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Visual Vertigo and Vestibular Rehabilitation Therapy: Optokinetic Stimulation and Virtual Reality-Based Rehabilitation

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Abstract

Background: Visual vertigo is a condition in which patients experience dizziness, unsteadiness, disorientation and imbalance in visually complex or moving environments. It is closely related to visual-vestibular mismatch, where the brain over-relies on visual cues over vestibular and proprioceptive cues. Vestibular rehabilitation therapy aims to reduce dizziness and improve gaze stability, postural control and daily function. Optokinetic stimulation and virtual reality are important rehabilitation approaches because they provide graded exposure to provocative visual motion and real-life visual environments.

Aim: This review article aims to summarize the essential points from the chapters on visual vertigo and vestibular rehabilitation therapy, focusing on the definition, mechanisms, clinical manifestations, assessment and rehabilitation of visual vertigo using optokinetic stimulation and virtual reality-based approaches.

Conclusion: Visual vertigo represents a disabling manifestation of visual-vestibular mismatch and visual dependence. Clinical evaluation depends mainly on history, symptom triggers and questionnaires. Vestibular rehabilitation, especially customized visual desensitization, optokinetic stimulation and virtual reality-based training, can improve tolerance to visual motion, decrease dizziness and support better postural stability. Virtual reality may add motivating and real-life training situations, but cost, availability and cybersickness should be considered.

Keywords: Visual vertigo; Visual-vestibular mismatch; Vestibular rehabilitation therapy; Optokinetic stimulation; Virtual reality; Head mounted display.

Introduction

This review article focuses on two related chapters: Visual Vertigo and Vestibular Rehabilitation Therapy. The first chapter explains the clinical problem, including visual-vestibular mismatch, visual dependence, symptom triggers and clinical assessment. The second chapter explains the rehabilitation approach, especially visual desensitization, optokinetic stimulation and virtual reality systems.

Only the most relevant points that directly serve the article topic were selected. The review therefore links the mechanism of visual vertigo with the rehabilitation methods designed to reduce visual motion sensitivity and improve balance and quality of life.

Definition and Epidemiology

Visual vertigo describes a medical condition in which individuals display an abnormal sensitivity to visual motion that leads to an immediate sensation of discomfort that is often described as dizziness (Steenerson et al., 2022). Patients often report a worsening of dizziness in moving visual backgrounds. They may experience severe panic symptoms including sweating and spinning sensation (Chin, 2018). Visual vertigo, visuo-vestibular mismatch, space and motion discomfort, OPK-mediated hypersensitivity (Hebert & Subramanian, 2019) and Visually-induced dizziness are all names for this condition (Goodwin et al., 2024).

Unfortunately, 30–50% of patients develop chronic symptoms of variable severity, including head movement and visually-induced dizziness (Cousins et al., 2017).Visual vertigo is one of the commonly presented symptoms among balance disordered patients and difficult to manage using the conventional method (Zainun et al., 2024).

Visual-Vestibular Interaction and Pathophysiology

Functionally, during a constant visual input, there should be a decrease in the vestibular system's sensitivity to head acceleration. This is essential to avoid mismatch between visual and vestibular inputs during involuntary head accelerations such as sitting facing in the opposite direction to that of the train in which you are traveling. Continuous vestibular inputs in such situations can be misleading with the perception of self-motion (Dokka et al., 2015). To avoid such mismatches there is a reciprocal inhibitory interaction between the visual and vestibular system (Brandt et al., 1998).

Where both systems suppress the other to produce a coherent sense of self-motion. Deactivation of the vestibular cortex prevents conflict between vestibular information of head motion from visually induced perception of motion and vice versa. Recent studies have identified areas of cortical activation during optic flow stimulation which are consistent with detection of self-motion (Cardin & Smith, 2010). In theory, this relationship allows the dominant sensorial weight to be shifted from one modality to the other, depending on which mode of stimulation predominates (Auvray, 2019).

Causes of visual vertigo:

Visual vertigo frequently develop after a vestibular insult. Any vestibular disorder, peripheral or central, can lead to visual vertigo, but patients with migraine, particularly vestibular migraine, are extremely prone to developing visual vertigo. A typical patient is a previously asymptomatic person who suffers an acute peripheral disorder (e.g., vestibular neuritis), and then after an initial period of recovery of a few weeks, Patients discover that the dizzy symptoms do not fully disappear. Furthermore, symptoms are aggravated by looking at moving or repetitive images. Patients may also develop anxiety or frustration because symptoms do not go away or because medical practitioners tend to disregard them (Bronstein et al., 2020). Also, Visual vertigo can happen in some conditions as after head trauma, whiplash, psychosis, and in some rare cases spontaneously (Mallinson, 2011).

