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Application Status and Prospects of Augmented Reality Technology in Neurological Rehabilitation

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Abstract: Augmented Reality (AR) technology is a research focus in the field of human-computer interaction. It superimposes computer-generated digital information onto the real world in real time and enables immersive interaction through the integration of virtual and real elements, thereby enhancing participants' perceptual interaction with the real world. Currently, AR technology is widely applied in the field of medical rehabilitation, particularly in the rehabilitation of neurological diseases. This article systematically sorts out the core technologies, clinical applications, and future trends of AR technology in neurological rehabilitation, focuses on analyzing its application effects in diseases such as stroke, Parkinson's disease, Alzheimer's disease, and cerebral palsy, and discusses the challenges and development prospects of this technology.

Keywords: Augmented reality technology; Neurological rehabilitation; Application status; Review

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1. Introduction

Neurological rehabilitation targets motor dysfunction from neurological injuries/diseases, aiming to restore motor/self-care ability and enhance quality of life. Diseases like stroke, Parkinson's, Alzheimer's, cerebral palsy cause neurological damage and motor disorders. Limb motor dysfunction mainly shows impaired voluntary movement (e.g., less spontaneous movement, smaller amplitude, slow execution, even inability). Traditional rehab relies on therapists' one-on-one guidance, with low efficiency and poor compliance. AR's rapid development breaks through neural/motor rehab: it boosts efficacy and patients' training enthusiasm. Recent AR-AI integration optimizes rehab models, driving more precise/intelligent development.

2. Overview of AR technology

1997 Azuma et al. defined AR as tech capturing/analyzing digital info to superimpose on reality. It merges virtual-real environments for interactive/immersive experiences, enhancing real-world perception, with three core features: virtual-real combination, real-time interaction, 3D registration [1,2]. Centered on tracking/registration, AR maps virtual-real coordinates via user viewpoints, overlaying virtual info on real scenes. Tracking methods: visual, hardware sensor-based,

hybrid. Interaction: touch (e.g., mouse/keyboard for virtual objects), air gesture (lower costs), device-mediated [3,4]. Virtual-real fusion needs geometric/lighting/temporal consistency, split into optical/video see-through (latter uses cameras, fuses images post-processing) [5]. For motor disorders, motion games integrate tracking, link physical activity with gamification, boosting compliance [6,7].

3. Mechanism of AR technology promoting neurological rehabilitation

Neurological rehab core relies on brain plasticity and functional reorganization. Intensive, repeatable, task-oriented training (with feedback) promotes brain region reorganization, enhances neural connections for motor control, and helps the nervous system re-adapt to sensory signals/inhibit abnormal reflexes [8]. AR enables such training: based on daily movements, it drives normal neurons near damaged brain regions to participate, reconstructs peripheral-central sensory feedback, aids nerve centers in correcting movements/restoring control, achieving functional recovery [9]. It also boosts cardiopulmonary fitness and quality of life. Additionally, AR activates multi-brain-region collaboration via visual/auditory stimuli, strengthens neural circuits; its gamification activates the brain's reward system, improving compliance and extending training duration [10].

4. Current application status of AR technology in neurological rehabilitation

4.1. Application of AR technology in stroke rehabilitation

Stroke is a top cause of adult death/disability globally. Post-onset, patients often have abnormal gait, balance issues, upper limb injuries, paralysis [11]. Post-stroke recovery core: synaptic reorganization and nerve repair. Conventional rehab (intensive, task-oriented with feedback) aids brain remodeling but is boring, low enthusiasm, poor compliance; cost/feasibility limit one-on-one training, and patients struggle to focus [12]. AR solves these: studies show it improves motor control, narrows recovery gaps, aids early rehab [13]. Common AR systems: conventional, mirror, mobile. 3D mirror therapy boosts upper limb recovery; gamified mobile AR (CARS) is portable for self-training [14]. ARISE combines mobile AR with sensor capture, offering gait balance feedback and personalized environments. AR improves prognosis, self-esteem, patient-therapist interaction [15–17].

