Article

Research Hotspots and Trends in the Research on the Application of VR in Rehabilitation Medicine

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Abstract: Objective: To sort out the research hotspots of the application of VR in rehabilitation medicine, analyse its research themes and research trends, and offer a reference for future related research in this field. Methods: This paper provides an in-depth analysis of the development process, research hotspots and research trends in the field of VR application in rehabilitation medicine research, taking the Web of Science core dataset as the source and using bibliometric analysis by CiteSpace. Results: The application of VR in rehabilitation medicine was composed of three stages, and the research topics were reviewed in five aspects: neurological rehabilitation, psychology treatment, pain distraction, cardiopulmonary rehabilitation, and visual spatial disorder. Limitations: The literature data only come from the Web of Science core dataset, and the data sample size was not comprehensive. Conclusion: Overcoming VR technology-induced vertigo and mental disorders from overuse of VR are both challenges to research on the application of VR in rehabilitation medicine. In addition, developing VR products with better experience, developing standardized guidelines, and conducting more high-quality clinical studies are all future research trends for the application of VR in rehabilitation medicine.

Keywords: VR; rehabilitation; bibliometric; research focuses; development trend

1. Introduction

Virtual reality (VR) is a multidisciplinary technology that generates a virtual digital world through computer simulation and provides complex, realistic and immediate feedback similar to reality using software programs and hardware devices (e.g., headphones, helmets, glasses, gloves, vests, etc.) to give users an immersive feeling and experience [1]. In recent years, VR technology has gradually entered and been applied to the medical field, especially in rehabilitation.

Rehabilitation medicine aims to improve the quality of life of sick, injured and disabled people and their eventual integration into society. Because VR has the characteristics of virtual tasks, interesting scenarios and high user participation, VR technology can provide a more realistic and convenient tool for all rehabilitation subjects to adapt to the real world in advance and can achieve excellent therapeutic effects in rehabilitation. In recent years, VR technology, as a frontier technology in rehabilitation medicine, has shown great advantages and is more widely used in multiple fields, such as neurological rehabilitation, pediatric rehabilitation, orthopedic rehabilitation, etc. For example, the use of a commercial wearable head-mounted display (HMD) and selected VR motion games for Parkinson's disease to maintain physical and functional abilities has shown good disease management effects [2]; a VR-based interactive cognitive training (VICT) system shows good effects for cognitive rehabilitation of traumatic brain injury (TBI) in children [3]; VR technology can also be combined with existing rehabilitation methods, such as walking exercises combined with virtual reality, which can improve gait and balance problems more significantly [4].

By reviewing relevant studies, this paper found that although there are numerous existing research results, most of them focus on the feasibility and effectiveness of VR technology for rehabilitation training of certain types of patients. To the best of our knowledge, there has been no systematic research on the research hotspots and research trends of VR application in rehabilitation medicine. Based on this, this paper systematically sorts the literature on the application of VR in rehabilitation medicine and summarizes and analyses the research hotspots, theme evolution, and development trends in this field through bibliometric methods, aiming to deepen the understanding of VR application in rehabilitation medicine research and provide a reference and theoretical basis for subsequent related research.

2. Study Design

2.1. Data Acquisition

According to Bradford's law, most of the key studies in each field are included in international journals, so Web of Science is taken as the data source in this paper. The search strategy was as follows: TOPIC: ("virtual reality*" OR "augmented reality*" OR "mixed reality*" OR "computer-mediated reality*") AND ("occupational therapy* " OR "physical therapy*" OR "physical medicine" OR "rehabilitation " OR "physicotherapeutics"), select the item type as "article", the time range is up to 2022, and finally get 2940 articles, the retrieval time was January 16, 2023.

2.2. Methodology

CiteSpace is a literature information visualization tool developed by Prof. Chaomei Chen's team at Drexel University, USA. First, this paper uses Excel 2019 to conduct a basic statistical analysis of the annual publication numbers of the literature; then, we conduct national (regional) collaboration network analysis of the literature through CiteSpace, as well as keyword co-occurrence network and coword timeline network analysis, as a way to explore the development history, hot topics and frontier topics of VR in rehabilitation medicine research [5].

3. Data Analysis

3.1. Analysis of Time Distribution

The interannual variation in the number of publications can visually reflect the distribution of the literature on the application of VR in rehabilitation medicine. Figure 1 shows the time distribution of research papers on the application of VR in rehabilitation medicine, the earliest of which were two articles both published in Computers in Biology and Medicine in March 1995. One paper presented examples of the applicability of virtual reality in the therapeutic rehabilitation of people with disabilities and how physicians can use virtual reality as a visualization tool to diagnose physical disabilities [6], and the other article introduced immersive virtual reality technology as a way to help cognitive psychologists and therapists perform clinical work with brain-injured patients while also suggesting that this new approach requires extensive research to validate it [7]. Before 2002, there were few studies related to VR application research in rehabilitation medicine; from 2003 to 2010, the number of related articles in this field showed a continuous upwards trend; especially from 2011, the growth rate was faster, which shows that research on the application of VR in rehabilitation medicine is receiving increasing attention.