Pathophysiology of visual vertigo:

Balance and posture of the body are maintained by complex integration of input signals from the vestibular, visual, and somatosensory systems (Walker et al., 2018). However, their usage is not uniform. Postural stability relies on a balance between the "weights" of the three types of sensory inputs and the accurate processing of signals transmitted from the central nervous system to the motor organs (Sienko et al., 2018). A mismatch between the different sensory modalities can raise a subjective sensation of vertigo and general balance discomfort (Bronstein, 2016).

In VV patients, the brain erroneously overweighs visual messages over other messages, especially vestibular messages. This is frequently caused by vestibular disease or a neurological abnormality, but it can also occur in seemingly normal patients whose vestibular system is intact and free from any peripheral or central nerve system damage (Chang & Hain, 2020). Two conditions could be present that would lead to this syndrome. First condition when the subject is visually dependent before the vestibular lesion. The second when the vestibular pathology triggers an increase in visual dependence (Agrwal, 2015).

From a pathophysiological perspective, the condition has been proposed to depend on a combination of central and peripheral vestibular remodulation, where the loss of vestibular function causes a sensory reweighing of spatial cues and subsequent visual dependency (Steenerson et al., 2022).

Clinical picture of visual vertigo:

Visual vertigo (VV) is a condition in which there is a worsening of vestibular symptoms in certain visual environments (Dimitriadis et al., 2018). Symptoms can be mild to severe, causing a significant burden on people's quality of life (Zur et al., 2015).Visual vertigo manifests through symptoms like dizziness, lightheadedness, imbalance, and visual blurring. While these symptoms often ameliorate with improved vestibular compensation, some individuals experience prolonged dizziness due to sluggish compensation (Nada et al., 2019).

This chronic dizziness is thought to result from a detrimental cycle initiated by vertigo symptoms. Initially, vertigo triggers anxiety and panic, prompting individuals to avoid activities that might induce vertigo. This avoidance not only delays vestibular compensation but also contributes to depression and restricted social behavior, ultimately diminishing overall quality of life (Vasudevan et al., 2024).

Common triggers include situations of vestibulo-visual conflict, such as cinemas, and intense visual environments, such as supermarkets. Patients often develop functional gait abnormalities and an excessive vigilance about balance sensations (Cousins et al., 2017).

Visual vertigo may itself become a major disabling symptom, particularly when part of the functional (i.e., nonorganic) syndrome of persistent perceptual postural dizziness (PPPD). It can be seen that visual vertigo can feature in patients with PPPD, but visual vertigo can exist without PPPD and, vice versa, PPPD can exist without visual vertigo (Bronstein et al., 2020).

Clinical assessment of visual vertigo:

Dizziness due to VV can be a challenge for clinicians because of the absence of an objective biometric measure that identifies criteria for diagnosis and treatment (Welgampola et al., 2015). Visual vertigo is currently a clinical diagnosis based on the patient's history of disease presentation (Sluch et al., 2017).

Clinical pictures

Visual vertigo manifests through symptoms like dizziness, lightheadedness, imbalance, and visual blurring. While these symptoms often ameliorate with improved vestibular compensation, some individuals experience prolonged dizziness due to sluggish compensation (Nada et al., 2019).

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Questionnaires:

Mallinson questionnaire:

It is 6 questions questionnaire used to diagnose VV. Patient feel unwell when:

1. Going on an escalator.
2. Watching traffic at an intersection.
3. Being in a supermarket.
4. Walking in a shopping mall.
5. Seeing checkerboard floor pattern.
6. Looking to moving fans **(Modified Arabic Version of Mallinson questionnaire) (Hosni et al., 2014).**

Patients should have at least three positive answers for the previous symptoms to be diagnosed as VV.

A. Situational Characteristics Questionnaire (SCQ):

Situational Characteristic Questionnaire (SCQ) consists of 19 questions answered in a scale from 0 (never) to 4 (always) that assess VV symptoms in relation to some visually challenging stimuli like walking in supermarket. The final score was obtained by dividing the total sum by the number of answered questions. Scores more than 0.9 reveal VV symptoms (Talaat et al., 2018).