4.2. Application of AR technology in Parkinson's disease rehabilitation

Patients with Parkinson's disease are often accompanied by symptoms such as bradykinesia, tremor, and balance disorders, which are difficult to cure with traditional drugs or surgery. Studies have shown that the optical see-through AR system based on Yapa-PBGA can support patients' home-based rehabilitation, providing one-on-one demonstrations, posture guidance, and progress monitoring to achieve the best results [18]. Wang et al. used the "Extend Hand" projection AR system to help patients type and interact with home appliances like ordinary people [19,20]. HoloLens 2 technology has also been used to develop a mixed reality rehabilitation tool for upper limb injuries [21]. Gamified AR tools can also improve patients' participation in rehabilitation, such as assisting in gait training [22,23]. It can be seen that by adding digital elements and providing personalized plans and feedback, AR technology enhances patients' participation and enthusiasm, and shows great potential as an effective auxiliary tool in the rehabilitation of Parkinson's disease.

4.3. Application of AR technology in Alzheimer's disease rehabilitation

Alzheimer's disease (AD) is a progressive neurodegenerative disease, also known as dementia. The main symptoms of AD include memory decline, cognitive dysfunction, changes in mental behavior, as well as loss of mobility and reduced social interaction [24]. At present, the treatment of AD mainly focuses on drug development to prevent, slow down, or stop the progression of the disease. However, AR technology can provide ecological validity for the cognitive function assessment

of AD through gamification [25].

4.4. Application of AR technology in cerebral palsy rehabilitation

Cerebral palsy (CP) is a group of permanent motor/postural disorders causing activity limitations, often with cognitive/behavioral impairments. These stem from non-progressive brain damage in early development [26]. Particularly in children with spastic CP, motor coordination defects and muscle weakness impair upper/lower limb functions, severely limiting daily activities [27].

Conventional treatments for these children include surgery, physical and occupational therapy [28]. However, traditional rehabilitation relies on simple repetitive movements that fail to engage children. Interactive tech like Virtual Reality (VR) and AR shows marked effects in CP rehabilitation [29]. Studies confirm AR effectively improves CP children's upper/lower limb balance [29]. An AR-based real-time feedback system (via infrared camera) also enhances their walking ability [30]. Compared with VR, AR offers better presence and reality judgment, giving it more advantages. Thus, AR is an emerging intervention for neurological diseases like CP.

5. Challenges faced by augmented reality technology in neurological rehabilitation

Though AR tech develops rapidly in integration, it still faces obstacles limiting wide market application. Firstly, in cost and resources: high hardware/software costs make it hard for resource-limited medical settings to adopt, worsening healthcare inequality; hardware accuracy and integration with existing clinical workflows also have limitations; Secondly, in device performance and user experience: AR devices have short battery life and are prone to malfunctions. In complex real environments, their audio/video/image quality/stability is insufficient, with issues like unnatural virtual-real integration and image flicker affecting rehabilitation. Additionally, devices like head-mounted displays have data delay, bulkiness, poor portability; prolonged wearing causes patient discomfort, limiting home/community use; Finally, personal privacy/information security issues and the challenge of gaining full medical staff recognition also hinder AR promotion [31–34].

6. Future development prospects and research directions

The future development of AR in the field of neuromotor rehabilitation can be advanced from three aspects. In terms of technological innovation, with the development of computer, sensor, and display technologies, technical bottlenecks such as signal delay can be overcome, and better AR devices can be developed. Furthermore, the in-depth integration of AI and AR can realize the customization of rehabilitation programs and the adjustment of training processes by analyzing rehabilitation data, thereby improving the accuracy of treatment. In terms of clinical application expansion, it is necessary to establish unified AR rehabilitation standards, conduct large-scale multi-center clinical trials to verify effectiveness and safety, and expand its application to the rehabilitation of diseases such as multiple sclerosis. In terms of multi-disciplinary integration, strengthening cooperation among rehabilitation medicine, computer science, and other disciplines can jointly promote the research and application of AR technology in neuromotor rehabilitation, and facilitate technological innovation and clinical transformation.

7. Conclusion

Augmented Reality has shown great application potential in the field of rehabilitation. It has achieved certain results in the rehabilitation treatment of various neurological diseases such as stroke and Parkinson's disease, and provided new methods and approaches for improving patients' motor function and quality of life. Although it currently faces some challenges in technology and clinical application, with the continuous advancement of technology and in-depth multi-

disciplinary integration, it is believed that AR technology will play a more important role in neuromotor rehabilitation in the future, promote the development of rehabilitation medicine towards intelligence and precision, and bring more hope to the majority of patients with neurological disorders.

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