treatment protocol for a series of training sessions. It aims to alleviate certain cognitive states. No reinforcement is given to

subjects whose brainwaves produce abnormal patterns in response to certain stimuli until the brainwaves improve. The most common treatment protocol in neurofeedback includes theta, alpha, beta, and the alpha/theta ratio ([Vernon, 2005](#)). Several studies have produced varying results regarding the effectiveness of neurofeedback in improving cognitive function and behavioural performance ([Loriette et al., 2021](#); [Tseng et al., 2021](#); [Vernon, 2005](#); [Zandi Mehran et al., 2015](#)). Despite neurofeedback's effectiveness having attracted attention for more in-depth research worldwide, relatively few clinical health facilities still provide neurofeedback as an option for neurotherapy. Instead, it is more readily available at private facilities, which can make it inaccessible to some people. The lack of randomised controlled trial (RCT) studies in neurofeedback may be a contributing factor. The lack of RCTs means there is less definite evidence of the efficacy of neurofeedback for treatment purposes ([Janssen et al., 2016](#)).

Given the growing number of studies on neurofeedback as a neurotherapy in many healthcare settings, a bibliometric analysis of these studies could be beneficial in revealing research trends in neurofeedback. This analysis can help future researchers identify specific areas of neurofeedback that can be explored further. Additionally, this type of analysis has been widely used to represent trend data of research in other areas, such as neuromarketing ([Alsharif et al., 2021](#) and [2023b](#)), neuroscience ([Lin et al., 2022](#)) and neurorehabilitation ([Tsiamalou et al., 2022](#)). To the best of our knowledge, no bibliometric analysis studies have been conducted in neurofeedback. Therefore, there is no comprehensive overview of the scope of neurofeedback publications and trends in this field over the past few decades. A bibliometric study focuses on the document analysis of citation-based measurement of journals, authors, and institutions in a specific area. The statistical data obtained from bibliometric studies provide insights into research significance, the influence of journals, and the contributions of authors, institutions, and countries within a particular research domain ([Szomszor et al., 2021](#)). Therefore, to track the advancement of neurofeedback research, it is essential to conduct a bibliometric study to analyse and visualise the literature on neurofeedback research from its inception to the present. Furthermore, quantitative bibliometrics analysis provides the progress of neurofeedback research and identifies research hotspots, research collaboration, management strategies, and cutting-edge trends in neurofeedback research ([Liu et al., 2022](#)). This