The questionnaire uses an analog scale to grade the intensity of dizziness triggered by daily situations typically inducing visual vertigo, including being a passenger in a car, walking in a supermarket, being under fluorescent lights, being at an intersection, going up escalators, being at shopping centres, watching movies, patterns, and watching television (Sluch et al., 2017).

The best tool for detecting VV is the situational characteristics questionnaire (Pavlou et al., 2006). An Arabic version has been developed by (Talaat et al., 2018).

Vestibular Rehabilitation Therapy

Concept, Goals and Methods of Vestibular Rehabilitation

Most patients with peripheral vestibular lesions have a benign cause and undergo spontaneous resolution due to the self-limiting nature as well as the process of central nervous system compensation (Shepard et al., 1990). Vestibular compensation is a homeostatic process that in occurs 2 stages (static and dynamic vestibular compensation). In static vestibular compensation, a process that promotes recovery of static symptoms in a short time period, the firing rates of bilateral vestibular nuclei neurons are rebalanced. Dynamic vestibular compensation is a process that promotes recovery of dynamic symptoms over a longer time period and involves different areas of the brain (Wijesinghe & Camp, 2020).

Nevertheless, some patients have poor compensation in the dynamic process (Wijesinghe & Camp, 2020). For these patients, dynamic symptoms continue during movements of the head or body. Symptoms such as dizziness and difficulties with gaze control limit the ability to maintain control of standing balance under different conditions, along with the ability to perform activities of daily living (van Kordelaar et al., 2018).

The most common causes are poor compensation from avoiding head movements, use of long-term vestibular suppressant medications, psychiatric disorders such as anxiety or depression, advanced age, existence of peripheral or central neurologic problems, recurrent peripheral vestibular disorders, and bilateral peripheral vestibular problems (Han & Han, 2021). Vestibular rehabilitation theraby (VRT) is an exercise-based intervention aimed to challenge the different organs involved with balance and posture to promote recovery and compensation (Whitney et al., 2016).

VRT typically includes exercises for adaptation, substitution, habituation, postural control and/or general conditioning. The goal of these exercises is to enhance gaze and postural stability, reduce dizziness and imbalance, and to improve quality of life through modifications of daily living activities (Loftin et al., 2020). VRT has been found to be effective in improving balance in patients with peripheral vestibular dysfunction (Hall et al., 2022) and individuals with vestibular hypofunction (Kundakci et al., 2018). VRT also appears to be an effective intervention in enhancing balance and postural recovery in individuals after damage of the central nervous system (Tramontano et al., 2021), including Parkinson's disease (Acarer et al., 2015), multiple sclerosis (García-Muñoz et al., 2020), concussion (Murray et al., 2017) and cerebral palsy (Tramontano et al., 2017). The types of vestibular rehabilitation have become remarkably varied over the years, ranging from group exercises and customized exercise programs to internet-based programs (Vugt et al., 2019).

Vestibular rehabilitation methods:

Conventional vestibular rehabilitation methods include Cawthorne-Cooksey exercises, multimodal Cawthorne-Cooksey exercises, vestibulo-ocular reflex adaptation exercises, habituation exercises, substitution exercises, and static and dynamic balance exercises (Rosiak et al., 2018). Alternative vestibular rehabilitation methods include augmented sensory feedback, movable platforms, full-screen optokinetic exercises, computer games (exergames), and virtual-reality-based vestibular rehabilitation. Alternative vestibular rehabilitation methods can be applied instead of conventional exercises or in combination with them. It can be preferred in patients who do not benefit from conventional methods (Mutlu, 2022).

Unsupervised and generic exercises are not effective because of the lack of motivation in our patients doing alone their exercises at home and because patient´s motivation is a key factor that must be considered (Rossi-Izquierdo et al., 2017). Several studies have demonstrated that patients may respond better to customized, supervised rehabilitation than to generic exercises or solely a home program. The reason for these differences may be that supervised vestibular rehabilitation promotes adherence and continued performance of vestibular exercises, which may lead to improved outcomes (Topuzet al., 2004).

Aim of VRT:

The goal of rehabilitation training is to promote and establish a stable degree of vestibular compensation. VRT consists of exercises that enhance the strength of the vestibulo-ocular reflex (VOR) to maintain the stability of vision, improve static and dynamic stability to maintain balance in everyday life, and increase the tolerance to head and bodily movements and reduce motion sensitivities (Ding et al., 2021).

