Advances in the Application of Multisensory Stimulation Therapy in Virtual Reality Technology in Rehabilitation

Lanxin Tang, Lining Yang, Zheng Yang, Defei Chen, Weilin Tan, Qiuyi Lu, Tailin Ran, Dingqun Bai

Department of Rehabilitation Medicine, First Affiliated Hospital of Chongqing Medical University, Key Laboratory of Physical Medicine and Precision Rehabilitation, Chongqing Health Commission, Chongqing, China

Abstract: Introduction: Multisensory stimulation, a traditional rehabilitation approach that activates neural functions through integrated visual and auditory pathways, has not achieved widespread clinical adoption due to limitations in facility conditions and equipment configurations. With the rapid advancement of virtual reality (VR) technology, diverse electronic devices now enable flexible delivery of multimodal sensory stimulation, offering innovative approaches for therapeutic applications. This systematic review examines the implementation and efficacy of VR-based multisensory stimulation therapy in rehabilitation, while analyzing current technological limitations to provide actionable insights for its clinical expansion and optimization.

Keywords: Virtual Reality, Multisensory Stimulation, Rehabilitation

1. Introduction

With the rise of human-computer interaction and artificial intelligence technologies, virtual reality (VR) has been increasingly applied across various fields. In clinical medicine, VR utilizes computer programs to create highly realistic 3D environments and enables human-computer interaction through multimodal sensory inputs, thereby achieving diverse therapeutic objectives. As a kind of rehabilitation intervention, multi-sensory stimulation (MSS) activates patients' neural functions by integrating visual, olfactory and tactile stimuli. Existing studies have confirmed that MSS has significant efficacy in stroke, mental illness and pain management. However, traditional multisensory stimulation is difficult to become a mainstream rehabilitation program due to the limitations of site space and equipment configuration requirements. With the advancement of VR technology, its portability and flexibility have become increasingly prominent, enabling multi-sensory stimulation through various electronic devices. Currently, this technology has been gradually applied in rehabilitation practices for stroke, dementia, and Alzheimer's disease, demonstrating significant translational medical potential.

2. Application of Multisensory Stimulation in Rehabilitation

Traditional multisensory stimulation techniques are represented by multisensory activity rooms

(snoezelen) and healing gardens. Among them, the multisensory activity room integrates multimodal stimulation elements such as sound and light control systems, aroma diffusion devices, and water touch devices to create an immersive dedicated therapeutic space, while the healing garden creates an ecological therapeutic space mediated by natural environmental elements, enabling patients to interact with natural stimuli such as plant fragrances and soil textures. Based on its low cognitive load and high universality characteristics, evidence-based studies have confirmed that this technology has significant clinical value in multidimensional rehabilitation fields such as neurodegenerative diseases, developmental disorders, chronic pain management [1], etc.

In the field of neurological rehabilitation, multisensory stimulation therapy plays a positive role in emotional regulation, behavioral correction and cognitive remodeling. The randomized controlled study conducted by the Sanchez team [2] included 32 patients with Alzheimer's disease. The experimental design divided the subjects into three groups: MSS group received multisensory activity room intervention, activity group received traditional rehabilitation training, and control group only maintained routine care. This technology effectively enhances cognitive-motor integration and social interaction in individuals with developmental disorders. A randomized controlled trial involving 80 children with autism spectrum disorder demonstrated that the experimental group receiving personalized multisensory stimulation (acoustic, vestibular, and gustatory channels) showed significantly improved PEP-3 scores and CARS (Child's Assessment of Social Relationship) scores compared to the traditional rehabilitation group. In chronic pain management, multisensory stimulation generates analgesic effects through neural modulation mechanisms. Gungormus et al. (2024) [3] demonstrated in a controlled trial of 42 patients with fibromyalgia syndrome that the real plant transplantation intervention group (experimental group) based on the concept of ecological healing showed reduced clinical pain scores and diffuse analgesic response activation compared to the simulated environment control group.

At present, although multisensory stimulation therapy is supported by evidence-based medicine [4], its clinical application is still limited by the spatial resource limitation of traditional intervention mode. Research indicates that established models such as multisensory activity rooms and therapeutic gardens, which require specialized physical therapy units, are currently primarily implemented in tertiary medical institutions. Notably, breakthroughs in artificial intelligence have injected innovative momentum into virtual reality technology. VR-MSS technology, based on human-computer interaction algorithms, has revitalized this field by creating digital multimodal stimulation environments.