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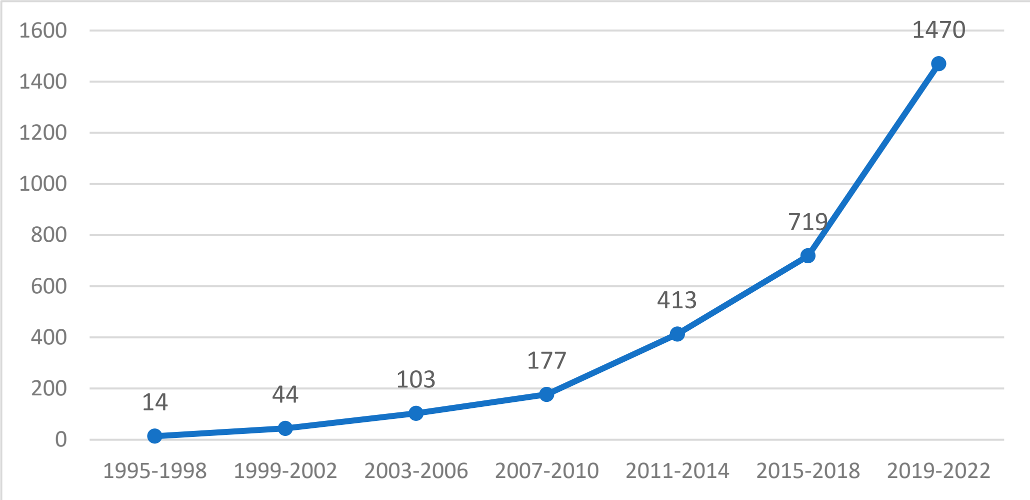

Figure 1. Time distribution graph of research papers on the application of VR in rehabilitation medicine.

3.2. Spatial Distribution Analysis

By mapping national (regional) collaborative research, it is possible to visually observe the sources of academic productivity of research on the application of VR in rehabilitation medicine and to understand the core strengths and mutual collaborative relationships of research in this field. In this paper, CiteSpace was used to generate a national collaborative network, as shown in Figure 2. It can be inferred that the United States is at the core, has collaborated with several countries, and started collaborative research earlier than most other countries and regions.

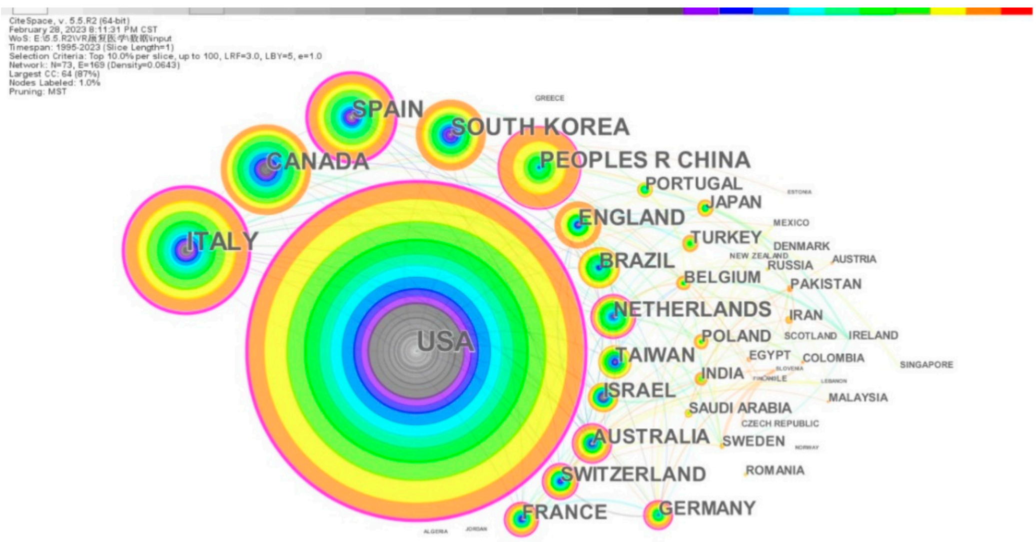

Figure 2. National collaborative network for research on the application of VR in rehabilitation medicine.

