

Virtual Reality-Based Vestibular Rehabilitation Therapy: A Scoping Review

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ABSTRACT

Introduction: Virtual reality (VR) technologies have been increasingly developed to support vestibular rehabilitation therapy by providing immersive and interactive environments that enhance patient engagement, improve therapeutic outcomes while ensuring patient safety. This scoping review aims to identify and compare the various types of VR-based vestibular rehabilitation approaches currently available. **Methods:** A scoping review was conducted following the Joanna Briggs Institute (JBI) framework to explore and compare distinct VR-based vestibular rehabilitation methods. Studies were included if they utilized VR in vestibular rehabilitation, were published in English between 2012 and 2022, and were available in full text. Searches were performed across electronic databases including PubMed, ScienceDirect, and ProQuest. Relevant data from the selected studies were summarized descriptively. **Results:** A total of nine studies met the inclusion criteria, comprising one observational study and eight experimental studies. Three primary categories of VR devices were identified: head-mounted displays, force plate systems, and hybrid VR setups. These devices were used to deliver vestibular rehabilitation interventions across various protocols and settings. **Conclusion:** All included studies reported that VR-based vestibular rehabilitation was effective and well-tolerated, despite notable differences in intervention procedures and outcome assessments. A systematic review is recommended to further evaluate the comparative effectiveness of VR-based versus conventional vestibular rehabilitation therapies.

Keywords:

Scoping review; virtual-reality; vestibular rehabilitation

INTRODUCTION

Vestibular Rehabilitation Therapy (VRT) is a specific exercises designed to improve symptoms (such as dizziness, vertigo, imbalance, gaze instability, and difficulties with daily activities) caused by vestibular organ dysfunction. VRT integrates physical exercises with multisensory stimulation to improve balance and reduce symptoms in adults (Alahmari et al., 2014). It is considered a safe and effective therapeutic approach, leveraging central neuroplastic mechanisms, which are adaptation, habituation, and substitution, to enhance postural stability and visual-vestibular integration, particularly in environments with conflicting sensory inputs (Lee et al., 2020). This, in turn, contributes to improved self-confidence and quality of life for affected individuals.

However, conventional VRT often requires patients to perform repetitive exercises for 20–40 minutes daily, which can be perceived as monotonous (Herdman, 2007, as cited in Rosiak et al., 2019). Additionally, patients may struggle to receive adequate feedback when training independently at home (Rosiak et al., 2019). These limitations have prompted interest in virtual reality (VR) technologies as a promising alternative for home-based rehabilitation.

VR is a widely adopted method for creating interactive, computer-generated simulations of real-world environments, using various display formats such as spherical screens, flat monitors, or head-mounted displays (HMDs) (Rosiak et al., 2019). Several VR systems have been applied in vestibular rehabilitation, including the Nintendo Wii Fit (which uses a force plate), treadmill-based simulations in virtual environments, and immersive HMD-based setups. Unlike traditional equipment, these VR platforms incorporate gamified elements that enhance enjoyment, focus, and patient adherence (Song, 2019). Moreover, VR provides real-time feedback and offers a more engaging and enriched therapeutic experience compared to conventional methods (Dara et al., 2012).

Although early VR systems were limited by high costs and space requirements, recent advancements have led to the development of affordable and compact devices—such as the Wii balance board and HMDs—that have demonstrated promising results and are increasingly viable for widespread rehabilitation use (Song, 2019).

While numerous studies have compared conventional and VR-based vestibular rehabilitation, few have focused specifically on the distinct types of VR technologies employed. Although the effectiveness of VR-based interventions has been well-documented (e.g., Alahmari et al., 2014; Meldrum et al., 2015), the diversity of VR

devices—such as head-mounted displays, force plate systems, and hybrid VR setups—warrants closer examination. Therefore, this study aims to identify and compare the distinct types of virtual reality-based vestibular rehabilitation currently available.

MATERIALS AND METHODS

Study Design

A scoping review was conducted for this study to identify and compare the distinct types of virtual reality-based vestibular rehabilitation. This study follows the updated scoping review framework from the Joanna Briggs Institute (JBI), introduced by Peters and colleagues in 2020. Their approach provides a clearer and more structured way to carry out scoping reviews, making the process more comprehensive and reliable. This framework includes; 1. Define objective and research questions, 2. Develop inclusion and exclusion criteria, 3. Data searching, 4. Data selection, 5. Data extraction, and 6. Data analysis.

