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Brain-Computer Interfaces in Assistive Technologies: A Bibliometric Review

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ABSTRACT

This study presents a comprehensive bibliometric review of scholarly literature on Brain-Computer Interfaces (BCIs) in assistive technologies, aiming to map research trends, intellectual structure, and collaborative patterns from 2000 to 2024. Using data retrieved from the Scopus database and analyzed through VOSviewer, this review identifies key contributors, institutional affiliations, and country-level collaborations. Results show a steady increase in publication output, with a sharp surge in 2024, indicating growing academic and clinical interest in BCI-assisted systems. The United States, Germany, and India emerge as the most productive countries, while institutions such as Eberhard Karls Universität Tübingen and Harvard Medical School lead in scholarly output. Author co-authorship analysis reveals influential figures and collaborative hubs, particularly in Europe and North America. Thematic clustering of keywords uncovers major research domains, including neurophysiological signal processing, machine learning applications, robotic control systems, and user-focused communication aids. Overlay and density visualizations suggest an evolution from foundational EEG-based research to more sophisticated, AI-enhanced and ethically grounded assistive technologies. This review provides a data-driven understanding of the field’s development and highlights future directions toward more inclusive, adaptive, and scalable BCI solutions for individuals with disabilities.

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1. INTRODUCTION

The rapid advancement in neurotechnology has enabled the development of Brain-Computer Interfaces (BCIs), a cutting-edge innovation that allows direct communication between the brain and external devices. BCIs interpret neural signals and translate them into actionable commands, bridging the gap between cognitive intentions and machine response [1]. Initially conceptualized for neurophysiological research, BCI systems have grown into robust tools with applications spanning clinical rehabilitation, communication aids, and smart environments. One of the most transformative applications of BCIs is in the realm of assistive technologies, aimed at improving the autonomy and quality of life for individuals with motor or sensory impairments [2]. The integration of BCI with assistive devices represents a paradigm shift, emphasizing not only technological sophistication but also user-centric empowerment.

The intersection between BCIs and assistive technologies is particularly crucial for people affected by neurological disorders such as amyotrophic lateral sclerosis (ALS), cerebral palsy, spinal cord injuries, and stroke. Traditional assistive tools—such as wheelchairs, prosthetics, and voice-assistive software—often require some form of muscular control, which may be limited or entirely absent in certain individuals [3]. BCIs offer an alternative interface that bypasses conventional motor pathways, allowing users to operate devices through thought alone. This capacity opens avenues for restoring mobility, enhancing communication, and facilitating environmental control, thus significantly improving personal independence.

The field of BCI-based assistive technologies has grown extensively in recent decades, spurred by advancements in neuroscience, machine learning, and wearable sensors. Electroencephalography (EEG)-based BCIs have become particularly prevalent due to their non-invasive nature, portability, and cost-efficiency [4]. Researchers have developed a variety of applications ranging from brain-controlled wheelchairs and prosthetic limbs to spellers and smart home interfaces [5]. These systems combine signal acquisition, preprocessing, feature extraction, and classification techniques to translate neural signals into discrete commands, forming a loop of cognitive interaction with the environment. However, despite substantial progress, challenges persist in terms of signal reliability, user training, adaptability, and real-world deployment.

In addition to technical innovation, the ethical, psychological, and social dimensions of BCI integration are drawing increasing scholarly attention. Issues of user consent, mental workload, data privacy, and long-term cognitive effects remain under scrutiny [6]. Furthermore, the inclusive design of BCI technologies—ensuring that devices accommodate the diverse needs of users across ages, cultures, and impairments—is critical for equitable deployment. This multi-dimensional complexity has resulted in a multidisciplinary research landscape involving neuroscientists, engineers, computer scientists, clinicians, ethicists, and rehabilitation specialists. Bibliometric analysis thus serves as a valuable tool to map the structure, dynamics, and evolution of this rich knowledge domain.

Over the last two decades, the growing corpus of scientific literature reflects the maturation and diversification of BCI applications in assistive technologies. Emerging themes include hybrid BCIs, integration with virtual and augmented reality, and brain-to-brain communication [7]. To date, no single comprehensive study has systematically quantified and visualized the research patterns and thematic clusters in this niche. A bibliometric review—anchored in quantitative citation data and co-authorship networks—can illuminate dominant research areas, prolific authors and institutions, core journals, and geographic trends. By doing so, it offers an empirical foundation to understand how scholarly interest in BCI-based assistive technologies is evolving and where future inquiry may be directed.

Despite the growing significance of Brain-Computer Interfaces in assistive technologies, the field remains fragmented, with diverse approaches, methodologies, and focus areas spread across disciplines and publications. This heterogeneity poses a challenge for researchers, clinicians, and policymakers who seek a coherent understanding of the field's development and future trajectory. The absence of a consolidated bibliometric analysis hampers the ability to identify influential research works, collaboration patterns, and emerging hotspots in BCI-related assistive technology development. Consequently, stakeholders may find it difficult to make informed decisions regarding funding, collaboration, and translation of research into practice. This study aims to conduct a comprehensive bibliometric review of the literature on Brain-Computer Interfaces in assistive technologies.

