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Education Article

Exploring the intersection of brain-computer interfaces and traditional, complementary, and integrative medicine

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ABSTRACT

Brain-computer interfaces (BCIs) represent a transformative innovation in healthcare, enabling direct communication between the brain and external devices. This educational article explores the potential intersection of BCIs and traditional, complementary, and integrative medicine (TCIM). BCIs have shown promise in enhancing mind-body practices such as meditation, while their integration with energy-based therapies may offer novel insights and measurable outcomes. Emerging advancements, including artificial intelligence-enhanced BCIs, hold potential for improving personalization and expanding the therapeutic efficacy of TCIM interventions. Despite these opportunities, integrating BCIs with TCIM presents considerable ethical, cultural, and practical challenges. Concerns related to informed consent, cultural sensitivity, data privacy, accessibility, and regulatory frameworks must be addressed to ensure responsible implementation. Interdisciplinary collaboration among relevant stakeholders, including TCIM and conventional practitioners, researchers, and policymakers among other relevant stakeholders is crucial for developing integrative healthcare models that balance innovation with patient safety and respect for diverse healing traditions. Future directions include expanding evidence bases to validate TCIM practices through BCI-enhanced research, fostering equitable access to neurotechnological advancements, and promoting global ethical guidelines to navigate complex sociocultural dynamics. BCIs have the potential to revolutionize TCIM, offering novel solutions for complex health challenges and fostering a more inclusive, integrative approach to healthcare, provided that they are utilized responsibly and ethically.

1. Introduction

1.1. Brain-Computer interfaces

Brain-computer interfaces (BCIs) (also referred to as brain-machine interfaces (BMIs)) establish direct communication pathways between the brain and external devices, enabling control through neural signals.[1] These systems can be invasive, using implanted electrodes, or non-invasive, utilizing electroencephalography (EEG) or near-infrared spectroscopy.[2] BCIs have diverse applications, including assistive technology for patients who are paralyzed, motor rehabilitation after stroke or spinal cord injury, and potential cognitive enhancement.[2-4] They can control various devices such as prostheses, wheelchairs, and computers.[4] BCIs are classified into sensory, motor, bidirectional, and cognitive types, serving different functions.[5] While non-invasive BCIs are safer and easier to implement, invasive BCIs offer higher information bandwidth.[5] Despite rapid advancements, challenges remain in improving signal acquisition, decoding techniques, long-term reliability, and addressing ethical considerations for widespread clinical use.[1,4]

1.2. Implantable versus wearable BCIs: functionality and potential

BCIs can be categorized into wearable and implantable systems, each with distinct advantages and applications.

Implantable BCIs are invasive and are surgically inserted devices that directly interact with neural activity, using microelectrode arrays to record high-resolution signals from specific cortical regions.[6] These systems enable bidirectional communication, allowing brain signals to control external devices while providing sensory feedback through electrical stimulation.[7] Implantable BCIs have shown promise in restoring motor functions for individuals with paralysis, such as controlling prosthetic limbs or wheelchairs.[2,8] They also have applications in addressing neurological conditions and enhancing sensory perception.[7] The precise decoding of brain activity offered by implantable BCIs makes them valuable tools for neurorehabilitation, potentially facilitating recovery

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of neural function in patients with severe stroke or spinal cord injury.[2] Invasive BCIs pose safety concerns, including potential damage to nerve cells, blood vessels, and an increased risk of infection due to their implantation in brain tissue. Additionally, issues such as biocompatibility, scar tissue formation, and the degradation of acquired brain signals highlight the need for a thorough understanding of the body's interaction with foreign objects to ensure the development of safe and effective BCI applications.[9] Ongoing research aims to improve biocompatibility, power management, and wireless data transmission for these devices.[7]

Wearable BCIs are non-invasive devices that measure brain activity externally, typically using EEG.[10] These wearable systems do not carry the same level of risk as invasive BCIs, but offer advantages over traditional EEG setups, including portability and the potential for long-term monitoring.[10] While they may have lower signal resolution compared to implantable BCIs, wearable BCIs can still effectively detect and classify mental states such as focus and relaxation.[11] Applications of wearable BCIs range from medical uses like epilepsy diagnosis to non-medical purposes such as enhancing cognitive performance and enabling hands-free control systems.[10,12] Recent advancements in wearable BCI technology have led to improvements in real-time mental state recognition, emotion detection, and even speech decoding.[12,13] Despite challenges in algorithm optimization, wearable BCIs show promise in revolutionizing human-machine communication and enhancing quality of life.[13]