Criteria of Study Characteristics

Any studies available in full text, written in English, published between 2012 and 2022, and involving VR-based vestibular rehabilitation were included. All study designs that provided a quantitative evaluation of virtual reality-based vestibular rehabilitation programs (e.g., randomized controlled trials, non-randomized controls, cohort studies, case-control studies, cross-sectional studies, and pre-post studies) were considered. The studies also needed to include therapeutic evidence and be specifically designed for patients with central or peripheral vestibular disorders. Studies focusing solely on augmented reality technology, those in the developmental phase of virtual reality-based vestibular rehabilitation, and review articles were

excluded.

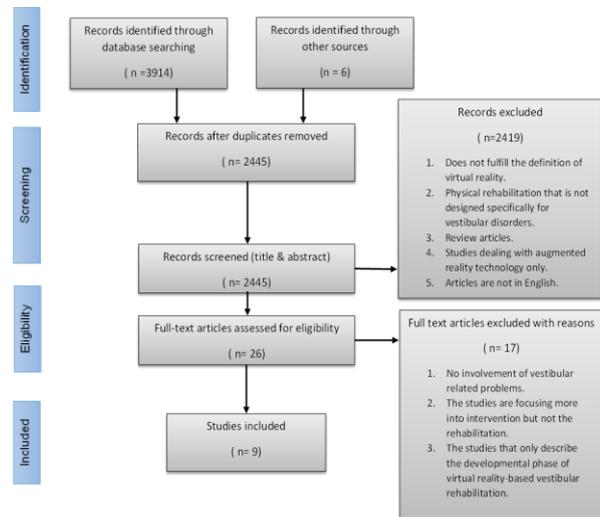


Figure 1: PRISMA flow diagram

Data Searching

Three electronic databases (i.e.; Pubmed, ScienceDirect, and ProQuest) were utilized for the searching of the related studies. The searches were performed using free-text keywords and combining keywords with Boolean operators which are “AND” and “OR” to identify the relevant studies. The search keywords are categorized into three blocks; “virtual reality” (block 1), AND “vestibular” (block 2), AND “rehabilitation therapy” (block 3) (refer to Table 1). A manual search through the reference list of identified articles was also conducted.

Table 1: Search Keyword and Boolean operator. The keyword group is combined by “AND”

| Block | Block 1 | Block 2 | Block 3 |
|----------|-------------------------------------|--------------------------------|--|
| | Virtual reality is combined by “OR” | Vestibular is combined by “OR” | Rehabilitation therapy is combined by “OR” |
| Keywords | Virtual reality Simulation | Vestibular Balance | Rehabilitation therapy Physical therapy Exercise program |

Data Selection

The identified articles underwent three stages of screening. First, the main author screened the title and removed any duplicates of studies. The full text of selected articles was obtained and reviewed for eligibility. Next, articles were reviewed independently by two independent reviewers who are the team members of this study. Only eligible articles that met the inclusion criteria were selected. Any disagreement between the two reviewers was discussed and solved by the second co-author. The process of selecting articles was summarized on a PRISMA flow diagram (Figure 1).

RESULTS

A total of 3,914 articles were identified through electronic database searches, with an additional six articles retrieved from reference lists of related studies. After removing duplicates, 2,445 articles remained for title and abstract screening. Of these, 2,419 were excluded, leaving 26 articles for full-text review. Ultimately, nine articles met the inclusion criteria and were included in the final analysis. Figure 1 illustrates the search and selection process, along with reasons for exclusion.

Study Characteristics

Among the nine studies reviewed, one was an observational prospective study, while the remaining eight were experimental in design (randomized controlled trials and pre-post studies). Specifically, seven studies employed randomized controlled trials (Garcia et al., 2013; Meldrum et al., 2015; Eftekharsadat et al., 2015; Anson et al., 2018; Viziano et al., 2019; Stankiewicz et al., 2020; Sessoms et al., 2021). The other two studies included one pre-post study (Alahmari et al., 2014) and one prospective observational study (Rosiak et al., 2019).

In total, 378 subjects were involved in the selected studies. Number of subjects ranged from 20 to 71 individuals with number of subjects for each group range between 10 and 36 individuals. The age range of the subjects were from 18 to 92 years. Due to a lack of information in the texts, other demographic data could not be extracted from the studies examined. The following data is based solely on patients with vestibular disorders who have undergone virtual reality rehabilitation. There are five studies (56%) that focused on the subjects with peripheral vestibular disorders only (Garcia et al., 2013; Meldrum et al., 2015; Viziano et al., 2019; Rosiak et al., 2019; Stankiewicz et al., 2020), two studies (22%) that involved the subjects with central vestibular disorders (Eftekharsadat et al., 2015; Sessoms et al., 2021), and the other two (22%) of the reviewed studies included both subjects with peripheral and central vestibular disorders (Alahmari et al., 2014; Anson et al.,

2018).