2. LITERATURE REVIEW

2.1. Evolution of BCI Technologies

BCIs have evolved from basic signal acquisition systems to sophisticated real-time interfaces capable of interpreting complex neural patterns. Early research focused on the feasibility of extracting reliable neural signals, primarily using electroencephalography (EEG) due to its non-invasive and cost-effective properties [8]. Over time, improvements in signal processing, feature extraction, and machine learning algorithms have significantly enhanced BCI performance, reliability, and applicability [9]. Recent studies highlight a growing emphasis on adaptive algorithms that improve system accuracy by learning user-specific neural features. For instance, motor imagery-based BCIs, which decode imagined movement intentions, have gained popularity for their potential in both clinical and non-clinical settings [10]. The rise of deep learning techniques has further accelerated signal classification accuracy, enabling more intuitive and responsive BCI systems [11]. These technological milestones have laid the foundation for BCI applications in the assistive domain, where usability, speed, and accuracy are critical.

2.2. BCI-Based Communication Systems

One of the earliest and most impactful assistive applications of BCI technology is in communication for individuals with severe speech and motor impairments. Speller systems allow users to select letters on a screen using brain responses elicited by stimuli [12]. These systems have been instrumental for patients with conditions like amyotrophic lateral sclerosis (ALS), where voluntary muscle control is lost but cognitive faculties remain intact. Extensive work has been done to enhance the speed and reliability of these spellers. For example, the RSVP (Rapid Serial Visual Presentation) paradigm and hybrid P300-SSVEP systems improve throughput and user experience [13], [14]. In addition, speech neuroprosthetics, which aim to synthesize speech from neural signals, represent an emerging subfield with profound implications for communication [15]. These advancements reflect a growing commitment to enabling inclusive, non-verbal communication channels through BCIs.

2.3. Motor Rehabilitation and Control Systems

BCIs are also widely studied for their potential in motor rehabilitation, particularly for individuals recovering from stroke, spinal cord injury, or limb amputation. Motor-imagery-based BCIs are integrated with robotic exoskeletons or functional electrical stimulation (FES) to create closed-loop neurofeedback systems that promote neuroplasticity and motor relearning [16]. Studies have demonstrated the efficacy of such systems in improving upper and lower limb function when combined with physiotherapy protocols [17]. In addition, brain-controlled prosthetics—using either EEG or intracortical recordings—allow amputees or paralyzed individuals to control artificial limbs with their thoughts [18]. These applications highlight the growing relevance of BCIs not just as passive assistive tools, but as active agents in neurorehabilitation and functional recovery. Furthermore, wheelchair navigation through BCI has received considerable research attention. Systems that allow users to control wheelchairs via motor imagery, P300 responses, or SSVEP paradigms have been developed and tested in real-world environments [19], [20]. Although challenges such as environmental variability and response delay persist, these studies mark significant progress toward autonomous mobility solutions for severely disabled individuals.

2.4. *Hybrid and Multimodal BCIs*

To overcome the limitations of single-modality BCIs, researchers have increasingly explored hybrid systems that combine multiple neurophysiological signals (e.g., EEG, EMG, EOG) or integrate BCI with other input modalities like eye-tracking, gesture control, or speech recognition [21]. These multimodal approaches offer improved system robustness, greater command variety, and reduced mental fatigue. For example, combining P300 and motor imagery signals enhances classification accuracy and provides users with alternative control strategies [22]. Other systems integrate eye movements with BCI to create intelligent switching mechanisms in speller or navigation systems [23]. Moreover, BCI integration with Virtual Reality (VR) and Augmented Reality (AR) environments is gaining traction, particularly for immersive rehabilitation, training, and cognitive therapy applications [24]. These innovations represent a shift toward more naturalistic and adaptive human-computer interactions in assistive contexts.

2.5. *Ethical, Psychological, and User-Centered Considerations*

As BCIs move from laboratories to everyday assistive environments, ethical and psychological considerations have become increasingly relevant. Issues surrounding informed consent, especially in populations with cognitive impairments, require careful navigation [25]. In addition, user satisfaction, mental workload, learning curve, and device fatigue are key factors influencing long-term adoption [26]. Research emphasizes the importance of participatory design, where end-users are involved in the development and customization of BCI-based assistive systems [27]. This user-centered approach ensures that devices are accessible, context-aware, and aligned with user expectations and preferences. Moreover, the growing availability of open-source BCI platforms and low-cost hardware is facilitating broader experimentation and democratization of BCI research [28]. Privacy and data protection are also critical concerns, as BCIs inherently process sensitive neural data that could reveal private thoughts or mental states [29]. Ensuring secure data transmission and transparent data policies is paramount, particularly in home-based or mobile BCI applications. Regulatory and legal frameworks are gradually emerging to address these concerns, but much work remains to ensure that ethical considerations keep pace with technological innovation.