Principles of Vestibular Rehabilitation Relevant to Visual Vertigo

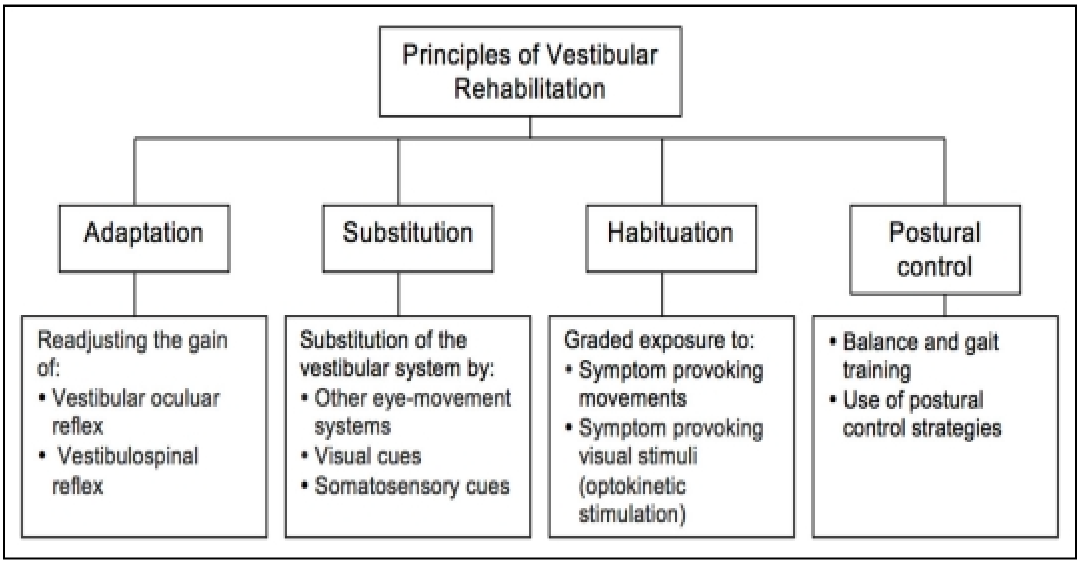

Figure (1): Principles of vestibular rehabilitation. Quoted from: **Law et al. (2024).**

The vestibular physical therapy is an exercise-based approach that includes a combination of four different exercise components to address the impairments, disabilities, and handicap identified during the assessment:

1. Exercises to promote gaze stability (gaze stabilization exercises, including adaptation and substitution exercises).
2. Exercises to habituate symptoms (habituation exercises, including optokinetic exercises).
3. Exercises to improve balance and gait (balance and gait training),
4. Walking to improve endurance **(Nocini et al, 2024).**

Habituation type exercises are generally preferred to decrease visual symptoms. The exercises are applied through graded, repetitive exposure to the movements or situations that provoke symptoms, with the goal of desensitizing the patient to that stimulus. This can involve training balance and the VOR with a variety of visual backgrounds, through the use of virtual reality or other immersive environments or through use of optokinetic exercises such as disco balls, screen savers or with take home DVDs showing optokinetic stimulation (Sulway & Whitney, 2019).

Duration of VRT:

Patients perform exercise for gaze stability 4 to 5 times daily for a total of 20 to 40 min/d plus 20 min/d of balance and gait exercises (**Herdman et al., 2007).** Each exercise may be done at least twice per day beginning with 5 repetitions each and increasing to 10 repetitions (**Krebs et al., 1993).**

Factors Affecting Recovery:

1. **Medications:** The use of centrally acting medications such as vestibular suppressants, antidepressants, tranquilizers, and anticonvulsants has no adverse effect on the ultimate therapy outcome. But the mean length of therapy in patients using medication is significantly longer before the ultimate outcome is achieved.
2. **Visual and somatosensory inputs:** Recovery is delayed if the visuomotor experience is prevented during the early stage after unilateral vestibular loss. Avoidance of movements and body positions that provoke vertigo also retards recovery.
3. **Time to begin treatment:** It was believed that the earlier the patients commence exercises, the quicker and better the results.
4. **Daily exercise duration:** Brief periods of unidirectional optokinetic stimulation (30 s, 10 times daily for 10 days) can produce VOR gain changes after unilateral vestibular loss in human beings.
5. **Site of lesion:** Patients with central lesion or mixed lesion have a prolonged period of therapy. Pure central lesion patients demonstrated a trend for a more successful therapy outcome compared with the mixed lesion group. A lesion of the cerebellum delays recovery. Patients with head injury and associated vestibular deficit show less improvement with treatment.
6. **Age:** Age does not affect the final level of recovery, but sometimes prolongs the length of time required to maximize the benefit from therapy.
7. **Psychogenic factor:** Complicating features of anxiety, depression, or excessive dependence on medications may hinder vestibular compensation **(Han & Han, 2021).**