Table 1 shows the information related to the top ten countries/regions in terms of the number of articles published. The United States topped the list with 703 articles, accounting for more than 23% of the total, which shows the importance that the United States attaches to research in this field. Italy, Canada, Spain, South Korea and China all have more than 200 articles. The top 10 countries and regions accounted for more than 83% of the total number of articles published, indicating that the main distribution of research strength on the application of VR in rehabilitation medicine is concentrated in these countries and regions. In terms of centrality, Italy ranked first with 0.32, and

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the United States and Spain ranked second and third with 0.26 and 0.25, respectively. These country/region nodes are marked with purple circles to indicate the importance of the node. Both the United States and England started publishing relevant articles in 1998, Italy (2001), Canada (2003), and South Korea (2003) started relevant studies in approximately 2002, and other countries/regions started publishing relatively later and began publishing after 2007. It is clear that the United States has a comparative advantage in terms of both the number of articles and their significant impact.

Table 1. Country/region & number of published articles.

Country/Region	No. of articles	Percentage	Frequency of citations	Centrality	Year of first publication
USA	703	23.912%	665	0.26	1998
Italy	331	11.259%	254	0.32	2001
Canada	231	7.857%	194	0.1	2003
Spain	230	7.823%	181	0.25	2007
South Korea	210	7.143%	166	0.06	2003
Peoples R China	207	7.041%	159	0.11	2013
England	165	5.612%	119	0.09	1998
Brazil	130	4.422%	98	0.01	2013
Austrilia	121	4.116%	83	0.12	2011
Netherlands	118	4.014%	91	0.16	2008

3.3. Keywords Statistical Analysis

By analysing the keyword coword network of the literature, the relevance of keywords to the research hotspots in specific academic fields can be explored. Figure 3 shows the coword network of keywords generated by CiteSpace. Among them, the important nodes with high frequency and centrality include virtual reality (1926 times, 0.13), rehabilitation (1616 times, 0.10), exercise (538 times, 0.12), gait (318 times, 0.11), environment (233 times, 0.18), and older adults (173 times, 0.11), all of which are key issues in this research area. In addition, keywords with high word frequency include stroke (1054 times), balance (349 times), video game (286 times), children (205 times), neurorehabilitation (183 times), cerebral palsy (158 times), and Parkinson's disease (158 times), which provide a reference for the following review of research themes.

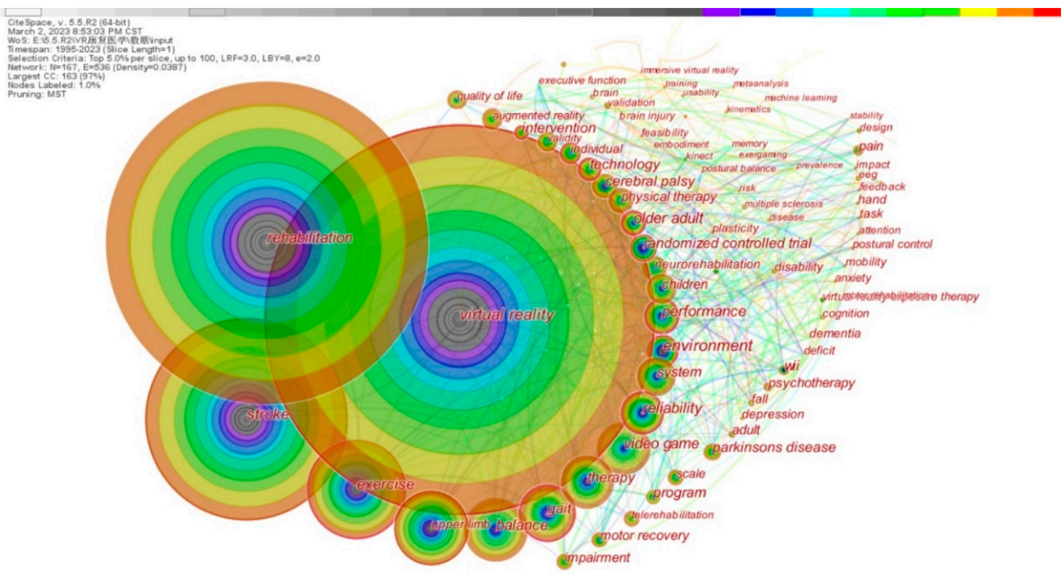

Figure 3. Coword network of keywords in the application of VR in rehabilitation medicine research.

3.4. Topics Evolution Analysis

To study the knowledge structure and research topic evolution path of research on the application of VR in rehabilitation medicine, this paper used CiteSpace to draw a coword timeline view, as shown in Figure 4. Based on a detailed analysis of the research topic evolution path of the field, this paper divides its development into three stages.