3. METHOD

This study employs a bibliometric analysis to map the research landscape of Brain-Computer Interfaces (BCIs) in assistive technologies using data retrieved exclusively from the Scopus database. The search was conducted using a combination of keywords including “brain-computer interface,” “assistive technology,” “rehabilitation,” “BCI,” and “neuroprosthetics,” with filters applied to include peer-reviewed journal articles, conference papers, and reviews published between 2000 and 2024. The extracted metadata comprising titles, abstracts, keywords, authorship, affiliations, publication sources, and citation counts was analyzed using VOSviewer to visualize co-authorship networks, keyword co-occurrence, and citation clusters. This bibliometric mapping enables identification of prominent research themes, prolific authors and institutions, and temporal trends in publication activity.

4. RESULTS AND DISCUSSION

4.1. Results

a. Descriptive Graph

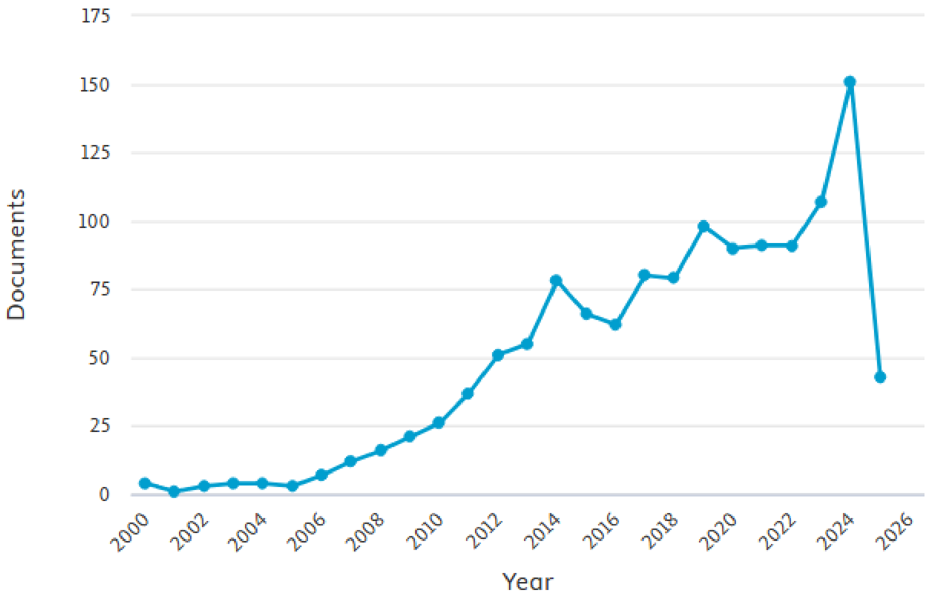

Figure 1. Documents by Year
Source: Scopus Database, 2025

The chart illustrates the annual publication trend of documents related to Brain-Computer Interfaces (BCIs) in assistive technologies from the year 2000 to 2025. The data reveals a clear upward trajectory in research activity, with a gradual increase from 2000 to 2010, followed by a more rapid acceleration starting in 2011. Notably, there is a sharp rise in publications between 2023 and 2024, peaking in 2024 with approximately 150 documents—the highest recorded in the dataset. However, there is a significant drop in 2025, which is likely attributable to the partial nature of data collection for that year.

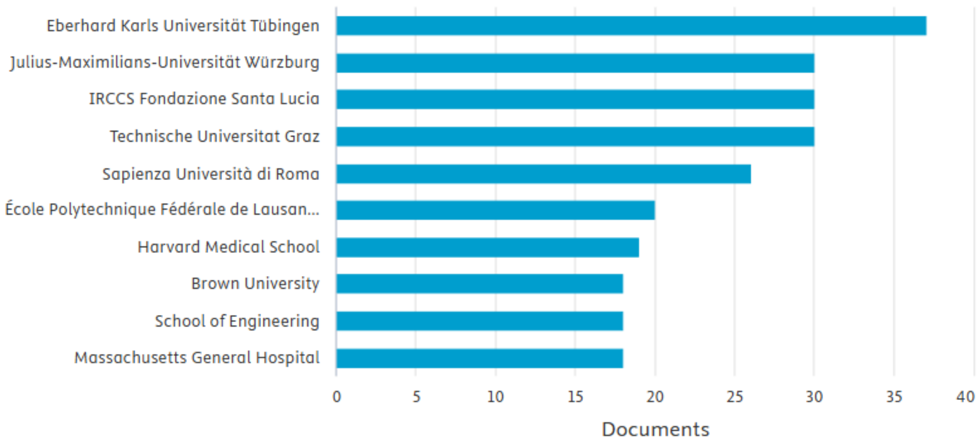

Figure 2. Documents by Affiliation
Source: Scopus Database, 2025

The chart presents the top contributing institutions in the field of Brain-Computer Interfaces (BCIs) in assistive technologies, ranked by the number of published documents. Eberhard Karls Universität Tübingen leads with nearly 40 publications, followed by Julius-Maximilians-Universität Würzburg, IRCCS Fondazione Santa Lucia, and Technische Universität Graz, each contributing around 30 documents. Sapienza Università di Roma and École Polytechnique Fédérale de Lausanne also show strong output, with approximately 25 and 20 publications, respectively. Notably, prestigious institutions from the United States such as Harvard Medical School, Brown University, Massachusetts General Hospital, and an unspecified School of Engineering are among the top contributors, reflecting a global and multidisciplinary engagement in this research domain. The data underscores the dominance of European institutions in BCI-related assistive technology research, with significant contributions from North American counterparts.