Management of Visual Vertigo Syndrome

There are three aspects in the treatment of patients with the VV syndrome. The first is specific measures for the underlying vestibular disorder, e.g., Menière’s disease, BPPV, migraine. However, a specific vestibular etiologic diagnosis cannot be confirmed in many patients with chronic dizziness with or without VV (Bronstein, 2016). Second, patients benefit from general reassurance and vestibular rehabilitation with a suitably trained audiologist or physiotherapist (Bronstein et al., 2020). Finally, attention should be paid to the psychologic and psychiatric aspects of these patients. That may involve a variable range of treatments, all the way from simple physician-led reassurance and explanations on the origin of the symptoms up to antidepressant drug treatment and psychotherapy (Bronstein, 2016).

Vestibular rehabilitation:

The customized vestibular rehabilitation program provides significant improvements in patient symptoms, gaze and postural stability compared with a generic exercise program. Specific measures targeting visual desensitization should be incorporated into rehabilitation programs to enhance tolerance to visuo-vestibular conflict.Visual desensitization exercises produce plastic adaptive changes that decrease perceptual and postural visual dependency in patients with VV (Moaty et al., 2017).

The gradual exposure to the visual scenes allows subjects to habituate to the provocative stimuli and aid to reduce manifestations. This includes training balance and the VOR with a variety of visual backgrounds, through the use of exercises that involve visuovestibular conflict or through the use of optokinetic (OPK) exercises or through virtual reality or other immersive environments (Sulway & Whitney, 2019).

Optokinetic Stimulation Exercises

Rehabilitation using optokinetic stimulation is one of the alternative treatment for vestibular disordered patients. The scientific value of this rehabilitation is to promote central nervous system adaptation when they faced complex and sensory conflicts in their daily life (Zainun et al., 2019). Given the common association with anxiety, treatment can also include psychological therapies (e.g. cognitive behavioural therapy, CBT) (Herdman et al., 2022).

Progressive graded exposure to optokinetic stimulation leads to reduction over-reliance on visual input for perceptual and postural responses and increase the weight of vestibulo-proprioceptive cues and increase the weight of vestibulo-proprioceptive cues. (Van Ombergen et al., 2015). It can be delivered via different modes such as virtual reality devices or video playback (Hall et al, 2021).

Methods of optokinetic stimulation:

Optokinetic stimulation can be delivered through:

1) **High-tech optokinetic stimulation:**

High-tech visual motion stimulation has included approaches such as exposure to optokinetic disks with multicolored circles, an optokinetic drum with rotating chair and striped curtain, and moving rooms. The high-tech stimulus (Stimulopt; Framiral, Cannes, France) is commercially available (Fig. 4A and B), provides full-field visual motion in the y- and z-axes, and the direction and speed can be controlled (**Pavlou et al., 2004).**

2) **Low-tech optokinetic stimulation:**

Wrisley and Pavlou (2005) reported that less intense stimulation could be provided by a “busy” screen saver (eg, mazes), a head-mounted display, or a DVD including visual stimulation recorded from the available clinical equipment. However, the individual effectiveness of any of these low-tech methods had not been investigated**.**

The DVD stimuli include individual 2-minute sequences of an optokinetic disk (Fig. 5A) or drum (Fig. 5B) moving in a clockwise, counterclockwise, vertical, or sinusoidal direction at varying speeds within a limited field of view (**Pavlou et al., 2004).** The DVD should be watched for 5 to 10 minutes in total, twice a day. If the patient's daily activities have been particularly tiring or stressful then the DVD should be only once watched that day or not at all if the patient feels overloaded **(Moatey et al., 2017).**

Exercises during watching the DVD are classified into a progressive sequence in which a patient is asked to focus on a special area of a moving image while sitting or standing at different distances from the screen or while walking forward and backward away from the screen with and without movement of head **(Pavlou et al., 2013).**

