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Practical Barriers and Strategies for Promoting the Application of Brain-Computer Interface Rehabilitation Aids

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ABSTRACT
Neurological injuries or diseases often result in severe motor and communication impairments in patients, significantly limiting their ability to perform activities of daily living and participate in society. Brain-computer interface (BCI) technology decodes neural signals to help patients restore or compensate for lost functions, thereby improving their ability to live independently and their quality of life. Consequently, this paper conducts an in-depth exploration of the key practical barriers to the promotion and application of BCI-based rehabilitation assistive devices, as well as feasible systematic strategies for advancing their development. The aim is to provide useful guidance for overcoming barriers to technology transfer and accelerating the realisation of the social value and widespread adoption of such assistive devices.

KEYWORDS
Brain-computer interface; Rehabilitation assistive devices; Functional impairment; Industrial collaboration

1 Introduction

Sensory-motor and communication impairments caused by neurological diseases and trauma are among the primary causes of disability, long-term care dependency and a significant decline in quality of life worldwide. Although traditional physiotherapy, occupational therapy and speech therapy play a role in functional recovery, their therapeutic effects are limited for patients with severe neurological impairments. Brain-computer interfaces (BCIs) record and decode neural signals from the brain using non-invasive or minimally invasive methods, converting them into control commands for physical devices, thereby bypassing damaged neural pathways. This enables patients to interact with the external world solely through their 'thoughts'. Although the prospects for brain-computer interface (BCI) rehabilitation aids are exciting, a series of issues—including the inherent complexity of the technology itself, the highly diverse patient population, high research and development and market costs, and a lack of professional service support—collectively constitute barriers to the effective translation and widespread adoption of the technology. Consequently, understanding the root causes of these challenges and exploring practical solutions has become the focus and value of this study.

2 Core Technological Support for Brain-Computer Interface Rehabilitation Aids

The widespread application of brain-computer interface rehabilitation aids is predicated on the availability of mature and reliable core technologies. These primarily include EEG signal acquisition, signal decoding and real-time feedback technologies. EEG signal acquisition involves affixing high-sensitivity sensors to the user's scalp to capture faint electrical signals generated by brain activity, and utilising advanced noise-reduction techniques to ensure signal purity. The currently dominant dry-electrode technology does not require the application of conductive gel, making it more convenient to use whilst reducing the risk of skin allergies, thereby meeting the requirements of long-term rehabilitation training. Signal decoding technology converts raw EEG waves into clear operational commands, and by establishing a mapping model between EEG features and corresponding motor intentions, the recognition accuracy is continuously improved [1]. Individual differences must be taken into account during decoding; therefore, personalised parameter calibration must be carried out during the initial phase of the system. This involves collecting EEG feature samples from each user while they concentrate on specific movements, thereby creating a unique recognition template for each user. Regarding real-time feedback technology, once the decoding system has generated the control commands, it must drive the mechanical device to perform the corresponding movements and provide synchronised sensory feedback. Assistive devices designed for motor function rehabilitation must be equipped with force sensors and position detectors to monitor in real time the degree of alignment between limb movement trajectories and pre-set rehabilitation movements.

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3 Practical Obstacles to the Widespread Adoption of Brain-Computer Interface Rehabilitation Aids

3.1 Inadequate Adaptability in the Development of Rehabilitation Aids

A major challenge facing brain-computer interface (BCI) rehabilitation assistive devices as they enter practical application is that their product designs fail to adequately address the actual physiological limitations and functional needs of various rehabilitation groups, resulting in limited applicability in real-world settings. Functional impairments caused by different diseases vary from person to person: patients with spinal cord injuries commonly experience loss of function in both lower limbs, whilst those with severe stroke may suffer from unilateral hemiplegia accompanied by difficulties in language comprehension; patients with amyotrophic lateral sclerosis (ALS) face progressive loss of muscle control. However, mainstream brain-computer interface rehabilitation assistive devices focus primarily on addressing basic functional levels such as simple arm control and character spelling, overlooking the urgent need for independent mobility among those with lower limb paralysis, and failing to meet the deeper communication needs of aphasia patients who wish to express complex vocabulary and complete sentences through the devices. Furthermore, the physical characteristics of the assistive devices themselves are a key factor limiting their widespread application [2]. Many brain-computer interface devices on the market are bulky due to their complex signal acquisition modules and processing terminals. Users are unable to move the devices and use them conveniently between different rooms, such as bedrooms and living rooms, thereby negating their value as flexible support in daily life and further restricting their use to fixed treatment rooms.

