Virtual Reality Technology as a Tool for Vestibular Rehabilitation

Ebtessam Hamed Nada, Dalia Helal Galhom, * Asmaa Abd AL-aziz Elsayed Mohammad, Nahla Hassan Gad

Audio-Vestibular Medicine Unit, Department of Otorhinolaryngology, Faculty of Medicine, Zagazig university, Egypt

***Corresponding author:** Asmaa Abd Elaziz Elsyed

Email: Asmaa.abdalaziz.2020@gmail.com,

Abstract:

Vertigo is a debilitating symptom, leading to increased healthcare utilization and lost patient productivity. Vestibular rehabilitation is used to manage the symptomatic manifestations of vestibular disease. However, vestibular rehabilitation is limited by accessibility and time commitment. Recently, virtual reality has been described as a vestibular rehabilitation tool that may circumvent these barriers to treatment. Despite this, the efficacy of virtual reality for vestibular rehabilitation remains unclear.

Keywords: Virtual reality, vestibular rehabilitation.

Regul Sci. ™ 2023; 9(1): 8997 - 9006

DOI: doi.org/10.18001 /TRS.9.1. 644

Introduction:

Virtual reality (VR) is an interface between humans and computers, which includes real-time simulation and interaction through various sensory channels, such as vision, hearing, touch, smell, and taste (1). This advanced form of a human-computer interface allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion (2).

VR immersion is the perception of one's physical existence in a non-physical world. This perception is created by surrounding the VR system user with visual, sound or tactile stimuli that provide an immersive environment (3).

VR consists of a simulated experience of a natural or imagery environment that may or may not resemble a life-like experience. VR-based technology consists of implementing VR using multimedia devices to allow individuals to interact with a VR environment. VR devices are essentially made of a multimedia displays (spherical, flat screen or head-mounted) that provides sensory information to the user (including visual, auditory and tactile information) and a control device that collects the user's actions (including motions, gestures, and speech) (4).

Principle:

Virtual reality's utility in the treatment of vestibular dysfunction lies in the possibility of achieving improved habituation, substitution, and adaptation through a more motivated vestibular rehabilitation **(5).**

The neuroanatomical connection of the retina with the vestibular processing areas of the brain supports the usage of VR in VRT. The cortical (e.g., insular cortex) and subcortical (e.g., vestibular nuclei) vestibular brain regions are multisensory and respond to both visual and physical stimuli (head or body movement). Potentials generated by visual input to the retina are transmitted to brain regions associated with the vestibular system and may affect neural activity in the vestibular system with further stimulation of vestibular modulation **(6).**

Also, the virtual environment created by VR technology can promote the illusion of bodily movement, increase immersion to enhance the activation of motor brain regions, mobilize the changes of brain neural plasticity, reconstruct the synapses of nervous system cells, and directly train the central nervous system **(7).**

According to **Garcia et al (8),** VR allows modification of environmental perception by applying a fake stimulus, creating a sensory conflict and changing the gain of vestibulo-ocular reflexes. It was observed that repetitive movements of an image on the retina by virtual reality devices capable of controlling visual stimuli might induce visual adaptations of vestibular responses, adjusting the vestibulo-ocular and vestibulospinal reflexes involved in body control and balance strategies.

Clinical utility of VR systems:

This technology is increasingly being used in medicine as an element of therapy. VR is used as an aid in physical rehabilitation after stroke, in Alzheimer disease, in Parkinson disease, for analgesic treatment of burns, in psychological therapies and in treating post-traumatic stress disorder. The benefits of using VR have also been increasingly reported for treating children with autism spectrum disorders (**9)** and in the rehabilitation of cerebral palsy **(10)**

Likewise, vestibular rehabilitation based on VR systems proved to be an effective treatment modality for mild traumatic brain injury, in treating persistent unsteadiness in vestibular disorders (e.g. acute vestibular neuritis and Meniere's disease), in gaze stabilization exercise training in UVH patients and in desensitizing patients to diverse disorienting visual stimuli **(11).**