Types of Virtual Reality Devices

Across these studies, three main types of devices were used to deliver virtual reality: head-mounted devices (HMD) (Viziano et al., 2019; Stankiewicz et al., 2020), force plate systems (Alahmari et al., 2014; Meldrum et al., 2015; Eftekharsadat et al., 2015; Anson et al., 2018; Sessoms et al., 2021), and hybrid VR devices (Garcia et al., 2013; Rosiak et al., 2019). Of the nine studies, five studies (56%) utilized force plate devices, while head-mounted and hybrid VR devices each accounted for two studies (22% each). Notably, among the studies using force plate technology, three different systems were employed: a treadmill (Alahmari et al., 2014; Anson et al., 2018; Sessoms et al., 2021), the Biodex Balance System SD (Eftekharsadat et al., 2015), and the Nintendo Wii Fit Plus (Meldrum et al., 2015).

Virtual Reality Technologies and Protocols in Rehabilitation Approaches

Table 2 presents a comparative overview of various studies employing virtual reality (VR) devices for rehabilitation. It categorizes the devices into head-mounted, force plate, and hybrid systems, each offering unique features and therapeutic approaches. Head-mounted devices, such as VR goggles and cockpit-style games, focus on immersive visual experiences and are often used in both clinical and home settings. Force plate devices, including systems like the Nintendo Wii Fit Plus and Biodex Balance System, emphasize balance training through interactive feedback and motion tracking. Hybrid devices combine multiple technologies—such as force platforms, motion sensors, and VR goggles—to deliver comprehensive rehabilitation programs that target postural control and sensory integration.

Across the studies, rehabilitation durations vary from short daily sessions to extended weekly programs over several weeks. Procedures range from supervised clinical exercises to home-based protocols, often involving gamified tasks to enhance engagement. The features of each system are tailored to simulate real-world scenarios (e.g., grocery shopping or rollercoaster rides) or provide visual feedback for motor control. Overall, the table highlights the diversity in VR rehabilitation strategies, showcasing how different technologies and protocols are adapted to meet specific therapeutic goals.

Table 2. Summary of virtual reality-based rehabilitation studies, outlining types of VR equipment, therapy duration, features, and procedures.

| Author(s) Year | Types of virtual reality device | Duration of rehabilitation | Features | Procedure |
|---------------------------|--|---|---|--|
| Viziano et al. (2019) | Head-mounted device | (i) Supervised session in the clinic: twice a week for 4 weeks for 30-45 min. (ii) At home: twice daily for 30-40 min. | The Track Speed Racing 3D game featured a point-of-view race in which the car was handled from the cockpit by tilting the head to the left and right to avoid drifting off the road and to accomplish all of the missions before the lap was completed. | Each patient was instructed to sit on a chair or sofa and complete the gaming protocol uninterrupted. |
| Stankiewicz et al. (2020) | Head-mounted device: New generation VR goggles based on Google Cardboard platform. | Five therapy sessions for five consecutive days with two sessions of 5-minutes with 5-minute intervals. | The VR goggles were utilized to simulate a rollercoaster ride. | Patients participated in the exercises under medical supervision. They will experience the simulation of a rollercoaster ride through the VR goggles. |
| Alahmari et al. (2014) | Force plate device: Treadmill and virtual grocery store displayed in an immersive environment | 1 session per week for 6 weeks, each session lasted for 1 hour. | Grocery store scene was displayed on three screens that surrounded the subject in a full-field immersive visual environment. The store contained 16 aisles and had eight levels of visual complexity. | Patients are required to walk on a treadmill as if they were in a virtual grocery store, and traveling through the aisles during each treatment session. While ambulating, the therapists will instruct the patients to locate products on the shelf, and the patients will verbally answer when they located the product. |
| Meldrum et al. (2015) | Force plate device: Nintendo Wii Fit Plus (NWFP) | 15-minute daily for 6 weeks | The NWFP combines an accelerometer and a force plate (Wii Balance Board) to provide visual and auditory feedback of subjects' centre of pressure during virtual reality exercises and games. | The subjects were loaned one NWFP for use at home along with a standardized weekly booklet that will detail their exercises and include an adherence diary. The subjects performed a daily rehabilitation programme. |
| Eftekharsad et al. (2015) | Force plate device: The Biodex Balance System SD | Twice a week for 12 weeks, each session lasted for 20 minutes | The system simulates specific movement patterns or strategies by placing marks on specified positions on the screen grid. | The subjects attempted to touch targets nine times in each session using an on-screen cursor that was manipulated by the subjects' legs on the device's platform. The stability of the platform was set to 6 (moderately stable). |
| Anson et al. (2018) | Force plate device: Trunk motion visual feedback | 3 times per week for four weeks, each session lasted for 30 minutes | The VFB device featured 10 rings of the bull's-eye that was one inch wide and corresponded to one inch of physical space on the treadmill. Two | The subjects were introduced on how to interact with both forms of trunk motion VFB during the first training |