2.1 Auditory Stimuli

Auditory stimulation is often used to improve gait and motor coordination in rehabilitation treatment through rhythmic auditory cues. Studies have shown that stroke and Parkinson's disease patients' stride length, walking speed and symmetry were significantly improved with the guidance of rhythm sound or music. In addition, music therapy can also improve patients' exercise motivation and emotional state, thus promoting neurological function recovery.

In virtual reality rehabilitation, auditory stimulation plays an important role in enhancing sensory feedback and motion control, showing significant advantages in gait and balance training. In a randomized controlled trial, Park et al. [5] integrated VR virtual reality with auditory stimulation in robotic-assisted gait training. Participants demonstrated significantly better performance on the Berg Balance Scale (BBS), 10-meter walk test (10MWT), and functional mobility assessment (TUG)

compared to those using visual cues or traditional training methods alone. This evidence indicates that multimodal feedback can enhance stroke patients' walking ability and postural control. At the same time, auditory stimulation can also improve cognitive function and mental health. A multicenter cohort study [6] enrolled 106 patients with post-stroke cognitive impairment and confirmed that VR training with audiovisual integration could significantly improve the MoCA score compared with conventional training. Although most studies support the clinical advantages of audiovisual joint stimulation, there are also controversies about its efficacy. A randomized controlled trial by Verdi et al. (2023) [7] involving 126 veterans with post-traumatic stress disorder (PTSD) demonstrated that VR exposure therapy using the Virtual Iraq system (featuring smoke inhalation stimuli) showed no statistically significant difference in the Clinical Apprehension Scale for PTSD (CAPS-5) improvement rates compared to traditional therapies. Researchers noted that pure audiovisual neural modulation exhibits ceiling effects, while current VR technology may face limitations in multimodal stimulus integration.

2.2 Tactile Stimulation

In traditional rehabilitation therapy, tactile stimulation is mainly used to promote the recovery of sensory function, reduce pain, and improve fine motor ability. Its methods include pressure stimulation, texture discrimination, cold/hot stimulation and functional hand training to enhance peripheral sensory input and promote cortical plasticity.

As a vital component of multisensory interaction in virtual reality (VR) rehabilitation, tactile stimulation significantly enhances both training immersion and therapeutic outcomes. Through force feedback gloves, vibration devices, or skin pressure stimulation, patients not only receive visual and auditory feedback during VR tasks but also engage with tactile inputs, thereby strengthening the activation of sensory-motor pathways. Studies have shown that VR upper limb rehabilitation training combined with tactile feedback can effectively improve hand function and movement coordination of stroke patients. Furthermore, in pain management, haptic feedback enhances analgesia by competitively inhibiting pain transmission pathways through multisensory channels. Hoffman's team (2023) [8] utilized an audiovisual-haptic integrated system (the Waltz of the Wizards platform with water temperature control) as the primary stimulus. Experimental data showed that the triple-modality group (audiovisual-haptic) demonstrated significantly lower pain intensity scores (VAS) compared to the dual-modality intervention group. The analgesic efficacy was equivalent to medium-dose intravenous morphine, with no drug-related adverse reactions observed throughout the treatment. This study confirms that multisensory VR interventions can achieve non-pharmacological pain relief, offering an innovative clinical solution to overcome traditional opioid dependence challenges. In summary, VR combined with tactile stimulation provides a more immersive and efficient rehabilitation pathway for patients with motor dysfunction. Future research could further optimize multimodal haptic feedback technology to enable more precise rehabilitation interventions.

2.3. Olfactory Stimulation

In traditional rehabilitation, olfactory stimulation is used to assist emotional regulation, pain reduction, and balance improvement. Common methods include aromatherapy, odor recognition training and olfactory exposure combined with motor tasks to enhance cerebral cortex excitability and alleviate anxiety and depression symptoms. This method has been widely used in stroke

rehabilitation, Parkinson's disease and elderly patients with cognitive impairment, which can improve exercise compliance, cognitive function and mental health, thus assisting the overall rehabilitation effect.