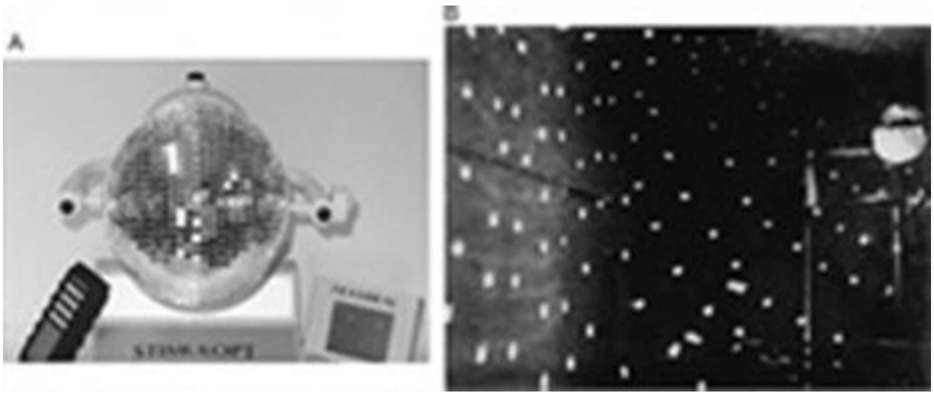

Figure (2): A and B, Apparatus used for the high-tech simulator-based intervention. A, The visual environment rotator apparatus (Stimulopt; Framiral, Cannes, France). B, Participants are asked to stare ahead while the visual environment rotator provides a full-field stimulus moving in different directions and at differing speeds. Participants practice exercises in sitting and standing positions and walking either toward and away from the stimulus or alongside it with or without sagittal or horizontal head movements.

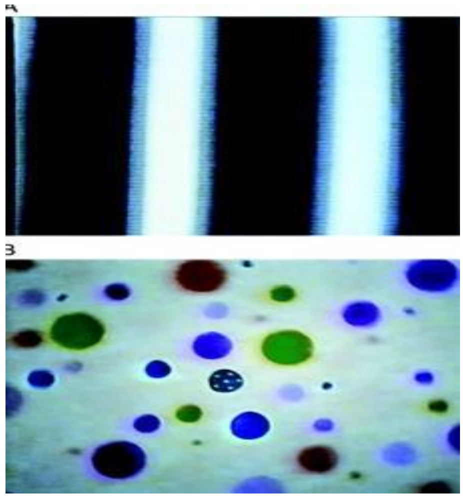

Figure (3): A and B, Still images from DVD stimuli. A, Still image from an optokinetic drum sequence rotating clockwise at 40 degrees per second. B. Still image from an optokinetic disc sequence rotating counterclockwise at 60 degrees per sec ond. Exercises while watching the DVD are divided into a progressive sequence in which patients are asked to focus on a particular area of the moving image while sitting or standing at varying distances from the screen or while walking toward and away from the screen with and without head movements.

Virtual Reality Systems in Vestibular Rehabilitation

Virtual Reality systems (VR):

The virtual reality-based rehabilitation is a recent technology with a sensory feedback approach that targets and challenges the vision, hearing, vestibular system and proprioceptors at a time in three-dimensional landscapes (Afridi et al., 2018). The use of VR in rehabilitation has been suggested as an alternative to conventional VRT because of the recent explosion of VR in this field. In vestibular rehabilitation, VR devices have been tested by clinicians because of their potential to achieve substitution, adaptation, and habituation, as well as positive effects on anxiety reduction and a visualization of visual vertigo (Sana et al., 2023).

Definition:

VR-based vestibular rehabilitative therapy is one of the most innovative and promising recent developments in rehabilitation technology in which the users interact with displayed images, move and manipulate virtual objects and perform other actions in a way that attempts to "immerse" them within the simulated environment engendering a feeling of presence in the virtual world (Hazzaa et al., 2023). Additionally, the facts that VR is a pleasurable training tool motivate patients to continue their rehabilitation (Morel et al., 2015).

Goals:

Virtual reality systems specific to vestibular rehabilitation have been developed to achieve three primary goals:

(1) Reduction of symptoms (vertigo, dizziness, space and motion discomfort/visual vertigo),

(2) Adaptation of the VOR and optokinetic responses,

(3) Retraining of postural stability.

There is preliminary support for the use of virtual reality to meet these goals (Nehrujee et al., 2019).

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 significantly (Fukui et al., 2021). Studies have shown that a VR protocol may be a safe option to improve postural control and quality of life in individuals with vestibular disorders (Park et al., 2019).

Types of VR systems:

Virtual reality systems investigated in patients with vestibular disorders can be categorized into two main types. Type I includes high-end systems, such as head-mounted displays and wide-field-of-view devices. Type II comprises commercially available off-the-shelf systems, including Nintendo Wii®, Microsoft Kinect®, and hybrid systems (Hall et al., 2014).