1.3. Clinical and experimental applications

BCIs have shown remarkable potential in restoring communication and motor function for individuals with paralysis. Intracortical BCIs allow users to control external devices with their neural activity; they have enabled high-performance communication, allowing users to type and control external devices with increased speed and accuracy compared to previous systems.[14] These interfaces have also demonstrated the ability to control robotic limbs and prosthetics, offering hope for mobility restoration in severe paralysis cases.[2,15] Beyond motor control, BCIs are being explored for applications such as seizure detection, vision restoration, and memory enhancement.[16] While invasive BCIs using microelectrodes in the cerebral cortex provide higher fidelity, less invasive methods like EEG are also being developed.[16] Despite promising results, BCI technology is still in early development stages and requires further technical improvements and clinical trials before widespread adoption.[16]

1.4. Advances in technology

Advancements in BCIs have been driven by progress in materials science, artificial intelligence (AI), and neural decoding algorithms. AI has significantly improved the analysis and decoding of neural activity, enhancing BCI applications in clinical settings and expanding human capabilities.[17] Developments in integrated microelectronics, wireless communications, and computational neuroscience have led to prototype head-mounted and fully implantable wireless systems for multi-channel neural recording.[18] Biocompatible materials, including soft electrodes and engineered interface coatings, have improved the longevity and performance of neural implants.[19,20] These advances have resulted in high-density interfaces capable of interacting with 3D populations of neurons across entire tissue systems.[19] Additionally, progress in miniaturization and wireless technology is paving the way for less invasive and more user-friendly BCI systems.[18,20]

1.5. Overview of traditional, complementary, and integrative medicine

Traditional, complementary, and integrative medicine (TCIM) has gained significant academic and public interest in recent decades for its holistic approach to health and well-being,[21-23] evidenced by an exponential growth in research literature published on the topic in recent years.[24] TCIM includes a wide variety of therapeutic practices originating from diverse cultural, historical, and epistemological contexts.[25] According to the World Health Organization, "traditional medicine" encompasses "the entirety of knowledge, expertise, and customs rooted in the theories, beliefs, and experiences of various cultures, whether explainable or not, utilized in the preservation of health and the management, prevention, diagnosis, or treatment of physical and mental ailments".[26] The US National Center for Complementary and Integrative Health (NCCIH) differentiates "alternative" health approaches as those used in place of conventional medicine, "complementary" approaches as those used together with conventional medicine, and "integrative health" as the structured combination of complementary and conventional approaches.[27-28] Increasing global acceptance of integrative medicine reflects recognition of its ability to enhance conventional treatments by addressing patients' physical, mental, and emotional well-being.[21] Throughout this article, the term TCIM will be used to collectively refer to these therapeutic approaches.

1.6. Intersection with brain–computer interfaces

The integration of TCIM with advanced neurotechnologies like BCIs represents an emerging, yet promising, area of research. BCIs, which acquire and translate brain signals into commands for external devices, have primarily focused on restoring function for individuals with disabilities.[4] However, their potential extends beyond these applications, offering opportunities to enhance human-system interactions and augment performance in various ways.[29] The convergence of TCIM and BCI technologies introduces exciting possibilities for personalized treatment plans, early disease detection, and improved patient engagement.[30] As BCI technology continues to evolve, it may contribute to rehabilitation, therapeutic benefits, and even augmentative channels for the brain, extending the boundaries of our biological systems.[9,31] The relationship between BCI and TCIM interventions can vary based on the intended application. In some cases, BCIs may be used concurrently with TCIM (e.g., real-time neurofeedback during meditation), while in others, BCIs may serve as an initial step to facilitate later TCIM interventions (e.g., post-stroke BCI rehabilitation followed by acupuncture or yoga for functional maintenance).

Although BCI technology is still evolving, its current applications in neurorehabilitation and neuromodulation suggest a foundation for future integrations with TCIM. This article explores such potential applications while acknowledging the experimental nature of the technology. It addresses key ethical, cultural, and practical considerations, such as patient autonomy, data privacy, and accessibility challenges. The article also discusses innovative applications, policy and regulation consideration, and the future of BCIs in the context of TCIM.