As a vital component of traditional rehabilitation therapies, olfactory stimulation has emerged as a key paradigm in virtual reality-based rehabilitation, demonstrating potential for enhancing cognitive training and balance functions. A research team from the Tokyo Institute of Science in Japan [9] developed an olfactory VR game that stimulates elderly participants' memory and spatial cognition through virtual environmental cues and visual feedback. After 20 minutes of training, participants showed significant improvements in visuospatial rotation tasks and verbal spatial memory tests, supporting the role of olfactory-visual integration in promoting cognitive function recovery. In addition, in vestibular rehabilitation training for patients with multiple sclerosis, it was found that when patients were given lavender essential oil olfactory stimulation during basic VR or traditional balance training, Berg Scale of Balance (BBS) and TUG time performance were significantly improved, while fear of falling psychological stress was reduced and daily behavioral self-efficacy was enhanced. Jiang's research team (2024) [10] conducted a double-blind crossover study using VR virtual driving, revealing that multisensory stimuli including visual, auditory, and olfactory inputs significantly reduced subject fatigue. The mint, grapefruit, and lavender treatments showed comparable effects, with the grapefruit group demonstrating the most pronounced fatigue reduction while the lavender group exhibited longer-lasting relief. Furthermore, olfactory-Virtual Reality (OVR) systems for emotional regulation and memory rehabilitation are gaining traction. Studies indicate that olfactory stimulation activates brain regions associated with emotions and memory, enhancing the personalization and immersion of VR relaxation therapy, thereby opening new avenues for psychological rehabilitation. A randomized controlled trial (n=127) [11] confirmed that an ecologically valid multisensory VR assessment system demonstrates significant diagnostic advantages for post-traumatic stress disorder (PTSD). The experimental group received VR scenarios simulated with smoke odor, while the control group received traditional image-video stimuli. Results showed that the VR group exhibited significantly higher symptom-induced rates on the Clinician-Administered PTSD Scale (CAPS) compared to the control group. This study provides an innovative assessment tool for early identification and screening of high-risk populations with PTSD.

2.4. Vestibular Stimuli

Interdivisional stimulation is mainly used in traditional rehabilitation to improve balance function, posture control and motor coordination. Vestibular stimulation methods such as rocking chair, rotating disk, balance beam and vestibular electrical stimulation can enhance the central nervous system's ability to regulate posture, thus improving the balance and gait performance of cerebral palsy, vestibular dysfunction and stroke patients. In addition, vestibular stimulation has been used in sensory integration training to promote the development of children's attention and motor planning abilities.

Frontal vestibular stimulation is getting more and more attention in VR rehabilitation, mainly used to improve balance, reduce vertigo and reduce pain recovery. A study using a VR vestibular rehabilitation program on the PS4 headset significantly improved patients' DHI scores, standing stability test (SOT), limit stability (LOS), and direction control. A study included 47 healthy people, and conducted vestibular stimulation with false stimulation/maximum threshold vestibular stimulation/precise rotation axis vestibular stimulation in 360° panoramic VR. The results showed

that the experimental group could effectively improve the patients' vertigo discomfort, but could not completely eliminate the discomfort. It has been shown that virtual visual rotation (especially when tilted to the left) improves the thermal pain threshold of subjects.

2.5 Proprioceptive Stimulation

Proprioceptive stimulation is mainly used to improve motor control, balance and postural stability in traditional rehabilitation therapy. By means of joint proprioception training, muscle stretching, weight-bearing exercise and functional movement training, neuromuscular feedback regulation can be promoted to help patients rebuild their movement patterns. This method is widely used in stroke, spinal cord injury and orthopedic rehabilitation, which can improve the effect of motor function recovery and reduce the risk of secondary injury.

The integration of proprioceptive stimulation into virtual reality rehabilitation has emerged as a groundbreaking approach to enhance motor control and balance recovery. While conventional VR training relies on visual feedback, intentionally reducing visual input while strengthening proprioceptive feedback enables patients to rely on their muscles and joints' inherent positional and kinesthetic awareness. This methodology effectively improves motor precision and control capabilities through enhanced proprioceptive guidance. In a stroke patient study, researchers developed a VR-based proprioceptive rehabilitation system and enrolled 10 stroke patients. During upper limb training, they randomly switched between visual feedback and proprioceptive feedback modes. Post-training assessments at baseline, one-week post-training, and final evaluation revealed that proprioceptive feedback significantly reduced click counts, deviation distances, and total error distances. Additionally, patients demonstrated marked improvements in motor control during behavioral tests.

2.6 Taste Stimulation

In traditional rehabilitation therapy, taste stimulation is often used to promote the recovery of swallowing function, especially in patients with swallowing disorders caused by stroke or neurological injury .Through different taste stimuli such as acid, sweet and bitter, the sensory input of the glossopharynx and mouth can be enhanced, and the pharyngeal reflex and swallowing-related neural pathways can be activated, so as to improve swallowing efficiency and reduce the risk of aspiration.