| | | | | |
|-----------------------|--|--|--|--|
| | (VFB) during treadmill walking | | webcams tracked the 3-D position of the three markers (at the navel, and each shoulder) | session. They were provided a brief training session and displayed the ability to keep the cursor "as close to the center of the bull's-eye as possible," with minimal displacement or angular deviations. |
| Sessoms et al. (2021) | Force plate device: CAREN system that comprises of an instrumented treadmill | 30 minutes twice a week over a 6-week period | The system comprises of an instrumented treadmill embedded on a platform that can move in six degrees of freedom. The platform is surrounded by a panoramic screen that immerses participants in a VR scenario. | The subject involved in a static stance by shifting the centre of mass to the limits of stability and facilitating weight shifting. Then, they engaged with the pitch and roll of the motion platform changes during dynamic tasks like walking to follow the virtual terrain. |
| Garcia et al. (2013) | Hybrid VR devices: A Balance Rehabilitation Unit (BRU) | 45 minutes twice a week for a total of 12 sessions | The equipment includes a computer with the test's program, a safety metal frame, protection support with straps and belts, a force platform, virtual reality goggles, an accelerometer, and foam cushions. Three modules were included: posturography, body balance rehabilitation, and postural training games (PTG). | Patients were instructed to stand in an orthostatic position without moving their upper limbs, heels, or feet for 60 seconds in order to assess each of the ten sensory conditions. A foam cushion of medium density was used in the third test condition. Virtual reality goggles were used from the fourth to the tenth condition. |
| Rosiak et al. (2019) | Hybrid VR devices | Ten 30-minute training sessions over the course of two weeks | A hybrid VR equipment comprising a force plate, an upper-body motion sensor, and a central unit with a flat-screen display. The software comprises 8 balance exercises with 28 difficulty levels that gradually escalate from a predetermined starting point based on the patient's performance. | Patients conducted a set of exercises coordinating upper body movement and maintaining the centre of pressure (COP) in a pre-set range or shifting the COP towards indicated positions while standing 1.5–2 metres from the display on the force plate. The exercise protocol comprised of two tasks: eliminating Meteorites from the outer space and placing hats on hangers with matching colours. |

DISCUSSION

This scoping review indicates that the implementation of virtual reality (VR) in vestibular rehabilitation is a promising approach, supported by an increasing number of studies exploring various VR devices. Across the reviewed studies, patients consistently demonstrated symptom improvement, with vertigo-related handicap

scores generally shifting from moderate to mild following VR-based interventions. For example, Viziano et al. (2019) reported significant improvements in vestibulo-ocular reflex, static posture, and functional performance during follow-up assessments in patients with unilateral hypofunction using head-mounted display (HMD) technology. Similarly, other studies documented enhanced balance control and gait stability when VR

systems incorporated force plate technology or hybrid VR devices, offering immersive environments that may increase patient engagement while maintaining safety compared to conventional settings. These findings suggest that VR-based rehabilitation not only provides an interactive experience but also delivers measurable functional benefits. Nevertheless, further research is needed to standardize protocols and determine the most effective and cost-efficient strategies for clinical implementation.

Sessoms et al. (2021) highlighted the advantages of incorporating a treadmill into virtual reality (VR)-based vestibular rehabilitation, as it enables objective analysis of functional responses such as gait mechanics and postural control. In their study, participants demonstrated measurable improvements in gait symmetry and stability, which provided clinicians with actionable data to tailor training to individual patient needs. Additionally, VR treadmill training allowed subjects to practice life-like scenarios in a safe environment, which was associated with increased confidence in returning to daily activities. VR devices also offer feedback systems—such as force plate technology, head-mounted displays (HMDs), and hybrid VR platforms—that facilitate motor learning. Schmick and Lee (2005) reported that feedback combined with repetitive practice can significantly enhance motor learning, supporting the theoretical basis for VR interventions. These features present substantial opportunities for therapists to monitor progress and optimize patient outcomes. Despite these promising findings, further research is needed to define optimal training parameters, establish standardized protocols, and identify cost-effective strategies for implementing VR-based vestibular rehabilitation.