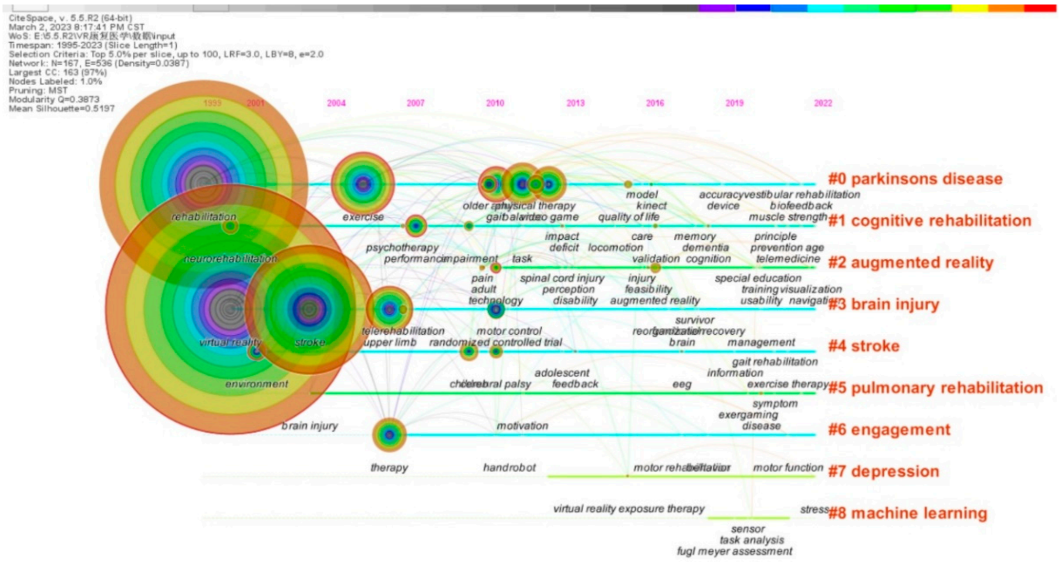

Figure 4. Coword timeline view of application of VR in rehabilitation medicine research literature.

Based on a detailed analysis of the research topic evolution path of the field, this paper divides its development into three stages.

3.4.1. Exploration Stage (since 1995)

With the emergence of VR products, researchers began to discuss the existing and potential applications of VR technology in rehabilitation, such as the prospect of application in neurological rehabilitation [8] and the exploration of help for motor rehabilitation and phobias [9]. At the same time, VR technology began to be used to develop products for rehabilitation, such as VR rehabilitation training using a diagnostic glove and WorldToolKit graphics library [10] and the development of a bedside rehabilitation system to experience virtual forest walks used to help improve the quality of life of bedridden patients and the elderly [11].

In addition, VR-based therapies are beginning to be explored for application in a variety of disorders, such as visual and auditory stimulation through VR technology for communication and education of children with autism [12]. Additionally, a representative example is the use of VR exposure therapy by researchers at Emory University to simulate a Vietnam war zone for the treatment of PTSD disorders in veterans, which has been proven to be effective and is still used in the medical field today [13].

3.4.2. Developmental Stage (since 2010)

In 2010, Microsoft introduced the motion tracking sensor "Kinect", which has made significant advances in both graphics processing and motion capture technology, further promoting research on the application of VR in rehabilitation medicine. Designing rehabilitation games through Microsoft Kinect for sports rehabilitation exercises of Parkinson's disease (PD) patients can effectively motivate the exercise interest of PD patients [14]. Hemiplegic stroke survivors trained with Xbox Kinect can significantly improve multiple aspects of upper extremity function, such as range of motion, motor function, and overall hand dexterity [15] Active virtual reality gaming (AVG) of Xbox 3 Kinect makes motor skills practice available and contributes to the rehabilitation of children with developmental coordination disorder (DCD) [16].

Another representative product is Oculus Rift, an immersive virtual environment using a very inexpensive wide field of view, launched by Oculus in 2013. Oculus Rift Virtual Reality (VR) goggles can elicit a strong illusion of presence and reduce pain during VR, which can be applied to daily burn wound care and physical therapy, allowing more patients (possibly even at home) to use VR for pain control due to its convenience [17]. Analysis of data collected by VR hardware can provide insight into neck flexibility and overall neck motion during head movement, which is applicable to assess pain-related stiffness as well as monitor progress [18].