Although high-end systems often provide a much more immersive experience, they are generally found only in large research facilities because of their high cost. Off-the-shelf systems, on the other hand, are less expensive and are therefore more readily available for use in small clinics and at home (Kinne et al, 2019).

High-End Systems:

High-end systems are highly immersive and have frontend flexibility (i.e., the therapist can control and adapt delivery of stimuli, such as the speed and direction of optokinetic stimulus). In addition, these systems allow for precise measurement of motion and postural stability. There are two basic types of high-end systems— head-mounted display and wide field of view (Hall et al., 2014).

Head-Mounted Displays (HMDs):

Among the different existing systems, the head mounted display (HMD) is the most suited for clinical and home use, because it is compact, portable, and requires little additional infrastructure. HMDs are also relatively cheaper than most of the other VR systems for an immersive 3D experience. However, current commercial HMDs are still expensive for most patients to afford for home-based training. Fortunately, with the recent developments in smartphone technology and VR headsets (such as Google Cardboard), it is now possible to develop affordable HMDs for everyday use. Given the ubiquitous nature of smartphones and the availability of affordable commercial HMD headsets, a smartphone-based HMD for vestibular rehabilitation would be easy to use, economical, portable, and allow easy implementation of home-based therapy (Nehrujee et al., 2019).

Heusel-Gillig and Hall (2014), suggested videos for virtual reality environment starting with the less-stimulating videos first and graded in severity according to patient tolerance. A session duration is not more than 10 minutes, if the symptoms provoked are moderate to severe, session will not continue.

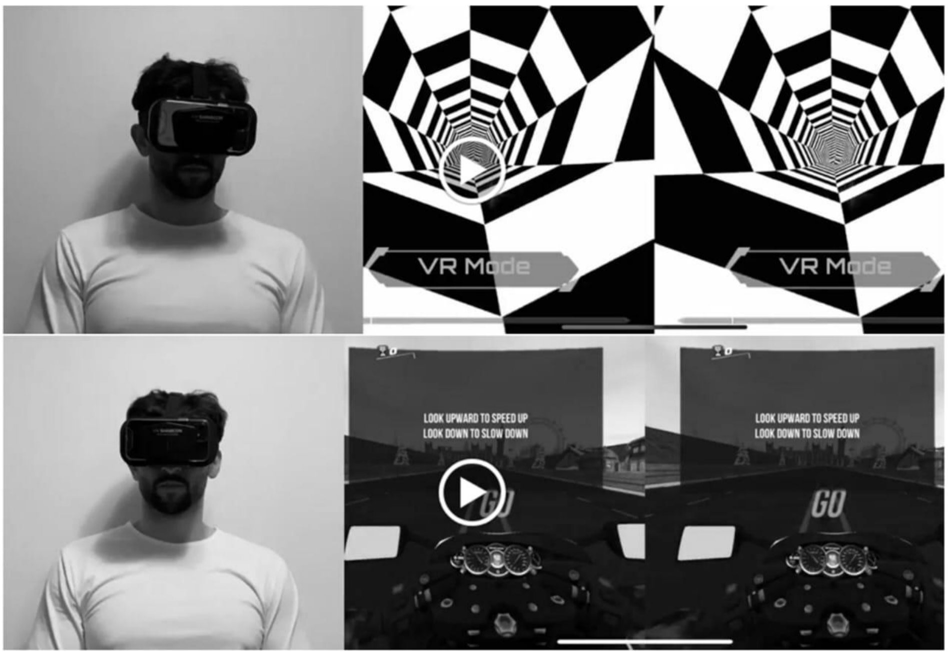

Figure (4): Head Mounted Display. Quoted from: **Heffernan et al. (2023).**

Advantages and Limitations of VR-Based Vestibular Rehabilitation

Advantages of VR systems:

VR-based vestibular rehabilitation combined with conventional vestibular exercises is a very effective method.

Advantages of conventional vestibular rehabilitation program are as follows:

1. Vestibular rehabilitation is basically an equipment-free therapy method. Equipment is only an auxiliary tool.
2. Conventional vestibular rehabilitation is a cost-effective and practical method.
3. It strengthens the communication and cooperation between the patient and the clinician.
4. It gives the patient the habit of exercising regularly in the living area.
5. It ensures the active participation of the patients in the rehabilitation process.