Additionally, the use of VR may be beneficial for addressing the vision-related symptoms and restriction in head movement caused by vestibular disorders. Recovery of the gain of the VOR requires visual inputs and active head movement, both of which can be encouraged and monitored with the use of virtual reality. VR technology could be classified according to the degree of immersion in the VR environment (generated by the VR device) into the non-immersive (traditional computer screen or tablet), semi-immersive (large 3D screen), and fully-immersive VR environments (360° screens or head-mounted displays (HMDs)) **(12).**

The degree of immersion depends on the level of isolation from the physical world that the VR environment offers to the user. A fully immersive VR can be achieved by combining computers, HMDs, body tracking sensors, specialized interface devices and real-time graphics to immerse a participant in a computer-generated simulated world that changes in a natural way with head and body motion. Conversely, non-immersive or semi-immersive VR (using computers and console game systems) involves the simultaneous perception of both natural and virtual worlds (**4**).

Two main types of virtual reality systems have been investigated in patients with vestibular pathology: ***high-end systems*** consisting of HMDs and wide field of vision, and ***off-the-shelf systems*** including Nintendo Wii®, Microsoft Kinect®, and Hybrid systems **(13)**.

1-High-end systems: They let the user totally immerse in computer generated world. These systems support a stereoscopic view of the scene according to the user's position and orientation and may be enhanced by audio, tactile and sensory inter-faces **(14)**. In addition, these systems are highly flexible so the therapist can control and adapt delivery of stimuli. Also, they allow for precise measurement of motion and postural stability. There are two basic types of high-end systems, ***head-mounted displays*** and ***wide field of view*** (13**)**.

A) Head-mounted displays (HMDs):

HMDs provide a fully immersive experience. For each eye, an HMD is composed of a modulated light source with drive electronics viewed through an optical system (combined with a housing), which mounted on a user's head via a headband or a helmet. They provide high-resolution images that mimic the user's movements. HMD allows individuals to move, walk around, turn in different directions, interact, and react to virtual events within the virtual environment through three-dimensional head and hand tracking using the headset and controllers, all of which may enhance gait and balance outcomes **(15)**.

Recently introduced VR headsets such as the Oculus Meta Quest Pro (Meta Technologies LLC, USA) or Apple Vision Pro (Apple Inc., USA) are equipped with infrared cameras that track eye movement similarly to the cameras in videonystagmography googles **(16)**. Future studies could include monitoring eye-movement patterns through such cameras which might improve the overall sensitivity and specificity of the VR equipment. Furthermore, integration of eye-tracking and artificial intelligence into the VR software could aid in monitoring of patients with neurodegenerative diseases **(17)**.

Cybersickness and simulator sickness are common consequences of using HMDs because of the sensory mismatch theory. The discrepancy in movement perception between proprioceptive and visual modalities can lead to effects like motion sickness. It is common for users of HMDs to complain of eyestrain, blurred vision, headache, nausea and short-term changes in binocular vision **(18)**.

The Balance Rehabilitation Unit (BRU) is a system that utilizes HMD and foam to test the sensory contributions to balance. The BRU consists of a force platform, a head mounted display (HMD), an overhead safety harness, and a foam cushion **(19)**. **Alahmari et al. (20)** compared VR-assisted dynamic posturography BRU with conventional dynamic posturography. For this comparison, they used the Center of Pressure (COP) parameters, which are derived from force-plate sensors and the conventional Sensory Organization Test (SOT)result. They found that the COP area and sway velocity correlated with the measurement of the SOT.

Currently, **de la O-Gómez et al (21)** demonstrated the efficacy of the BRU system of rehabilitation in patients with unilateral peripheral vestibular disorders as compared to conventional vestibular rehabilitation therapy, which is essential for enhancing patient outcomes. Comparing the BRU technology to supervised conventional therapy revealed its efficacy and the benefits of using the BRU system in motivating patients and encouraging their confidence to improve treatment adherence and reduce symptoms.