In 2014, Google released its VR product cardboard. Because of its low price and positive experience, its application in rehabilitation has also developed rapidly, which is beneficial for the rehabilitation therapy of patients with mechanical strabismus and/or amblyopia who have lost eye movements [19]. Immersive experience based on Google Cardboard allows for prolonged training that can effectively reduce pain intensity and is an effective intervention to improve motor function and reduce pain perception [20].

3.4.3. Promotion and Application Stage (since 2019)

With the gradual maturity of VR technology, an increasing number of manufacturers have started to develop personalized VR devices for different patients to build targeted training scenarios. The serious game REHAB FUN VR environment developed with the Unity engine helps children with cerebral palsy improve their motor and cognitive abilities [21]. A novel, 3D, customizable, personalized home eXErgames for Rehabilitation system was introduced to rehabilitate stroke patients [22]. The next generation BrightArm Compact (BAC) rehabilitation table and its novel game controllers were designed for ambidextrous training, forward/backwards rotation, grip strengthening, and finger extension [23]. The Oculus Rift DK2 and a motion tracking system were used for upper limb rehabilitation [24]. VR for rehabilitation was found to be effective in incentivizing patients and maintaining a high level of patient compliance, matched with the abundant training scenarios of the reward and punishment mechanism [25]. In addition to providing adequate scenarios, the application of VR technology also enhances the potential for neuroplasticity in the rehabilitation process [26].

4. Analysis of Research Topics on the Application of VR in Rehabilitation Medicine

As seen from the keyword clustering and topic evolution, VR is mainly applied in rehabilitation medicine in the areas of neurological rehabilitation, psychological treatment, pain distraction, cardiopulmonary rehabilitation, and visual spatial disorders. In this paper, the research themes are summarized into the following five dimensions for review.

4.1. Neurological Rehabilitation

Neurological rehabilitation mainly focuses on the rehabilitation of motor, sensory, speech, swallowing, cognitive disorders and other dysfunctions caused by neurological diseases, involving conditions such as stroke, cognitive disorders, Parkinson's disease, traumatic brain injury, vestibular rehabilitation, and neurological rehabilitation in children, as shown in Table 2. VR technology has incomparable advantages in neurological rehabilitation and is one of the directions to which VR has been applied most in rehabilitation.

Table 2. Research on the application of VR in neurological rehabilitation.

Type of disease	**Conclusions**	Literature
Stroke	The immersive experience and interactivity of VR can stimulate patients' active cooperation and improve patients' cognitive and psychological states.	[27–29]

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	VR technology can help stimulate stroke patients to regain limb function.	[30,31]
	Conversational therapy in the VR environment is useful for language recovery in post stroke aphasia patients.	[32,33]
Geriatric Cognitive Impairment	Virtual-reality-based cognitive training (VRCT) enhances the brain, cognitive and physical health of older adults with MCI and is more effective than traditional therapies.	[34,35]
Parkinson's Disease	VR improves the cognitive function, learning, and memory of Parkinson's patients.	[37–39]
	VR has a significant effect on motor rehabilitation in Parkinson's patients.	[40–42]
Traumatic brain injury	VR improves cognitive and behavioural abilities in patients with Traumatic brain injury (TBI).	[43,44]
Vestibular Rehabilitation	Regular and frequent application of visual stimulation has a positive effect on the vestibular adaptation mechanism.	[45,46]
Neurological Rehabilitation in Children	Rehabilitation intervention based on VR improved the cognitive function of children with hemiplegic cerebral palsy (HCP).	[49–51]
	VR intervention for children with dyslexia improves treatment outcomes.	[52]

4.1.1. Stroke rehabilitation

Stroke is one of the most serious neurological diseases. The immersive experience and interactivity of VR can increase the efficiency of stroke rehabilitation training and stimulate patients' active cooperation.

In terms of improving cognitive function in stroke patients, immersive VR environments can improve the psychological state of post stroke patients, especially anxiety symptoms [27,28] and can effectively reduce the time patients spend in the hospital [29].

In terms of restoring limb function, studies have shown that the addition of VR technology to conventional physiotherapy (CP) procedures resulted in significant improvements in balance and motor function over CP-treated stroke patients [30]; combining virtual reality (VR) therapy and mirror therapy (MT) exercises has the potential to replace traditional physiotherapy in the rehabilitation of lower limbs after stroke [31].

Additionally, virtual reality is considered to be an effective adjunctive therapy for enhancing functional recovery of verbal ability in post stroke aphasic patients [32], and VR applications specialized in verbal rehabilitation in aphasic patients have been developed [33].