3.2 Inadequate Assistive Technology Promotion Service System

These new types of neurotechnology-driven assistive devices require rigorous physical and functional assessments, as well as technical fine-tuning, to be effective. This demands that technical service personnel not only understand the principles and parameter settings of the equipment but also possess knowledge of neurorehabilitation, enabling them to meticulously interpret contextual variables such as the user's electromyographic (EMG) and electroencephalographic (EEG) signal characteristics. The current market, however, lacks professional fitting engineers with such multidisciplinary backgrounds. At the same time, potential users and their families often have no way of comprehensively accessing essential information, such as which brain-controlled devices on the market are suitable for specific functional impairments or how particular brands perform in practice. This forces them to invest significant time and energy in searching online and comparing different organisations offline. Once a product has been selected, users must navigate complex procedures involving multiple departments and administrative channels, such as obtaining diagnostic certificates, undergoing qualification reviews by the Disabled Persons' Federation, and applying for rehabilitation programmes. This places a significant burden on rehabilitation patients—who often have limited mobility and energy—and their carers. Furthermore, the understanding of brain-computer interface (BCI) technology among most frontline rehabilitation therapists, community doctors and nurses remains largely theoretical; they are unable to provide clear guidance on operational queries raised by device users. This disconnect between cutting-edge technology and on-the-ground service delivery hinders the full realisation of the technology's potential, whilst also undermining users' confidence in continued product use and their actual rehabilitation outcomes.

3.3 Insufficient Coordination within the Assistive Technology Industry

In the practical promotion of brain-computer interface rehabilitation assistive devices, the sector faces the challenge of insufficient industrial synergy; this lack of coordination severely undermines the overall efficiency of technology transfer and market penetration [3]. Firstly, a stable feedback loop for demand assessment and technical validation has not been established between technology R&D entities and clinical application entities. Technology companies responsible for product development often fail to fully integrate into real-world rehabilitation settings, making it difficult for them to accurately grasp the specific characteristics of patients' functional impairments in clinical practice or the practical challenges healthcare professionals face when operating the equipment; Similarly, whilst medical institutions possess an understanding of clinical pain points and frontline needs, they lack in-depth knowledge of the principles behind cutting-edge technologies. Consequently, they struggle to translate complex rehabilitation requirements into clear engineering terminology, resulting in equipment that is unsuitable for routine use in rehabilitation settings. Secondly, due to limitations in resources and investment, some enterprises face numerous bottlenecks in tackling technical challenges. There is a lack of in-house R&D capability for key components such as high-precision signal acquisition sensors, whilst the processing efficiency and stability of critical algorithms—such as environmental noise filtering algorithms—remain inadequate. As reliable breakthroughs in core technologies have yet to be achieved, overall product performance remains constrained. Furthermore, collaboration between this industry and the healthcare sector is insufficient; the proportion of products incorporated into standard hospital rehabilitation programmes and routine post-illness support processes

remains low. Whilst functional impairments caused by chronic diseases are extremely common and increasingly prevalent among the elderly, there are few practical implementation cases in care homes or in the context of age-friendly home adaptations within communities.

4 Strategies for Promoting the Adoption of Brain-Computer Interface (BCI) Rehabilitation Assistive Devices

4.1 Optimising Assistive Device R&D and Product Adaptation

The promotion of BCI rehabilitation assistive devices must address the practical difficulties faced by the rehabilitation community. The design and development process requires a detailed understanding of the core needs associated with different types of disabilities. This involves conducting long-term observations at rehabilitation centres to record the behavioural challenges patients face in specific daily living scenarios, such as eating, using the toilet, and reading and writing, and translating these specific needs into product functional parameters. The user interface of assistive devices for limb movement control should be simplified to a basic mode, enabling a single EEG feature to control an entire set of pre-programmed movement sequences; gesture switching functions must be designed with clear visual cues to avoid the risk of accidental activation. For brain-controlled toys intended for children, electronic components should be encased in soft silicone shells to prevent accidental damage from collisions; for users with impaired vision, voice-guided systems should be developed to automatically issue verbal prompts for position correction when electrode placement is difficult [4]. At the same time, adaptation to everyday living scenarios must be enhanced. Assistive devices for home use must have their overall dimensions controlled, with the device height not exceeding the footprint of a standard domestic microwave oven; brain-controlled communication boards powered by portable batteries must meet the basic requirement of supporting six hours of continuous operation on a full charge. For outdoor use, the device should possess anti-interference capabilities, employing a protective solution combining a metal casing with digital filter circuits to effectively resist wireless signal crosstalk in the market environment. For rehabilitation scenarios requiring multi-device coordination, external interfaces must be provided to enable the brain-controlled switch to regulate both the speed of electric wheelchairs and the elevation angle of nursing beds.