2. The potential of brain–computer interfaces in TCIM

Fig. 1 illustrates the structural components and diverse applications of BCIs within the context of TCIM, highlighting their potential applications.

2.1. Enhancing mind-body interventions

TCIM interventions such as mindfulness meditation and biofeedback have been shown to improve neural plasticity and self-regulation, which may enhance BCI adaptation and performance. Conversely, BCIs can provide real-time neurofeedback to optimize the effects of TCIM interventions by monitoring and reinforcing beneficial neural activity. Studies have shown that individuals who undergo mindfulness-based stress reduction (MBSR) training exhibit improved BCI accuracy compared to control groups.[32,33] This improvement is associated with increased alpha-band neural activity during intentional rest periods in BCI tasks.[32] The enhancement in BCI performance correlates with the duration of meditation practice and improved sustained attention,[32] however, even short-term meditation practice (4 weeks) has been found to enhance BCI performance accuracy.[33] Neurologically, MBSR training

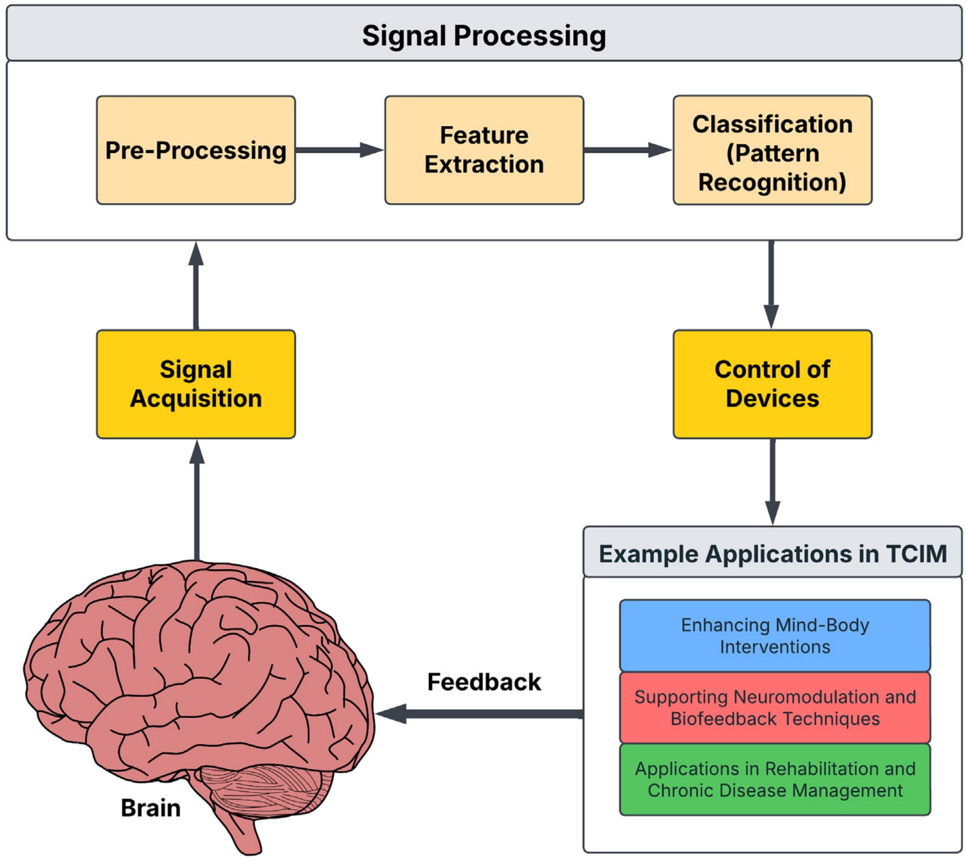

Fig. 1. Structure of a BCI and Example Applications in TCIM. A BCI functions as a closed-loop system, where user actions generate feedback, such as an imagined hand movement controlling a robotic arm. This process begins with signal acquisition, where brain activity is recorded and converted into usable signals. Next, pre-processing removes noise and artifacts to enhance data quality. In feature extraction, relevant patterns are identified using advanced algorithms, followed by classification, which interprets the user's intent. Finally, the processed signal triggers device control, allowing interaction with external systems like computer cursors or robotic limbs. This streamlined process enables BCIs to translate neural activity into practical applications. With respect to TCIM, some examples of applications include enhancing mind-body interventions, supporting neuromodulation and biofeedback techniques, and applications in rehabilitation and chronic disease management.