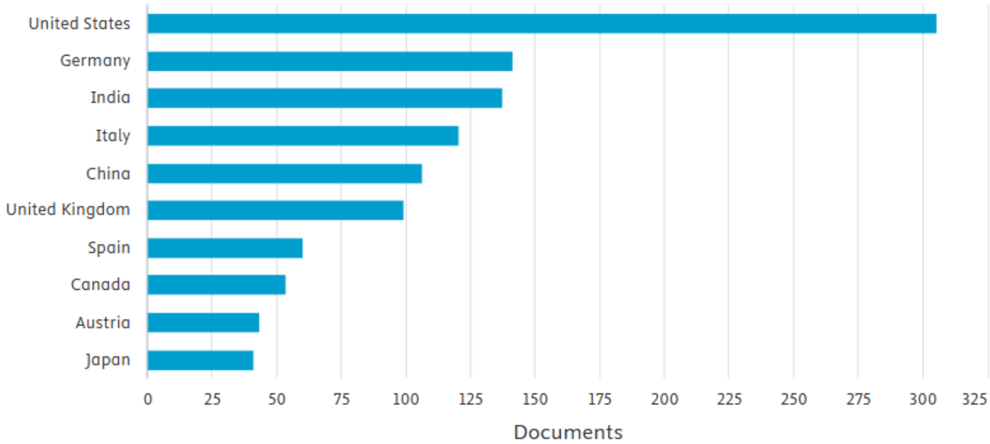

Figure 3. Documents by Country
Source: Scopus Database, 2025

The bar illustrates the top ten countries contributing to research in Brain-Computer Interfaces (BCIs) for assistive technologies, measured by the number of published documents. The United States leads by a significant margin with over 300 publications, highlighting its dominant role in advancing BCI research. Germany and India follow with comparable outputs, each exceeding 125 documents, indicating strong European and Asian participation. Italy, China, and the United Kingdom also contribute robustly with document counts ranging from 100 to 125, reflecting a balanced geographic spread in BCI research across continents. Meanwhile, Spain, Canada, Austria, and Japan round out the list, each contributing between 40 and 70 documents. This global distribution underscores the widespread academic and technological interest in BCI-assisted solutions, with particularly strong representation from North America, Europe, and Asia.

Table 1. Most Cited Article

Citations	Author and Year	Title
10376	[30]	Brain-computer interfaces (BCIs) for communication and control
3714	[31]	EEGNet: a compact convolutional neural network for EEG-based brain–computer interfaces
3614	[32]	A review of classification algorithms for EEG-based brain–computer interfaces
2700	[33]	Brain computer interfaces, a review
2224	[32]	A review of classification algorithms for EEG-based brain–computer interfaces: a 10 year update
1634	[34]	Brain–computer interfaces
1400	[26]	Brain–computer interfaces in neurological rehabilitation
1244	[35]	A survey of signal processing algorithms in brain–computer interfaces based on electrical brain signals
1069	[36]	Towards passive brain–computer interfaces: applying brain–computer interface technology to human–machine systems in general
1065	[37]	Brain-computer interfaces in medicine

Source: Scopus, 2025

b. Keyword Co-Occurrence Network Visualization

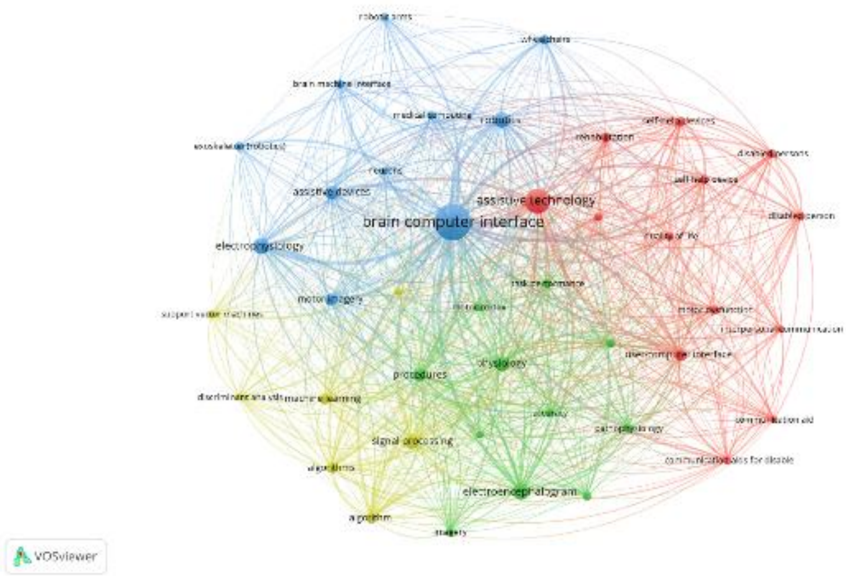

Figure 4. Network Visualization
Source: Data Analysis, 2025

The visualization shown is a keyword co-occurrence network map illustrating the thematic structure of research in Brain-Computer Interfaces (BCIs) in assistive technologies. Each node represents a frequently occurring keyword in the analyzed literature, and the size of the node reflects its frequency. The lines (or edges) between nodes indicate co-occurrences, with thicker lines signifying stronger associations. The map is divided into multiple colored clusters, each representing a distinct thematic area within the research domain, based on the strength of keyword co-appearances. The blue cluster (top-left) is centered on terms such as "brain computer interface," "assistive devices," "robotics," and "exoskeletons," indicating a strong research focus on hardware-oriented assistive systems. This includes the development of robotic arms, brain-machine interfaces, and wheelchair control systems that can be operated via BCI signals. The cluster reveals the close connection between BCI technologies and robotic engineering, emphasizing technical integration as a dominant research theme in assistive solutions for physical disabilities.