4.2 Improving the Service System for Assistive Device Promotion

The specialised nature and individual variability of brain-computer interface (BCI) rehabilitation aids necessitate the establishment of a dedicated fitting service team. The initial assessment phase must include three fundamental tests: medical functional evaluation results regarding the user's residual motor abilities, observational records of daily living patterns, and baseline data on EEG signal characteristics, in order to determine the optimal configuration for the brain-controlled device. Service personnel must carry portable fitting toolkits to conduct on-site work. Following initial installation, they must also accompany the user through three rehabilitation training cycles to ensure the user masters core operational skills. Concurrently, a multi-stakeholder, one-stop service platform should be established to support users: rehabilitation institutions should regularly upload assessment data to record patients' rehabilitation progress; manufacturers should synchronise device update information and provide reports on spare parts stock levels; and medical institutions should share pathological data to determine the scope of expanded indications. Furthermore, the technical dissemination capabilities of professional groups should be strengthened. The curriculum for rehabilitation therapists must ensure scientifically sound and reliable training outcomes: foundational theoretical instruction should include courses on the principles of EEG signal acquisition, whilst practical training requires trainees to complete simulated treatment sessions for typical cases; only those who pass the training will be granted certification to operate the equipment. Concise device support tutorials should be designed for community care workers, covering basic requirements such as restart procedures for unexpected system crashes and daily cleaning and maintenance protocols [5].

4.3 Promoting the Collaborative Development of the Assistive Technology Industry

A key strategy for promoting the efficient and widespread application of brain-computer interface rehabilitation aids is to strengthen multi-party collaborative mechanisms among relevant industries. Regular technical liaison seminars should be established, with clear provisions requiring R&D engineers to periodically station themselves at key rehabilitation hospitals and community rehabilitation centres to closely monitor patients' actual usage. They must meticulously record various performance details, fault characteristics and user operational difficulties identified during practical operation. Frontline rehabilitation physicians and therapists should systematically study relevant technical knowledge and promptly compile the treatment experience accumulated in clinical practice, along with patients' expectations for functional

improvement, into clear product improvement proposals. At the same time, they should actively explore pathways for integrating assistive devices into the entire chain of residents' daily lives. In the healthcare sector, we will promote the deep integration of brain-controlled devices into standard post-operative rehabilitation assessment processes, neurological recovery programmes, and disability prevention initiatives for chronic conditions in the elderly, ensuring that these devices become an integral part of standard rehabilitation resources, just like traditional therapeutic equipment. Within the elderly care service system, we support the incorporation of real-world requirements—such as daily care in care homes, interventions at community activity centres for the elderly, and the maintenance of self-care abilities for those living at home—into the product design phase. This enables the development of a range of age-friendly products that ensure safety whilst supporting independent living. By establishing device usage guidelines and training packages jointly validated by multiple organisations, we will facilitate knowledge sharing and consistent improvement in operational capabilities across different social service providers. This will enable products to integrate seamlessly into patients' hospital treatment, post-discharge rehabilitation and long-term home care scenarios, thereby meeting diverse needs.

5 Conclusion

In summary, the widespread adoption of brain-computer interface (BCI) rehabilitation aids requires a focus on enhancing the precision and user-friendliness of product design, establishing a comprehensive professional service system covering the entire lifecycle of the equipment, and promoting the deep integration of industry, academia, research, healthcare and clinical practice, alongside the coordinated development of related industries. Efforts should also be made to actively expand their routine application across multiple settings, including medical rehabilitation, elderly care, education and employment. In the future, as the technology matures through iterative development and with the joint efforts of all stakeholders, brain-computer interface rehabilitation aids are expected to evolve from expensive experimental equipment into affordable, routine rehabilitation support tools, benefiting the vast number of vulnerable groups in urgent need of functional restoration.

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