4.1.2. Geriatric Cognitive Impairment

Mild cognitive impairment (MCI), also referred to as the predementia stage, is one of the most common cognitive dysfunctions seen in the elderly population. Studies suggest that virtual reality-based cognitive training (VRCT) can enhance brain, cognitive, and physical health in older adults with MCI [34]. VR-based cognitive-motor rehabilitation (VRCMR) can increase subjects' interest and motivation for training with the purpose of increasing training participation [35], resulting in greater improvement in the areas of visual-spatial perception, visuomotor organization, orientation, thinking operation, and attention/concentration than the conventional cognitive rehabilitation (CR) intervention group [36].

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4.1.3. Parkinson's Disease

VR has also been proven to be effective in the cognitive and motor rehabilitation of Parkinson's disease. The effect of the corresponding VR cognitive application or training system on the cognitive and behavioral recovery of patients with Parkinson's disease was able to exercise their memory, executive functions, attention, logical thinking, and speed of thought, thus improving their cognitive functions in terms of executive and visuospatial abilities [37,38]. Furthermore, patients with Parkinson's disease showed learning or retention of performance improvements after Nintendo Wii Fit™ training [39].

The effect of VR on motor rehabilitation of patients with Parkinson's disease is also evident. Virtual reality and motion picture training combined with conventional physiotherapy can remarkably improve resting tremor, rigidity, posture, gait, and slow body movements in Parkinson's patients [40]. A commercial wearable head-mounted display (HMD) combined with the VR motion game is useful for rehabilitation work in a variety of settings for mild to moderate Parkinson's patients. A boxing exergame combined with a wearable commercial HMD is a suitable physical activity for PD and its applicability in different environments [2]. Nonimmersive virtual reality exercise games can enable older Parkinson's patients to effectively improve gait and balance through virtual reality exercise games [41] and can be conducive to increasing patients' confidence and mobility [42].

4.1.4. Traumatic brain injuries

Traumatic brain injury (TBI) is a devastating injury that can lead to deficits in multiple domains. In addition, virtual reality combined with treadmill training is safe and feasible for patients with TBI, and those who participated in VR balance interventions represented greater enjoyment of training compared to those who participated in conventional therapeutic approaches and those who just used a treadmill [43]. Meanwhile, the combination of VR training resulted in greater improvement in patients' cognitive performance [44].

4.1.5. Vestibular Rehabilitation

Motion sickness (MS) can be triggered by direct or indirect stimuli due to mismatches in the visual-vestibular autonomic pathways. VR proved to be significantly effective and useful for MS rehabilitation. According to the study, regular and frequent application of visual stimulation with VR games for MS patients has a positive influence on vestibular adaptation mechanisms [45], improving dizziness, balance, gait, effects of fatigue, quality of life, and muscle tone [46]. It is evident that immersive virtual reality vestibular training programs provide a more enjoyable rehabilitation manner [47], increasing the efficiency of the process and reducing the risk of inadaptability to exercise.

4.1.6. Neurological Rehabilitation in Children

Virtual reality technology provides immersive training content that is both appealing to children and effective in some neurological disorders in children, such as cerebral palsy and children with dyslexia. The study demonstrated the feasibility, safety, and initial efficacy of VR-based interactive cognitive training (VICT) systems for executive function rehabilitation in children with TBI [48]. VR-based rehabilitation increased hemiplegic cerebral palsy (HCP) children's cognitive functions, such as orientation, spatial perception, praxis visuomotor construction, and thinking operations [49], and significantly improved the reaction time of children with cerebral palsy [50]. The Horse-Riding Simulator (HRS) with virtual reality (VR) is an effective adjunct to the rehabilitation of children with spastic cerebral palsy, which has an excellent effect for the rehabilitation of children with spastic cerebral palsy (CP) in terms of gross motor function and balance control [51]. Moreover, a virtual reality rehabilitation system (VRRS) can prolong the training time and improve the treatment compliance of children with dyslexia [52].

4.2. Psychological Treatment

VR provides a secure environment for patients to experience and explore freely. Patients' various perceptual activities, such as vision, hearing, and touch, as well as emotional reactions, such as joy, sadness, tension, and fear, will be fully expressed. These technical features of VR are well suited for psychological treatment (Table 3).

Table 3. Research on the application of VR in psychological treatment.

Type of disease	Conclusions	Literature
Autism spectrum disorder	VR technology for rehabilitation benefits the cognitive development and social communication skills of children with ASD	[53,54]
Depression	Immersive VR therapy is an effective nonpharmacological intervention for post stroke depression	[55–57]
Schizophrenia	Multi-Modal Adaptive Social Intervention for VR (MASI-VR) offers a pathway to recovery for patients with schizophrenia	[58–60]

In autism spectrum disorder treatment, VR is a useful and promising tool to improve the cognitive function of individuals severely affected by autism spectrum disorder [53]. The application of virtual reality technology can intervene and encourage cognition, imitation, and social interaction in children with autism spectrum disorders, and VR technology-based rehabilitation benefits the cognitive developmental abilities and social communication skills of children with ASD [54].