leads to increased frontolimbic alpha activity and decreased alpha connectivity among limbic, frontoparietal, and default-mode networks.[34] These changes in neural activity are positively correlated with BCI performance improvement.[34] Overall, mindfulness meditation appears to reduce mind wandering and enhance self-awareness during BCI control, leading to more precise neural signal control and improved BCI outcomes.[33,34]

Past research highlights the potential of integrating BCIs with mindfulness and breathing practices for mental health and stress management. BCIs allow users to control applications using brain waves, providing real-time feedback on neural activity.[35] This technology can enhance self-regulation skills, awareness, and emotional control when combined with mindfulness training.[35,36] This technology can be applied in real-world settings to improve meditation experiences.[37] Breathing techniques have shown efficacy in treating various psychiatric and stress-related conditions by normalizing stress responses and autonomic function.[36-38] Technology-assisted breathing interventions, using static cues or real-time physiological feedback, can further improve these practices.[39] While the clinical effectiveness of neurofeedback remains controversial, modern imaging technologies like real-time fMRI are advancing the understanding of underlying mechanisms.[40] Some researchers have argued that neurofeedback training, particularly targeting specific neural rhythms like theta and alpha waves, has been associated with improvements in relaxation, focus, and even musical performance under stress.[41] The effectiveness of these interventions may be influenced by task-specific, cognitive, motivational, and technology-acceptance factors.[42] While more research is needed, the integration of BCI and neurofeedback techniques shows potential for developing personalized and effective treatments in various clinical and non-clinical applications.[38,42] Enhancing mind-body interventions with BCIs may offer promising avenues for treating health conditions and maintaining overall well-being.[43]

2.2. Supporting neuromodulation and biofeedback techniques

Neuromodulation has emerged as a specific treatment without systemic side effects, and BCIs offer potential for an integrated approach to pain management.[44] Recent research supports the potential integration of BCIs even with therapies such as acupuncture. A novel virtual acupuncture technique using virtual reality and EEG demonstrated similar brain activity to manual acupuncture, suggesting BCIs could provide real-time monitoring of neural responses.[45] Neuroimaging studies have shown that acupuncture modulates activity in key brain networks, including the default mode and central-executive networks.[46] These effects extend beyond the treatment period, influencing pain modulation and autonomic regulation.[47] Acupuncture has been found to impact various autonomic functions, such as heart rate, blood pressure, and skin conductance, by activating specific brain regions and modulating neurotransmitters.[48] The integration of BCIs with acupuncture could provide more precise tracking of these neural and physiological responses, potentially enhancing the efficacy and understanding of energy-based therapies.

2.3. Applications in rehabilitation and chronic disease management

The integration of BCIs with TCIM practices offers a promising approach to neurorehabilitation and chronic disease management. BCIs have shown promise in enhancing motor recovery for stroke patients. Studies have demonstrated that BCI-monitored motor imagery practice can improve motor function in subacute stroke patients.[49] Combining BCI training with goal-directed physical therapy has been found to significantly improve hand and arm movements, as well as gait, in chronic stroke patients with initial paralysis.[50] BCIs facilitate neuroplasticity and functional recovery in completely paralyzed stroke patients using non-invasive technologies like EEG.[51] A meta-analysis of randomized controlled trials revealed that BCI-based post-stroke motor rehabilitation is associated with a medium to large effect size in improving upper limb motor function, as measured by the Fugl-Meyer Assessment. Additionally, several studies reported BCI-induced functional and structural neuroplasticity at a subclinical level, suggesting that BCI technology could be an effective intervention for post-stroke upper limb rehabilitation.[52]

Research supports the integration of TCIM with conventional approaches for chronic pain management. BCIs have the potential to enhance TCIM interventions, such as neurofeedback-assisted yoga for stress management and BCI-guided energy therapies for chronic pain relief.[53] Mindfulness-based interventions and acupuncture have also shown promise in reducing pain intensity, increase mobility, improving physical function, and enhancing overall well-being.[54-56] By combining these modalities, clinicians can potentially improve treatment outcomes and decrease pain-related medication use.[56] However, further research is needed to validate long-term efficacy and overcome methodological limitations in existing studies.[53]

Similarly, BCIs may optimize chronic disease management by reinforcing behavioral changes and promoting adherence to interventions such as yoga or tai chi. These practices, which improve both physical and mental well-being, can be enhanced by BCIs that track neural responses to movement, offering real-time feedback to ensure proper alignment, balance, and relaxation during practice. This integration could lead to more personalized and effective treatment protocols for chronic conditions, offering a comprehensive approach to healing that combines technological precision with the holistic, mind-body focus of TCIM.