The red cluster (top-right) revolves around human-centric and rehabilitative themes, with frequent keywords such as "assistive technology," "disabled persons," "rehabilitation," and "communication aid." This indicates a substantial body of work dedicated to exploring how BCIs can enhance daily living, communication, and social participation for individuals with disabilities. Topics such as user-computer interaction, self-help devices, and interpersonal communication suggest that this cluster represents studies that bridge technological solutions with practical human needs in real-world contexts, especially for people with severe motor impairments. The green cluster (bottom-center) focuses heavily on neurophysiological and analytical foundations, including keywords such as "electroencephalogram," "motor cortex," "signal processing," and "physiology." This indicates a strong emphasis on understanding the biological basis of brain signals, the development of processing algorithms, and their applications in classifying cognitive or motor intentions. The presence of terms like "imagery," "pathophysiology," and "accuracy" shows that researchers are deeply invested in improving the precision and robustness of BCIs through neuroscientific and computational advances.

The yellow cluster (bottom-left) is closely tied to machine learning and data analysis techniques, with keywords such as "algorithms," "support vector machines," "discriminant analysis," and "learning." This reflects the growing integration of artificial intelligence in BCI research, particularly in improving classification accuracy, feature extraction, and adaptive system behavior. The emphasis on machine learning shows that BCI systems are becoming increasingly intelligent and personalized, capable of adjusting to user-specific brain patterns over time. The network map reveals a multidisciplinary convergence within BCI-assisted technology research, with clusters representing engineering applications, human-centered assistive solutions, neuroscientific foundations, and machine learning-based system enhancement. The central positioning of keywords such as "brain computer interface" and "assistive technology" demonstrates their pivotal role as connecting nodes across all thematic areas.

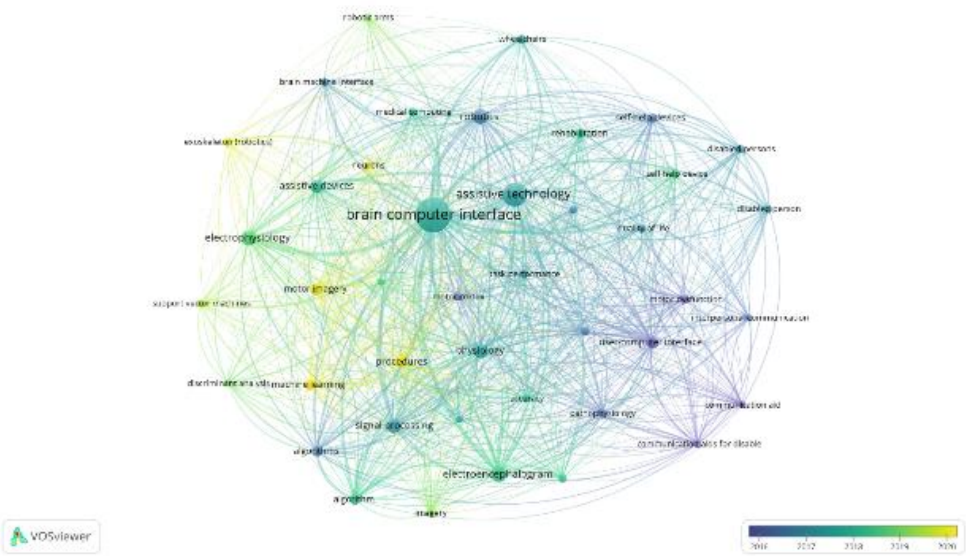

Figure 5. Overlay Visualization
Source: Data Analysis, 2025

The overlay visualization map displays the temporal evolution of keywords associated with research on Brain-Computer Interfaces (BCIs) in assistive technologies. Keywords are color-coded according to the average publication year in which they appeared, ranging from blue (earlier years, ~2016) to yellow (more recent, ~2020). Central terms such as “brain computer interface” and “assistive technology” appear in green, indicating consistent attention over time, with strong connections across various thematic subdomains. This suggests that these topics have served as the foundational core of the field over multiple years. More technically focused terms such as “motor imagery,” “machine learning,” “signal processing,” and “support vector machines” tend to appear in green to yellow shades, reflecting ongoing and relatively newer developments, especially in applying AI-driven classification methods and optimizing system performance. The emergence of these terms in more recent years indicates a shift toward enhancing BCI systems through intelligent algorithms, adaptive learning, and personalized user experiences—key themes for improving both the accuracy and accessibility of assistive BCI technologies. In contrast, keywords appearing in cooler tones (blue to green) such as “electroencephalogram,” “physiology,” “communication aid,” and “disabled persons” represent established areas of research that have been foundational since the earlier years of the BCI field. Their earlier emergence reflects the initial focus on signal acquisition methods, target user populations, and essential assistive applications.