In the treatment of depression, VR therapy integrated with neurological rehabilitation has a positive effect on improving mood and reducing depressive symptoms in post stroke patients [55], and a feasible plan for the treatment approach has been published [56]and is considered to be an effective nonpharmacological intervention for post stroke depression [57].

In schizophrenia treatment, multimodal adaptive social interventions in virtual reality are feasible and acceptable in improving social functioning and clinical outcomes in patients with schizophrenia [58]. For example, a cinematic virtual reality-based application, cinematic VR, has shown satisfying acceptability in patients with schizophrenia [59]. A virtual reality-based vocational rehabilitation training program developed for schizophrenic patients can improve general psychosocial functioning and memory in schizophrenic patients [60].

4.3. Pain Rehabilitation

VR has been used for pain distraction in a wide variety of known painful medical procedures. For example, Oculus Rift VR goggles can assist in pain control in the occupational therapy of pediatric burn patients and can be used for pain distraction in the rehabilitation of children with burns [17]. Additionally, VR can be used as a powerful nonpharmacological pain reduction technique for adult burn patients during physical therapy and potentially for other painful procedures or painful populations [61]. For young children with burns, the employment of VR during physical therapy is more enjoyable and may allow them to experience less anxiety [62].

4.4. Cardiopulmonary Rehabilitation

Medical services in cardiopulmonary rehabilitation have been successfully carried out through virtual reality technology, and the specific applications are shown in Table 4.

Table 4. Research on the application of VR in cardiopulmonary rehabilitation.

Type of disease	Conclusions	Literature
Cardiovascular rehabilitation	Virtual reality (VR), as a supplementary tool of traditional cardiac rehabilitation (CR) program, plays a positive role in treatment.	[63,64]

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Lung rehabilitation	VR rehabilitation therapy can improve patients' lung function, cognitive function and exercise tolerance.	[65]
COVID-19 treatment	VR intervention offers a differentiated form of intervention that positively affects people being treated with COVID-19.	[66,67]

In cardiovascular rehabilitation, VR, as an assistant tool to conventional cardiac rehabilitation (CR) programs, performed well in compliance and satisfaction in patients with stage II ischemic heart disease compared to the conventional treatment group [63]. The use of exercise games adding virtual reality therapy in cardiac rehabilitation patients led to higher scores in heart rate, respiratory rate, and perceived exertion scores during their performance and at 5 minutes after treatment [64].

In lung rehabilitation, VR-based pulmonary rehabilitation training can effectively improve lung function, cognitive function, and exercise tolerance and reduce the symptoms of dyspnea and the efficiency of medication in elderly chronic obstructive pulmonary disease (COPD) patients with mild cognitive dysfunction (MCI) [65].

Rehabilitation was a critical aspect of healthcare systems during the COVID-19 pandemic; COVID-19 survivors suffered from reduced lung function, critical illness polyneuropathy and myopathy, and cardiorespiratory deconditioning. Therefore, it is important to prepare new interventions that allow healthcare providers to maximize responses to rehabilitation challenges. VR can provide a differentiated form of intervention during hospitalization for COVID-19, and virtual reality software can have a positive impact on the motivation and engagement of those being treated with COVID-19 compared to conventional physical therapy interventions. In addition to in-hospital treatment, cognitive rehabilitation can also be delivered through a remote rehabilitation modality in conjunction with VR [66]. The study indicated that VR-based rehabilitation improves exercise tolerance and reduces anxiety and depressive symptoms in COVID-19 patients [67].

4.5. Spatial Neglect

VR also shows benefits for improving patients' spatial neglect (SN) and is an effective way to improve visual field recovery, spatial cognition and mood in patients with unilateral spatial neglect after stroke [68]. Satisfactory therapeutic effects can be obtained by using virtual reality in 3D space to examine and treat unilateral spatial neglect [69]. In addition, the immersive and modifiable aspect of VR to translate Musical Neglect Therapy (MNT) to a VR therapy tool can increase the patient's enjoyment of the treatment [70].

5. Challenges and future trends

The rapid progress of VR technology has opened a new vision for clinical rehabilitation treatment by providing a new means of rehabilitation, higher treatment compliance and better patient management in a hospital or home environment, with better efficacy for a wide range of diseases. It is foreseeable that the application of VR technology will be an important direction for the future development of rehabilitation treatment. At present, some results have been achieved in the research of VR technology in rehabilitation, but there are still many issues that must be solved by rehabilitation experts and engineering experts. Therefore, this paper presents the following challenges and future perspectives, taking into account the current hotspots and topic evolution development.