3. Ethical, cultural, and practical considerations

3.1. Ethical concerns

BCIs in medical contexts raise considerable ethical concerns, particularly regarding privacy, autonomy, and consent. The intimate connection between BCIs and the brain poses risks to privacy and data security, as these devices can access and potentially expose sensitive neural information.[57-60] Ensuring informed consent is challenging due to the complexity of BCI technology and its potential long-term effects on cognition and identity.[61] There are also concerns about patient autonomy, as BCIs may influence mental states and decision-making processes. Ethical concerns arise regarding the safety and efficacy of these technologies, especially for enhancement in healthy individuals, where risks may outweigh benefits.[62] Furthermore, the vulnerability of certain patient groups and the potential for stigma further complicate ethical considerations.[57] BCIs offer potential benefits for patients with severe neurological impairments, including restored communication and motor control.[63,64] However, their use raises significant ethical concerns. These include managing patient expectations, weighing invasiveness and risk-benefit ratios of different electrode types, and assessing decision-making capacity in neurologically compromised individuals.[63] Additional challenges involve personhood, stigma, autonomy, privacy, safety, and responsibility.[58] While BCIs may enhance patient autonomy, they also create accountability issues for both individuals and systems.[64] The introduction of BCIs into medicine necessitates consideration of additional goals beyond traditional medical objectives, including neural diversity, neural privacy, agency, and authenticity.[65] Despite extensive discussion of these issues, there is a lack of concrete recommendations for addressing them, highlighting the need for further research and practical solutions.[57] To address these issues, researchers have recommended developing best practices for informed consent protocols, implementing robust data protection measures, and conducting further empirical research on stakeholder perspectives.[57,58,61] The responsible development of BCIs requires careful consideration of access, equity, and expectation management.[66]

3.2. Cultural sensitivity

Cultural perspectives play a crucial role in the acceptance and integration of BCIs within TCIM practices. TCIM approaches often emphasize holistic, spiritual, and community-based healing methods, viewing the body, mind, and spirit as interconnected. These practices are deeply rooted in cultural philosophies and natural, non-invasive approaches to health.[67] Introducing advanced neurotechnologies like BCIs may be perceived as incongruent with these values, particularly in Indigenous or culturally distinct communities.[68] As such, the integration of BCIs in TCIM settings raises ethical, social, and cultural concerns that need to be addressed, and as the complexity of brain-computer integration technologies increases, so do the associated ethical challenges.[57,58,68,69]

Research has highlighted the ethical, social, and cultural implications of BCIs and other neurotechnologies, emphasizing the need for inclusive dialogue and responsible development to address concerns related to identity, privacy, and cultural sensitivity.[69,70] The integration of BCIs must respect diverse healing traditions and acknowledge cultural attitudes towards invasive technologies.[68] Engaging with Indigenous communities is particularly crucial, requiring a respectful approach that weaves Indigenous knowledge into brain research strategies.[71,72] Ethical issues surrounding BCIs include questions of human dignity, autonomy, and user safety.[69] To address these challenges, researchers recommend establishing globally-coordinated ethical guidelines, implementing new privacy measures, and adopting public guidelines for equitable distribution of neurotechnological devices.[70] Collaboration among all stakeholders is essential to ensure the ethical development and use of BCIs.[69]

3.3. Practical challenges

Considerable practical challenges exist in integrating BCIs into TCIM. These include the need for advanced technological infrastructure, specialized hardware and software, and highly trained personnel, which may be unavailable or unaffordable in many healthcare settings.[4,73] The high development costs and potentially small target group challenge commercial viability, potentially exacerbating existing socioeconomic inequalities.[62,73] Additionally, BCIs face challenges in reliability, user-centered design, and long-term validation in real-world settings.[4,73] Overcoming these obstacles requires a multidisciplinary approach, a broader focus on usability, increased resource allocation and inclusion of target users in the design process, and international collaboration to advance BCI technology and its applications in medicine, including within the field of TCIM.[9,73,74]

Even assuming the aforementioned challenges have been adequately addressed, the training and education of practitioners in these technologies remain a significant challenge. TCIM education research is limited, with gaps in areas such as educational technology and e-learning.[75,76] To effectively incorporate BCIs into TCIM, specialized educational programs are needed that balance technical knowledge with the holistic principles of TCIM. These programs must be tailored to practitioners' unique needs, ensuring that new technologies are used effectively while maintaining patient-centered care.[75] Overcoming these barriers are crucial for realizing the potential of BCIs in healthcare and ensuring equitable access to these promising technologies.