Recently, **Nehrujee et al. (22)** developed the VEstibular GAming System (VEGAS), consisting of a smartphone-based 3D virtual reality headset (Convergence VR Tech Labs Pvt. Ltd.) and two games with graded levels of difficulty that utilize optokinetic stimulation and discrete head movements in the pitch and yaw planes to achieve rehabilitation. This system was shaped to be useable and safe to use in patients with unilateral vestibular dysfunction.

Similarly, **Heffernan et al (23)** concluded two VR mobile racing games. These video games replicated both habituation and gaze stabilization exercises that could be effective adjunctive therapies to vestibular rehabilitation.

B) Wide field of view (FOV) systems:

Wide field of view (FOV) systems are screen-based projection devices. The original wide FOV system (cave automatic virtual environment, CAVE) was created as a small room where each wall is a rear-projected screen. The Balance Near Automatic Virtual Environment (BNAVE) is a wide FOV projection-based immersive display system that was developed to investigate the multisensory interactions in postural control. It consists of three rear -projected screens on which images are synchronized and controlled by a network server. When the viewer is standing at the average expected viewing position, the BNAVE display fills all of the 180-degree horizontal field of view and 95-degrees of the vertical field of view **(24)**

The advantages of wide FOV systems are their ability to provide motion cues in the periphery, which can result in a greater sense of self-movement, compared with more limited FOV devices and the users can see their body parts in relation to the virtual environment. Also, Wide FOV systems are the systems of choice to avoid the simulator sickness that is common with HMDs. Although the space required and cost make these systems impractical for clinical use, their wide FOV allow research laboratories to investigate how different motion cues affect balance and vestibular rehabilitation **(13).**

2- Off the Shelf Systems (exergames):

Exergaming (game-based exercise) are defined as computer games combining active physical exercise with game-play. This technology uses accelerometry and video camera-mediated motion detection to track players' movements and converts them into gaming commands. Exergame devices are controlled using a broad variety of sensor systems and depending on the source of input, different algorithms are needed for game control and feedback. Exergaming devices have several advantages as they can motivate people to practice, and the users can train both cognitive and motor skills by performing dual tasks. Additionally, the focus of attention is not on the movements itself, but on the outcome of the movements in the game **(25).**

Commercially available video games such as Wii© (Nintendo Co. Ltd., Kyoto, Japan), PlayStation Move© (Sony Corp, Tokyo, Japan), and Kinect© (Microsoft, Redmond, WA, USA) had been emerged. Many clinics are adopting the use of these off-the-shelf devices for exercise, social interaction and rehabilitation because they are affordable, accessible and can be used within the clinic and home **(26).**

2-A: Nintendo Wii:

The Nintendo Wii® was one of the first commercially available interactive consoles. This was because of being easy to learn and use. The Nintendo Wii® is able to track spatial movements through sensors between the console/sensor bar and handheld controllers to feature into game play. Nintendo Wii Fit® was introduced in 2008, as an initiative to provide fitness into the video games field (27**).**

The Nintendo Wii Fit balance program provides a novel adaptive option to traditional balance training modes of exercise, which is attractive to individuals of all ages. Recently, Nintendo introduced a new interactive platform game, Wii Fit Plus, which was designed to provide multiple modes of exercise **(28).**

2-B: Microsoft Kinect:

A recent development in the field of exergames is the XBOX 360 Kinect (Microsoft corp., Redmond, WA). Kinect- based VR training includes auditory and visual stimulation, feedback information about "winning" or "losing" and repetitions of the same motion can provide a variable rehabilitation tool that reduces barriers to individuals performing rehabilitation exercises **(29).**

The most recently released Xbox Kinect system has an RGB camera and a dual infrared depth sensor for the automatic detection of limb and body position and motion. The system uses these elements to capture data to create a 3-dimensional human body model in real time, called an avatar, which allows for patient to use their own body as the controls to play a game. The reliable visual feedback from the on-screen player's avatar may provide accurate feedback on movement **(30).**

2-C: Hybrid system:

Hybrid systems employ different combinations of components, usually from low-cost systems (such as the Nintendo Wii® remote controller or Microsoft Kinect®) to establish vestibular-specific exercises. These systems are differentiated by levels of immersion, technical specifications, frontend flexibility, availability, cost, and the evidence supporting their application to rehabilitation. Using a combination of VR, motion sensors, and a posturographic platform in rehabilitation as a hybrid therapy was found to be effective by **Rosiak et al (31)** in reducing the subjectively assessed symptoms in patients with peripheral vestibular dysfunction.