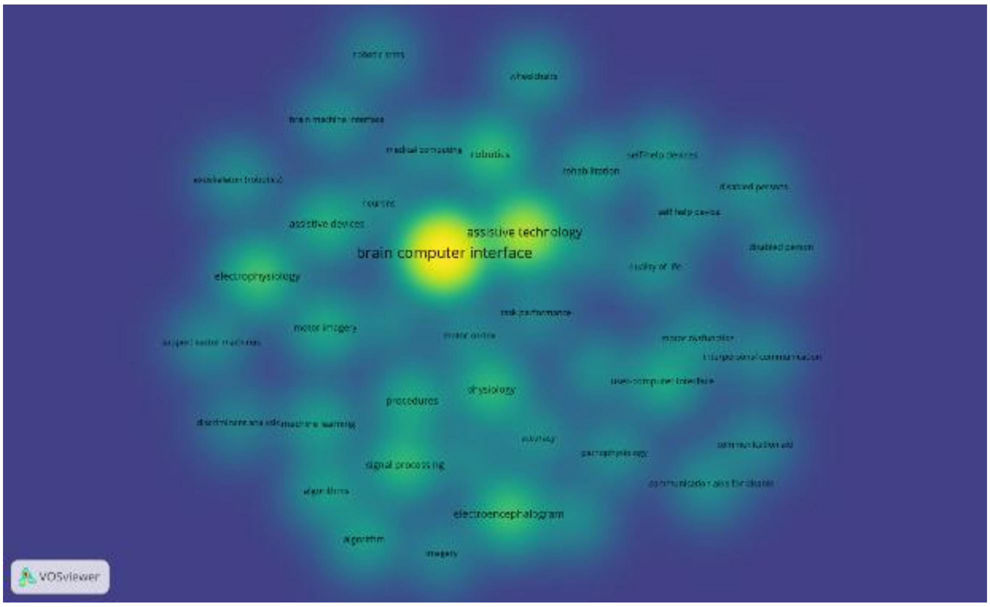

Figure 6. Overlay Visualization
Source: Data Analysis, 2025

The heatmap visualization displays the density of keyword co-occurrences in the research domain of Brain-Computer Interfaces (BCIs) applied to assistive technologies. Brighter areas—particularly those in yellow—represent regions with high concentrations of frequently occurring terms, while darker regions (shades of green to blue) indicate lower density. The terms "brain computer interface" and "assistive technology" occupy the central and most intense region, signaling their foundational importance and frequent usage across the dataset. Closely surrounding them are highly co-occurring keywords such as "assistive devices," "motor imagery," "signal processing," "electroencephalogram," and "user-computer interface," which reflect the most actively studied concepts in this field. The gradient of density radiating outward from the center highlights how peripheral terms—like "robotic arms," "wheelchairs," "quality of life," and "communication aids for disable"—are thematically linked but less central in the overall research network. These terms still represent important subdomains but may appear more in specialized contexts or emerging applications. The visualization emphasizes that BCI research in assistive technologies is anchored by a strong technical and biomedical core, while also encompassing broader themes related to rehabilitation, communication, and human-computer interaction. This suggests a mature yet still expanding research ecosystem that balances foundational work with applied innovation.