4. Innovative applications

Innovative applications of emerging technologies, particularly implantable BCIs, hold transformative potential for enhancing the integration of TCIM practices. Several promising areas are currently being explored.

4.1. Adaptive neurotechnologies

Research has explored the potential of adaptive BCIs to enhance mind-body practices and meditation. Studies have demonstrated that BCIs can monitor and modulate neural activity in real-time, particularly in the alpha band, to improve meditation experiences and outcomes.[32,37] Adaptive neurofeedback systems have been developed to adjust feedback based on users' physiological states and performance, potentially optimizing mind-body interactions.[77-81] Wearable neurofeedback devices, such as MeditAid, have shown promise in supporting self-regulation of attention during meditation, especially for novice practitioners.[82] MBSR training has been found to enhance BCI performance by increasing control over neural activity, suggesting a synergistic relationship between mindfulness practices and BCI technology.[32] These advancements indicate the potential for adaptive BCIs to personalize and deepen the therapeutic effects of various mind-body interventions.

4.2. Brain-Computer interface integration with energy-based therapies

Research has explored the potential of integrating BCIs with energy-based therapies, such as Reiki. While these practices remain controversial, studies have shown promising results in pain reduction and anxiety management.[83] BCIs may offer the ability to monitor neural and physiological responses, potentially enhancing the precision and efficacy of these therapies.[84] For instance, BCIs could track changes in brainwave patterns during sessions, providing feedback on relaxation levels and emotional states.[85] This data-driven approach could complement practitioners' intuitive skills and bridge the gap between empirical validation and traditional expertise. The integration of BCIs with energy-based therapies represents an innovative frontier in healthcare, combining ancient healing practices with advanced neurotechnology to create more personalized and integrative therapeutic experiences.[84,86] As research in this area advances, new paradigms in patient care are likely to emerge.

4.3. Artificial intelligence-enhanced BCIs

The integration of AI with BCIs and TCIM offers promising advancements in personalized healthcare. AI-enhanced BCIs can improve analysis and decoding of neural activity, leading to better clinical outcomes for patients with motor impairments.[45] In the context of TCIM, AI can assist in personalized treatment planning and health trend prediction.[87] AI-powered personalized medicine enables tailored interventions based on patients' genetic, epigenetic, and phenotypic profiles, potentially improving management of chronic conditions.[88] However, challenges such as data privacy, maintaining human touch in patient care, and mitigating algorithmic bias must be addressed.[87,88] Future research should focus on the ethical implementation of AI in healthcare.

5. Policy and regulation considerations

The successful integration of BCIs into TCIM will require the establishment of robust, forward-thinking regulatory frameworks that address ethical, safety and efficacy, and accessibility concerns. Several key policy and regulatory considerations are vital to guide this process.

5.1. Ethical governance

Regulatory policies for neurotechnologies must prioritize patient rights, including informed consent, privacy, and cultural sensitivity.[70,89] As BCIs collect sensitive neural data, patients should be fully informed about potential risks and benefits.[70] Policies should address cultural concerns, particularly in TCIM practices rooted in diverse cultural traditions.[90] The principle of respect for persons underpins informed consent, recognizing individuals as autonomous agents capable of deliberation.[91] However, some communities prioritize collective consent over individual autonomy, creating ethical dilemmas in multicultural settings.[90] To address these challenges, recommendations have included establishing globally-coordinated ethical guidelines, implementing new privacy measures, preventing bias, and ensuring equitable distribution of neurotechnological devices.[70] These efforts aim to balance cultural sensitivities with individual rights in the development and application of innovative medical technologies.