5.1. Current Challenges

5.1.1. VR-induced motion sickness

Current VR technology generates VR environments mainly through large projection screens or head-mounted displays. Due to the inconsistency between visual and physical perceived motion, visually induced motion sickness may occur, with patients presenting with symptoms such as headache, sweating, nausea, vomiting, fatigue and disorientation, and may also cause safety issues

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and other health problems. Motion sickness is the main obstacle to overcome with current immersive VR technology.

5.1.2. VR-Dependent Mental Disorders

A fully immersive VR environment can easily cause the juxtaposition of perception and hallucination, blurring the boundary between reality and hallucination. When users are happy with the virtual environment and interpersonal interactions, overly dependent on VR companions, or their nerves are connected to the VR world, they lose themselves, ignore real-world problems and real interpersonal relationships, and then generate mental disorders, which makes VR no different from electronic drugs, which require a reasonable training schedule and attention to training content.

5.2. Future Prospects

5.2.1. Improving User Experience

At this stage, the sensitivity of most sensors cannot fully meet the rehabilitation needs of patients. It is expected that researchers will develop a full range of somatosensory VR products as soon as possible that can give users a full-body experience and contain the senses of touch, hearing, smell and taste. Meanwhile, researchers need to pay attention to how to reduce the discomfort of users' experience, increase their emotional experience and regulate their emotions, making the virtual environment and the real environment achieve a seamless connection. In addition, VR rehabilitation products also aim to create a virtual entity that integrates initiative, responsiveness, autonomy, sociality, mobility, and adaptability to meet the various needs of patients in terms of movement, speech, emotion, and social interaction.

5.2.2. Develop standardized guidelines

Currently, the application of VR technology in rehabilitation lacks more standardized treatment guidelines to guide the development of VR rehabilitation programs. More research, especially randomized controlled trials, is still needed in the future to confirm the effectiveness of VR rehabilitation programs.

5.2.3. Conduct more high-quality clinical studies

Owing to the high cost of VR equipment, the existing clinical application studies generally have a small sample size of subjects, and there is variability in the effects of patients applying VR technology; thus, the rehabilitation training conditions are unclear, and the effectiveness of clinical application is still expecting more high-quality studies.

6. Conclusion

This paper presents a bibliometric analysis of research on the application of VR in rehabilitation medicine. The main work and findings are represented in the following aspects.

Through the analysis of the time distribution graph, this paper identifies trends in the research output of the application of VR in rehabilitation medicine. From the initial exploration of how to use virtual reality in rehabilitation, research on the application of VR in rehabilitation medicine has continued for 28 years and has received increasing attention from researchers. Especially after 2011, the literature has grown dramatically, and a large number of research results have been achieved.

The distribution of this research in the world was confirmed through the analysis of national collaboration networks. The United States, Italy, Canada, Spain and China are the major countries for research on the application of VR in rehabilitation medicine, while the United States exceeds other countries in terms of number and influence. Globally, the proportion of multinational and cross-regional collaborations in research on the application of VR in rehabilitation medicine is increasing, and the research is gradually becoming more specialized, comprehensive, and holistic.

Through keyword coword timeline network sorting out and analysis, we find the core literature and topic evolution paths of research on the application of VR in rehabilitation medicine. This paper divides research on the application of VR in rehabilitation medicine into three stages: the exploration stage, the development stage, and the promotion and application stage. The research content of each stage is related to the technological development at that time.

A thematic review of research on the application of VR in rehabilitation medicine was summarized by analysing the keyword coword network. The hotspots of research on the application of VR in rehabilitation medicine are diverse. The research themes in several areas of neurological rehabilitation, psychological treatment, pain distraction, cardiopulmonary rehabilitation, and visual spatial disorders all reflect the main focuses of research on the application of VR in rehabilitation medicine.

Finally, this paper presents the current challenges and future prospects for the application of VR in rehabilitation medicine. Overcoming VR technology-induced vertigo and mental disorders from excessive VR use are both challenges for research on the application of VR in rehabilitation medicine. Furthermore, developing VR products with better experience, developing standardized guidelines and conducting more high-quality clinical studies are all future research trends for the application of VR in rehabilitation medicine.

This paper systematically sorts and summarizes the relevant research on the application of VR in rehabilitation medicine and provides references for future practice and exploration in this field. However, this paper also has limitations. Only the literature in the WOS core dataset was searched and analysed; thus, the data sample was not comprehensive. The next study will expand the scope of the literature for a more comprehensive analysis.

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