VR -based vestibular rehabilitation exercises categories:

Mutlu (3) had categorized VR-based vestibular rehabilitation exercises into the following types:

1. Environment or condition simulations: Boat, airplane, escalator, metro station, and elevator simulations in devices with stable floors are very effective for habituation in patients who cannot tolerate crowded or active environments. The number, speed, and visual characteristics of the parameters in the simulation should be started at a level that can be tolerated by the patient and gradually become more complicated. In unilateral peripheral vestibulopathy, especially if the vestibulo-ocular reflex gain is very low, patients are uncomfortable with the motion simulations when they turn their heads towards the pathological side so motion simulation by changing the head position is very useful in these patients.

*2. **Optokinetic simulations:*** Images created using horizontal, vertical, or rotatory moving points, planets, or other different shapes. Background, size, number, movement speed, and direction of objects can be adjusted according to the patient's tolerance. In fixed systems, it can be worked in sitting and standing. In systems with a movable platform, ground motion also allows the patient to try to control posture while watching moving objects.

3. ***Head-eye coordination***: They are used as adaptation and substitution exercises as they support both oculomotor and head movements and vestibuloocular reflex. Managing the movements of an object (for example, an airplane, planet, or bird) with head movements, watching the moving object with head movements, focusing on the target where it turns the head, can be given as examples of exercises in this category. These exercises activate the patients' head and eye movements and can be done in systems with a fixed floor while sitting or standing on a hard floor or foam. They can also be combined with moving platforms.

*4. **Exercises involving upper extremity***: Exercises involving upper extremity movements in vestibular rehabilitation are very important as they require trunk movements or stepping on motionless platforms. The sensors held by the patients in both hands can be used for shooting arrows, popping balloons, or painting objects. These exercises involve bending forward, reaching up, turning back, or stepping. Parameters of the simulation can be changed in accordance with the patient. Items that increase cognitive activity can be added to exercises.

*5. **Activity simulations:*** These exercises are used very effectively, especially in systems with moving platforms. For example, ski simulation creates an effective dynamic balance exercise by adjusting almost all parameters of the visual environment, the task and the movement according to the patient.

Advantages of VR:

• Perceived enjoyment: as VR is a method to enhance motivation and adherence leading to effective repetitive task-training even after discharge from rehabilitation facilities (32). This is especially true in video game based approaches. By providing visual and auditory rewards, such as displaying gratifying messages in real time ("Great", "Very Good"), patients are motivated to exercise. So, they will get better while having fun (33).

- VR can provide real-time multisensory feedback and facilitates task variation through the application of various virtual environments that simulate real and daily life tasks (34).
- VR video games provide training conditions that favor an integration between cognitive and motor stimulation. More complex training involving dual tasks such as cognition and motor activity, requires automatic control during movements since the focus of attention is on the game

shown on the display, promoting motor function improvement when compared with conventional training **(35).**

- Availability of low-cost VR devices and the use of VR at home if a telerehabilitation service is available, thus contributing to reduction in healthcare costs and improvement of rehabilitation outcomes **(4).**
- VR technology enables therapists to provide standardized rehabilitation protocols, controlled stimulus presentations that allows analysis of objective clinical progress and performance measures **(36).** Also, VR environments can be tailored to patient needs and provide personalized feedback on performance **(37).**

Limitations of VR:

- VR practice may cause symptoms of motion sickness and poor equilibrium. This syndrome is characterized by discomfort, fatigue, nausea, and disorientation. It arises from the discrepancy between a more vigorous motion perceived by vision and hearing and a weaker motion perceived by the vestibular system and proprioception, which leads to simulator sickness. The frequency and severity of simulator sickness depend on the device (HMD vs. non-wearable displays), the type of tasks (e.g., walking vs. driving), and the individual's clinical and demographical features ((**4).**
- VR may induce eyestrain-related issues such as eye fatigue, discomfort, dryness, redness and reduced visual acuity which falls under computer vision syndrome **(38).**
- The high cost of new VR devices. For this reason, video game–based therapy and non-immersive VR systems are playing an important role in cost effective rehabilitation. This paired with the fact that some devices may need some specific training to use **(39).**
- Some limitations are related to particular groups of patients who are afraid of new devices or are very sensitive to their environment. For example, introducing VR devices may agitate schizophrenia patients with persecutory delusion and paranoia **(40).**

References:

1. Song, J(2019): Virtual Reality for Vestibular Rehabilitation. Clinical and Experimental Otorhinolaryngology Vol. 12, No. 4: 329-330
2. Schultheis, M.T.; Rizzo, A.A (2001). The Application of Virtual Reality Technology in Rehabilitation. Rehabil. Psychol. 46, 296–311.
3. Mutlu, B. (2022): Vestibular Rehabilitation: Conventional and Virtual Reality-Based Methods. In Recent Advances in Audiological and Vestibular Research. IntechOpen.
4. Naro, A., & Calabro, R. S. (2021). What do we know about the use of virtual reality in the rehabilitation field? A brief overview. Electronics, 10(9), 1042.
5. Viziano, A., Micarelli, A., Augimeri, I., Micarelli, D. & Alessandrini, M (2019). Long-term effects of vestibular rehabilitation and head mounted gaming task procedure in unilateral vestibular hypofunction: A 12-month follow-up of a randomized controlled trial. *Clin. Rehabil.* 33, 24–33.
6. Matsumura, M., & Murofushi, T. (2021). Vestibular rehabilitation after vestibulopathy focusing on the application of virtual reality. *Journal of Otorhinolaryngology, Hearing and Balance Medicine*, *2*(2), 5.
7. Wu, J., Zhang, H., Chen, Z., Fu, R., Yang, H., Zeng, H., & Ren, Z. (2022). Benefits of

virtual reality balance training for patients with Parkinson disease: systematic review, meta-analysis, and meta-regression of a randomized controlled trial. *JMIR Serious Games*, *10*(1), e30882.