Advantages of the virtual reality-based vestibular rehabilitation program are as follows:

1. Enjoyable
2. Motivating
3. It can create a real-life perception as it completely covers the visual field
4. Provides an effective habituation in patients who cannot tolerate environmental movement
5. It can simulate special environments that cannot be achieved in clinical conditions
6. The floor can be movable or fixed
7. The amount of movement on the moving floor can be adjusted
8. Provides the opportunity to gradually complicate the exercise **(Mutlu, 2022).**
9. Additionally, it improves gait capability, lower extremity function, and consequently balance (**Gibbons et al., 2016).**
10. VR technologies have been made more immersive through the use of head mounted displays (HMD), wearable devices that place a view port over a user's eyes, allowing them to peer into the virtual scene and often direct their gaze with physical head motions as if they were really there **(Ang & Quarles, 2023).**

Disadvantages of VR systems:

1. High end types of VR systems are not commercially available with expensive cost, need extensive space and specially trained staff **(Hall et al., 2014).**
2. The use of HMDs produces motion intolerance symptoms referred to as cybersickness. Some studies found almost half of the participants could not complete a 10-min task in immersive Virtual Reality (VR) **(Martirosov et al., 2022).** Symptoms are nausea, dizziness, disorientation, and general discomfort during or after VR exposure (**Kim et al., 2015**).

Multiple theories have been proposed to explain cybersickness. These theories identify different possible triggers for this sickness, including sensory conflict, postural instability, inappropriate eye movements, eye strain, and difficulty focussing **(Munafo et al., 2017)**. The lack of peripheral field of view has been associated with "cybersickness" or "simulator sickness" **(Moss & Muth, 2011).**

Simulator sickness can include symptoms of nausea, dizziness, faintness, headache, double vision, and/or fatigue and is thought to be a result of sensory conflict. The time lag between head movement and the visual display update is also known to cause simulator sickness **(Hall et al., 2014).**

Fig. 5 shows an example of a visual-vestibular sensory conflict in VR environment, where the viewer feels self-motion (head-movement) through the vestibular system, but the visual system perceives a linear motion with the HMD. That is, the user experience visually induced self-illusion (commonly known as vection) while being actually stationary **(Kim et al., 2018).**

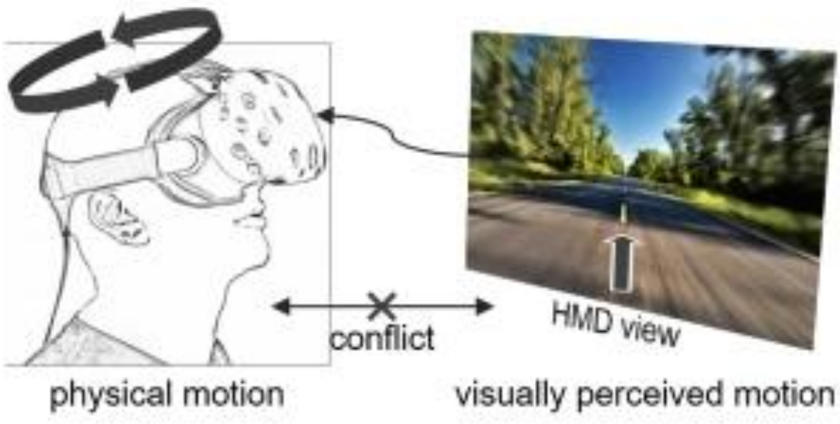

Figure (5): Example of a visual-vestibular sensory conflict caused by a difference between the visually perceived motion and a user's physical motion when wearing an HMD. Quoted from: **Kim et al. (2018).**

Conclusion

Visual vertigo is mainly related to abnormal sensitivity to visual motion and visual-vestibular mismatch. Patients commonly complain of dizziness, lightheadedness, imbalance and visual blurring in visually complex environments such as supermarkets, cinemas, traffic scenes, escalators and patterned floors.

The important clinical points are the history of vestibular insult, visual triggers, symptom burden and questionnaire-based assessment. SCQ and visual vestibular mismatch questionnaires are useful because they focus on daily situations that provoke visual vertigo symptoms.

Vestibular rehabilitation is the key management approach when it is customized to the patient. Habituation and visual desensitization exercises are especially relevant because they expose the patient gradually to provocative visual stimuli. Optokinetic stimulation can reduce over-reliance on visual input, while virtual reality can provide immersive, motivating and real-life training environments.

Virtual reality-based rehabilitation is promising, portable and clinically useful, especially through head-mounted displays and smartphone-based systems. However, its limitations include cost, availability, need for training and possible cybersickness. Therefore, VR should be considered as a supportive rehabilitation tool rather than a complete replacement for individualized vestibular rehabilitation.

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