The outcome measures used across the analyzed studies varied considerably, encompassing both self-report and performance-based assessments. This variability highlights the need for more rigorous and standardized evaluation methods in future research. For instance, the Dizziness Handicap Inventory (DHI), a widely recognized and easy-to-administer tool for assessing vestibular disorder-related handicaps (Jacobson & Newman, 1990), was not applied consistently; only five studies utilized DHI (Garcia et al., 2013; Alahmari et al., 2014; Eftekharsadat et al., 2015; Viziano et al., 2019; Sessoms et al., 2021). While multiple scales and questionnaires exist, adopting standardized tools such as the DHI would enhance comparability across studies. Additionally, the Vestibular Rehabilitation Benefits Questionnaire (VRBQ) may be considered, as it is specifically designed to measure changes in symptoms and quality of life between rehabilitation sessions (Morris et al., 2008). Establishing consensus on core outcome

measures will be essential to improve the rigor and interpretability of future VR-based vestibular rehabilitation research.

From a practical perspective, the amount of time spent in virtual reality-based training and the number of sessions is the most crucial component in increasing the therapeutic effect. It is noteworthy that all the selected studies implemented variety of rehabilitation duration per session which the minimum recorded was 15 minutes, up until 60 minutes per session. Surprisingly, Bergeron et al. (2015) reported that, current meta-analysis appeared to show that the amount of time spent in VR-based therapy was more important than the number of sessions in determining average efficiency. According to the findings, a minimum of 120–150 minutes of exposure time is required to identify a meaningful improvement for the patient. These findings suggest that longer sessions, even with fewer appointments, may be both effective and convenient. However, session duration should be tailored to the patient's physical condition and tolerance to ensure safety and maximize benefit.

One of the strengths of this review is that the studies addressed at a wide range of patients with vestibular disorders which includes peripheral, central, or mixed that are similar to those seen in clinical settings. Virtual reality environments are incredibly beneficial for a variety of diseases. However, one of the possible limitations of implementing VR-based vestibular rehabilitation is the related cost of utilizing such protocols as clinical tools. This could be a major issue against the execution of virtual reality settings in clinical settings if there are crucial attempts of cost reductions in the health care system (Bergeron et al., 2015). Nevertheless, very positive outcomes have been demonstrated with affordable prices such as a Nintendo Wii which was studied by Meldrum et al. (2015). Another limitation that may limit the execution of virtual reality-based vestibular rehabilitation is cybersickness. This condition may occur if there is an exposure to interactive virtual environments that can cause discomfort during or after the session due to unnatural and conflicting multisensory stimuli (Bonalo et al., 2009; Nolin et al., 2012; Kiryu & So, 2007 as cited in Bergeron et al., 2015). According to Nolin et al. (2012), motion sickness-like, including nausea, vomiting, headache, somnolence, loss of balance, and altered eye-hand coordination are among the symptoms reported by the subjects.

Limitation of the study

There are several limitations noted in this review. In terms

of inclusion criteria, it was restricted only to include studies that were published in English and within the last 10 years, which was from 2012 to 2022 as it was aimed to review the most recent technology of virtual reality devices that have been utilized in vestibular rehabilitation therapy. Other languages especially from non-English speaking countries may be considered in future review studies whereby there are possibilities of other types of virtual reality-based vestibular rehabilitation therapy.

CONCLUSION

There are nine studies discovered with distinct types of virtual reality devices and all the rehabilitation procedures demonstrated the promising potential of virtual reality-based rehabilitation for vestibular disorders. Despite major variances in procedure and result evaluation, all studies showed that virtual reality-based rehabilitation methods were effective and well-tolerated. The overall time spent in virtual reality training is the most important parameter for predicting treatment success and the amount of symptom reduction. To sum up, some recommendations for future research are proposed, including standardizing intervention protocols and evaluation tools, documenting side effects, and determining if virtual reality-based rehabilitation should be integrated with conventional rehabilitation. A systematic review is recommended to examine the effectiveness of virtual reality-based vestibular rehabilitation therapy compared to conventional vestibular rehabilitation.

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