c. Co-Authorship Visualization

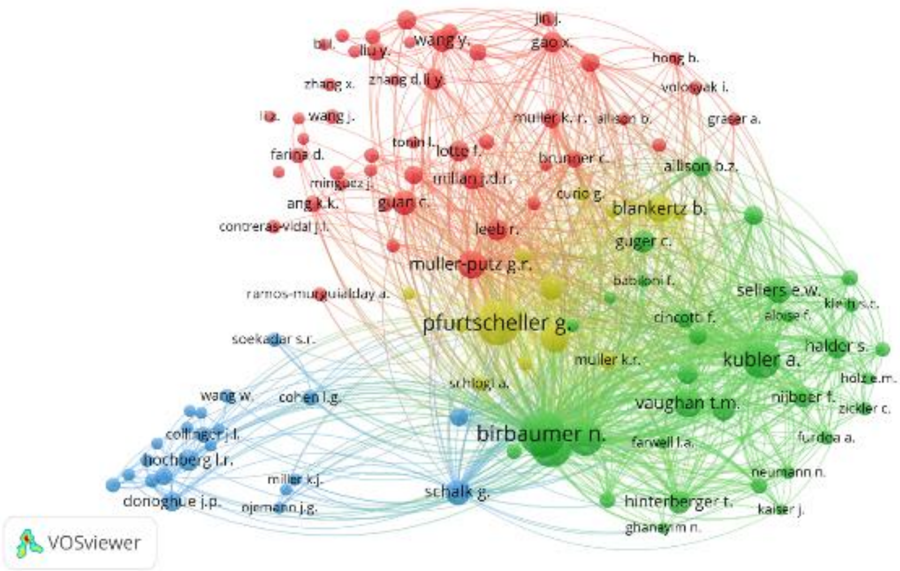

Figure 7. Author Visualization
Source: Data Analysis, 2025

The author collaboration network map highlights the key contributors and co-authorship patterns in the field of Brain-Computer Interfaces (BCIs) applied to assistive technologies. Nodes represent individual authors, with larger node sizes indicating higher publication counts or citation impact, while the colored clusters reflect groups of authors who frequently collaborate. At the center of the network, G. Pfurtscheller, N. Birbaumer, and G.R. Müller-Putz emerge as pivotal figures connecting multiple research groups, signifying their foundational roles in advancing BCI research. The green cluster, containing authors like A. Kübler, B.Z. Allison, and E.W. Sellers, indicates a strong focus on user-centered and clinical BCI applications. The red cluster, with contributors such as C. Guan, D. Zhang, and K.K. Ang, points to significant research from Asian institutions emphasizing signal processing and algorithmic development. Meanwhile, the blue cluster, with names like J.P. Donoghue, J.L. Collinger, and K.J. Miller, reflects a North American cohort focused on invasive BCI and neuroprosthetics. This map underscores the field's collaborative and international nature, where regional clusters contribute distinct yet interconnected advances to the BCI-assistive technology landscape.

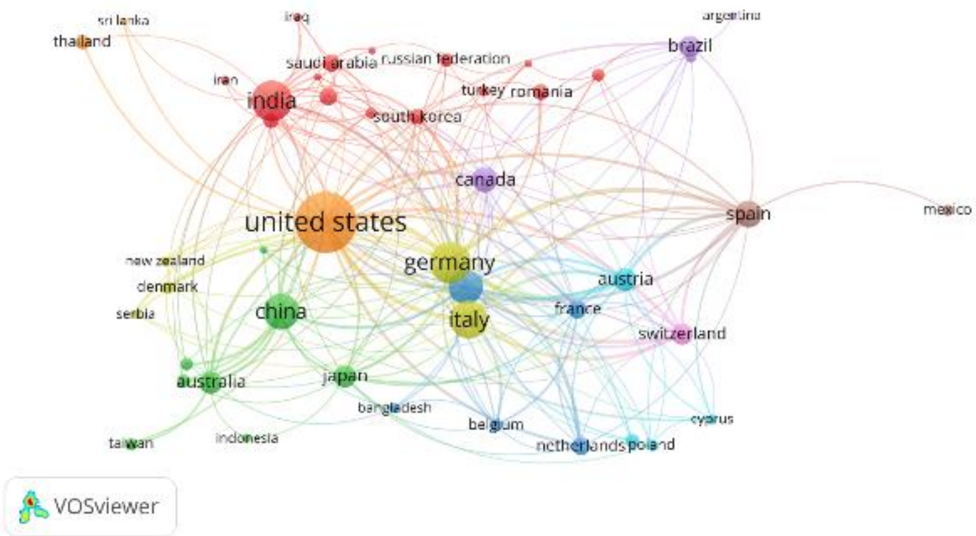

Figure 8. Country Visualization
Source: Data Analysis, 2025

The country collaboration map highlights the international co-authorship networks in the research field of Brain-Computer Interfaces (BCIs) in assistive technologies. The United States emerges as the most prominent and highly connected node, indicating its central role and extensive collaboration with a wide range of countries, including Germany, China, India, Canada, and several European nations. Germany, Italy, and India also appear as major hubs, reflecting their strong contributions and active involvement in cross-border research partnerships. The clustering pattern shows regional collaborations—such as China–Australia–Japan and Germany–France–Netherlands—alongside intercontinental ties. Countries like Spain, Brazil, and Iran show growing engagement, albeit with more limited but distinct regional networks.

4.2. Discussion

The bibliometric analysis of scholarly contributions on Brain-Computer Interfaces (BCIs) in assistive technologies reveals a rapidly expanding and interdisciplinary research landscape characterized by steady growth, global participation, and evolving research themes. The trajectory of publication output from 2000 to 2024 shows a clear upward trend, particularly gaining momentum after 2010. The surge in publications in 2024—reaching the highest number of documents—reflects growing academic interest and technological advancement in BCI applications tailored for assistive functions. This sharp rise underscores the maturity of foundational technologies and a transition toward applied, user-centric systems in healthcare, rehabilitation, and human augmentation.

The geographic distribution of scholarly output further illustrates the globalization of BCI research. The United States dominates in total publication count, followed closely by Germany, India, Italy, and China. The high output from the U.S. can be attributed to its strong funding infrastructure, early adoption of neural interface research, and institutional leadership in both biomedical engineering and clinical neuroscience. Meanwhile, India's significant presence is notable for a developing country, indicating increasing research investment and interest in affordable, accessible assistive technologies. European countries like Germany and Italy maintain robust BCI programs with strong ties to neuroscience and engineering faculties, facilitating interdisciplinary collaboration and real-world deployment.