In the realm of virtual reality, integrating taste stimuli remains in its early exploratory phase. Current research primarily focuses on enhancing therapeutic immersion and effectiveness by combining multisensory stimuli in virtual environments to influence real-world taste perception. Study demonstrates that VR environments can modulate users' subjective evaluations of food attributes such as saltiness and spiciness, indicating that visual-taste synergy significantly impacts sensory perception. In addition, a randomized controlled experiment showed that the combination of taste with visual, auditory, tactile and olfactory stimuli not only contributes to psychological recovery, but also significantly improves mental health.

4. Conclusion

In recent years, VR has developed rapidly in rehabilitation medicine, increasingly integrating visual, auditory, tactile, olfactory and other multi-sensory stimuli to improve perceptual integration, engagement and treatment effectiveness, enhance immersion and promote exercise, cognition and

pain management. In the field of cognitive rehabilitation, a number of studies have shown that interventions containing VR multisensory stimulation are significantly better than conventional treatments in terms of global cognitive function, attention, memory and emotional improvement, and patients are more receptive to them. However, current research predominantly focuses on single-sensory interventions or short-term approaches, lacking systematic exploration of long-term follow-up studies and multisensory integration mechanisms. Furthermore, individual variations and inadequate technical standardization have hindered clinical implementation.[12]

Funding

Comprehensive platform for complex environment simulation and behavioral monitoring and analysis for the disabled (2023YFC3604501)

References

[1] H S, I S, M B, et.al. The Snoezelen approach in pain management in psychiatry. Soins. Psychiatrie, 2019, 40 (320). DOI:10.1016/j.spsy.2018.11.008.

[2] SÁNCHEZ A, MARANTE-MOAR M P, SARABIA C, et.al. Multisensory Stimulation as an Intervention Strategy for Elderly Patients with Severe Dementia: A Pilot Randomized Controlled Trial[J/OL]. American Journal of Alzheimer's Disease and Other Dementias, 2016, 31(4): 341-350. DOI:10.1177/1533317515618801.

[3] GUNGORMUS D B, FERNÁNDEZ-MARTÍN M, ORTIGOSA-LUQUE M E, et. Effects of Nature-Based Multisensory Stimulation on Pain Mechanisms in Women with Fibromyalgia Syndrome: A Randomized Double-Blind Placebo-Controlled Trial. Pain Management Nursing: Official Journal of the American Society of Pain Management Nurses, 2024, 25(1): 46-55. DOI:10.1016/j.pmn.2023.06.014.

[4] Progress in clinical research on multisensory stimulation therapy, China National Knowledge Infrastructure

[5] PARK J, CHUNG Y. The effects of robot-assisted gait training using virtual reality and auditory stimulation on balance and gait abilities in persons with stroke. NeuroRehabilitation, 2018, 43(2): 227-235. DOI:10.3233/NRE-172415.

[6] Application of virtual reality scenario cognitive rehabilitation training combined with music therapy in patients with post-stroke cognitive impairment, China National Knowledge Infrastructure.

[7] EK V, AC K, MA G, et.al. Impact of dissociation on exposure therapy for PTSD outcomes and Adherence among U.S. Military service members. Journal of psychiatric research, 2023, 166. DOI:10.1016/j.jpsychires.2023.09.011.

[8] HG H, MR F, A G P, et.al. Adding tactile feedback increases avatar ownership and makes virtual reality more effective at reducing pain in a randomized crossover study. Scientific reports, 2023, 13(1). DOI:10.1038/s41598-023-31038-4.

[9] A Virtual Reality Game Integrating Smell to Fight Cognitive Decline. https://www.sciencedaily.com/releases/2025/04/250430142346.htm.

[10] X J, K M, J C, et.al. Scented Solutions: Examining the Efficacy of Scent Interventions in Mitigating Driving Fatigue. Sensors (Basel, Switzerland), 2024, 24(8). DOI:10.3390/s24082384.

[11] T S, F R, D S, et.al. Psychophysiological reactivity, coping behaviour and intrusive memories upon multisensory Virtual Reality and Script-Driven Imagery analogue trauma: A randomised controlled crossover study. Journal of anxiety disorders, 2018, 59. DOI:10.1016/j.janxdis.2018.08.005.

[12] PARISI A, BELLINZONA F, DI LERNIA D, et.al. Efficacy of Multisensory Technology in Post-Stroke Cognitive Rehabilitation: A Systematic Review. Journal of Clinical Medicine, 2022, 11(21): 6324. DOI:10.3390/jcm11216324.