5.2. Patient safety and efficacy

Regulatory guidelines for BCIs and TCIM interventions require rigorous safety and efficacy standards. Clinical guideline development for TCIM should consider factors beyond evidence-based efficacy, including burden of disease, magnitude of effect, and current use.[92] For BCIs, ethical challenges necessitate the creation of a global governance framework and special guidelines for clinical research.[93] BCI development requires interdisciplinary cooperation and objective evaluation criteria to improve signal processing, translation algorithms, and user.[94] Standardization of BCI technologies is crucial for ensuring interoperability, regulatory compliance, and widespread user access. The scarcity of specific BCI standards hinders device design and poses barriers to clinical and consumer applications, emphasizing the need for the BCI community to address these.[95]

5.3. Promoting accessibility

BCI-TCIM integration may benefit various populations, including individuals with neurological disorders (e.g., stroke, spinal cord injury, neurodegenerative diseases), patients with chronic pain conditions, and even healthy individuals seeking cognitive enhancement or stress reduction through biofeedback and mindfulness-based neurofeedback. The accessibility of BCI technologies allows for broad applications across clinical and wellness settings, particularly in low-resource settings. Key challenges include a narrow focus on reliability rather than usability, limited target populations, and insufficient user involvement in design.[73] Ethical considerations around access and equity are crucial for responsible BCI development.[66] Similar issues affect medical and assistive health technologies for aging populations in low- and middle-income countries, where access is often limited despite growing need.[96] To address these challenges, policymakers should invest in digital health literacy education, promote inclusive technology design, incentivize equitable healthcare delivery, and improve infrastructure accessibility.[97] These strategies can help overcome barriers related to individual factors, technology design, health system structure, and social determinants of access, ultimately promoting more equitable adoption of neurotechnologies and other health innovations.

6. The future of brain-computer interfaces in the context of traditional, complementary, and integrative medicine

6.1. Interdisciplinary collaboration

Interdisciplinary collaboration between TCIM and conventional practitioners, researchers, and policymakers, among other relevant stakeholders is crucial for developing effective integrative healthcare models.[98,99] This integration can address limitations in biomedicine and meet patient demands for holistic care.[99] The development of BCIs in medicine exemplifies the potential for interdisciplinary collaboration, combining neuroscience, engineering, and clinical expertise to restore function for disabled individuals.[4] Successful collaboration requires capable leadership, stakeholder endorsement, and interprofessional education to build trust and understanding.[98] Organizational strategies such as co-location, shared electronic health records, and condition-specific referral protocols can facilitate integration.[100] As integrative healthcare evolves, formal evaluation processes incorporating outcomes recognized by both conventional and TCIM practitioners are essential for ensuring quality and safety.[100]

6.2. Expanding evidence bases

The potential integration of TCIM with advanced technologies like AI and BCIs can contribute to the expanding of evidence bases. These technologies may offer opportunities to objectively measure and validate TCIM practices, potentially enhancing their scientific credibility and acceptance within healthcare frameworks.[87] BCIs could provide neural data to monitor brain activity during practices like acupuncture or mindfulness meditation, offering insights into their neural mechanisms.[101] Studies suggest that certain TCIM modalities, including acupuncture and mindfulness-based interventions, show promising results in managing chronic pain and improving overall well-being.[102] However, challenges remain in implementing TCIM services and translating research into practice. Experiences from China and the United States demonstrate varying approaches to TCIM implementation, from multi-level interventions to the development of clinical practice guidelines, highlighting the need for tailored strategies to facilitate wider adoption.[103]

7. Conclusion

The integration of BCIs with TCIM represents an emerging, yet promising, area of research. BCIs have demonstrated potential in optimizing mind-body techniques, such as meditation, and in providing measurable insights into energy-based therapies. Their capabilities, particularly when combined with AI, could enable personalized and targeted approaches to TCIM. However, realizing these possibilities requires addressing significant challenges, including ethical considerations related to informed consent and data privacy, cultural sensitivities inherent to TCIM practices, and barriers to accessibility and equitable adoption. Progress in this area will depend on fostering interdisciplinary collaboration between conventional practitioners, researchers, and policymakers, among other relevant stakeholders. Developing robust regulatory frameworks and ethical guidelines will be critical to ensuring the safe and equitable application of BCIs in this context. Additionally, efforts to validate TCIM practices using BCIs could strengthen their integration into conventional healthcare systems. By merging traditional healing with modern neurotechnology, BCIs could revolutionize healthcare and offer personalized TCIM treatments for a wide range of conditions, provided it is done responsibly and ethically.

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JYN: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Conflict of interest

The author has no competing interests to declare.

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Ethical statement

This is an educational article; it did not require ethics approval or consent to participate.

Data availability

All relevant data are included in this manuscript.

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