At the institutional level, European universities lead the research output, with Eberhard Karls Universität Tübingen standing out as the most prolific. Other major contributors include Julius-Maximilians-Universität Würzburg, IRCCS Fondazione Santa Lucia, and Technische Universität Graz. The dominance of these institutions reflects Europe's early and ongoing commitment to neurotechnology and rehabilitation science, particularly in clinical settings involving patients with motor impairments. Interestingly, institutions from the U.S., such as Harvard Medical School and Massachusetts General Hospital, also appear prominently, often acting as bridges between engineering solutions and clinical applications. These results highlight the critical role of academic medical centers and rehabilitation institutions in pushing BCI research from theory into therapeutic reality.

The analysis of author collaborations reveals several influential researchers, including G. Pfurtscheller, N. Birbaumer, and G.R. Müller-Putz, who have played pivotal roles in shaping the field. Their works span from foundational EEG-based control systems to neurorehabilitation and user-centered BCI frameworks. The cluster map reflects well-established collaboration networks across Europe, North America, and Asia, with key hubs connecting interdisciplinary teams. Authors like A. Kübler and B.Z. Allison have also contributed significantly to the development of BCI spellers and user-interface design for locked-in patients, exemplifying a growing emphasis on user experience and ethical considerations.

When examining country-level collaboration, the map indicates strong bilateral and multilateral partnerships, particularly among developed countries. The United States appears as the most connected node, serving as a central actor in facilitating international research projects. It maintains vibrant collaborations with Germany, India, Canada, and several Asian and European nations. These partnerships reflect both academic mobility and global concern for assistive technologies, particularly as aging populations and neurodegenerative conditions become more prevalent. Clusters of regional cooperation, such as between China–Japan–Australia and Germany–France–Netherlands, suggest common interests in robotics, signal processing, and user-centered device development.

Keyword co-occurrence analysis further sheds light on the conceptual structure of the field. The most prominent terms include "brain computer interface", "assistive technology", "electroencephalogram", "motor imagery", and "signal processing." These terms indicate that the research core is built upon the interplay between signal acquisition, machine learning-based interpretation, and the design of assistive systems. Thematically, the field is divided into several major clusters: (1) neuroengineering and signal processing; (2) robotics and hardware interfaces; (3) rehabilitation and clinical applications; and (4) user interaction and communication aids. These clusters not only highlight the multidisciplinary nature of the field but also suggest evolving subdomains tailored to specific use cases.

The temporal overlay map of keywords reveals interesting trends in thematic evolution. Earlier research (pre-2017) focused heavily on basic neuroscience and physiological signal acquisition, as reflected by keywords like "electroencephalogram," "physiology," and "communication aid." As the field matured, newer topics began to emerge, such as "machine learning," "algorithms," and "support vector machines," suggesting a shift toward AI-driven interpretation and real-time classification systems. In the most recent years, increasing attention has been paid to user experience, quality of life, and interpersonal communication, indicating a broader vision that goes beyond technical performance to include psychological and social dimensions of BCI use.

The heatmap visualization confirms that the intellectual center of this research domain lies at the intersection of technical engineering and assistive application, with the densest areas being "brain computer interface" and "assistive technology." This convergence is vital, as it reflects the field's maturity: from laboratory-based feasibility studies to clinically validated and practically deployed solutions. However, the heatmap also highlights underexplored but emerging areas such as "quality of life," "pathophysiology," and "user-computer interface," which represent future growth opportunities for more human-centered design and inclusive technology development.

From a practical standpoint, this bibliometric study confirms that BCI-assisted technologies are moving toward clinical translation and everyday usability. Wheelchair control, robotic prosthetics, and communication spellers are no longer conceptual prototypes but are being tested in hospitals, rehabilitation centers, and even home environments. However, despite significant progress, persistent challenges remain. These include the reliability of EEG signals in non-clinical settings, the lengthy training time for users, and the high cost of BCI systems—particularly for populations in low- and middle-income countries. There is also a critical need for ethical frameworks to address privacy, data security, and the mental burden placed on users engaging with neuroadaptive systems. Importantly, the bibliometric trends suggest a growing awareness of interdisciplinarity and user co-creation in BCI research. The inclusion of psychologists, physiotherapists, and end-users in the design and deployment process is increasingly emphasized in recent publications. This participatory approach aligns with the broader movement toward human-centered AI and accessible technology, ensuring that BCI systems are not only technically efficient but also socially and ethically responsive.

5. CONCLUSION

This bibliometric review has provided a comprehensive overview of the research landscape surrounding Brain-Computer Interfaces (BCIs) in assistive technologies, revealing significant growth in scholarly output, widespread international collaboration, and the emergence of key thematic areas. The findings highlight a dynamic, interdisciplinary field anchored in neural signal processing, machine learning, robotics, and user-centered design. The United States, Germany, India, and several European countries lead both in productivity and collaborative influence, while core institutions and influential authors have shaped the trajectory of BCI development toward practical, user-oriented applications. Keyword analysis indicates a shift from foundational neurophysiological studies toward intelligent, adaptive systems that prioritize accessibility and real-world functionality. As the field advances, future research should emphasize ethical integration, inclusivity, and scalable solutions to ensure that BCI-based assistive technologies are both technically robust and socially impactful, ultimately enhancing the autonomy and quality of life for individuals with disabilities.

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