8. Garcia AP, Gananca MM, Cusin FS et al. (2013). Vestibular rehabilitation with virtual reality in Meniere's disease. Braz J Otorhinolaryngol. 79(3):366–374. https://doi.org/10.5935/1808-8694.20130064
9. Stankiewicz ,T Gujski,M Niedzielski,A and Chmielik, L(2020). Virtual Reality Vestibular Rehabilitation in 20 Patients with Vertigo Due to Peripheral Vestibular Dysfunction. Med Sci Monit, 26: e930182
10. Luna-Oliva, R.M. Ortiz-Guti´errez, R. Cano-De La Cuerda, R.M. Pi´edrola, I.M. Alguacil-Diego, C. S´anchez- Camarero and M.D.C (2013). Mart´ınez Culebras, Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study, *NeuroRehabilitation* 33, 513–521. doi:10.3233/NRE-131001
11. Micarelli, A. and Viziano, A. (2017). Three-dimensional head-mounted gaming task procedure maximizes effects of vestibular rehabilitation in unilateral vestibular hypofunction: a randomized controlled pilot trial. International Journal of Rehabilitation Research ·
12. Juliano, J.M.; Spicer, R.P.; Vourvopoulos, A.; Lefebvre, S.; Jann, K.; Ard, T.; Liew, S.-L (2020). Embodiment is related to better performance on a brain–computer interface in immersive virtual reality: A pilot study. Sensors, 20, 1204.
13. Hall C., Meldrum D. and Whitney S. (2014). The Role of Emerging Technologies in Vestibular Rehabilitation. In S. J. Herdman (Ed.), Vestibular rehabilitation, Philadelphia: F.A. Davis (4th ed.), pp. 537–553.
14. Bhardwaj,A., Bhardwaj, M and Gaur, A (2016). "Virtual reality: An overview," *International Journal of Scientific and Technical Advancements*, Volume 2, Issue 4, pp. 159-164.
15. Delgado,F and Der Ananian, C (2020). The Use of Virtual Reality through Head-Mounted Display on Balance and Gait in Older Adults: A Scoping Review; GAMES FOR HEALTH JOURNAL: Research, Development, and Clinical Applications
16. Adhanom, I. B., MacNeilage, P. & Folmer, E (2023). Eye tracking in virtual reality: A broad review of applications and challenges. Virtual Real 27, 1481–1505.
17. Przybyszewski, A. W., Śledzianowski, A., Chudzik, A., Szlufk, S. & Koziorowski, D (2023). Machine learning and eye movements give insights into neurodegenerative disease mechanisms. Sensors 23, 2145.
18. Rebenitsch L, Owen C (2016). Review on cybersickness in applications and visual displays. Virtual Reality. 20:101– 25.
19. Nogueira S, Ferreira E, Geisinger D, San Roman C, Suarez H (2010). Model of postural control system applied in Parkinson's disease patients. Conf Proc IEEE Eng Med Biol Soc. 5452–5. [PubMed: 21096282]
20. Alahmari, K. , Marchetti, G. , Sparto, P. , Furman, J. & Whitney, S (2014). Estimating postural control with the balance rehabilitation unit: Measurement consistency, accuracy, validity, and comparison with dynamic posturography. Arch. Phys. Med. Rehabil. 95, 65.
21. de la O-Gómez, A. , Sierra-Ramírez, J. , Ramos-Maldonado, D., & Hernández-Caballero, M. (2023). Effectiveness of Balance Rehabilitation Unit (BRU) Posturography Versus

Conventional Rehabilitation in Patients With Unilateral Peripheral Vestibular Dysfunction. Cureus, 15(9).

22. Nehrujee A, Vasanthan L, Lepcha A, Balasubramanian S (2019). A Smartphone based gaming system for vestibular rehabilitation: a usability study. VES. 29(2–3):147–60
23. Heffernan, A., Booth, L., Fletcher, R., & Nunez, D. A. (2023). Vestibular rehabilitation potential of commercially available virtual reality video games. Journal of Otolaryngology-Head & Neck Surgery, 52(1), s40463-023.
24. Sparto, P. J., Whitney, S. L., Hodges, L. F., Furman, J. M., & Redfern, M. S. (2004). Simulator sickness when performing gaze shifts within a wide field of view optic flow environment: preliminary evidence for using virtual reality in vestibular rehabilitation. Journal of neuroengineering and rehabilitation, 1, 1-10.
25. Fitzgerald D, Trakarnratanakul N, Smyth B, Caulfield B (2010). Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. J Orthop Sports Phys Ther, 40:11–19
26. Lange, B., Flynn, S., & Rizzo, A. (2009). Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation. *Physical Therapy Reviews*, *14*(5), 355–363.
27. Khoury, A (2018). Motion capture for telemedicine: A review of nintendo wii, microsoft kinect, and playstation move. *Journal of the International Society for Telemedicine and eHealth*, *6*, e14-1.
28. Miller, C. A., Hayes, D. M., Dye, K., Johnson, C., & Meyers, J. (2012). Using the Nintendo Wii Fit and body weight support to improve aerobic capacity, balance, gait ability, and fear of falling: two case reports. *Journal of geriatric physical therapy*, *35*(2), 95-104.
29. Shobhana, N. G., & Rakholiya, S. (2020). The effect of X box 360 kinect-virtual reality intervention on balance and gait training in stroke patient: An interventional study. *Indian J Public Health Res Dev*, *11*, 589-594.
30. Park, D. S., Lee, D. G., Lee, K., & Lee, G. (2017). Effects of virtual reality training using Xbox Kinect on motor function in stroke survivors: a preliminary study. *Journal of Stroke and Cerebrovascular Diseases*, *26*(10), 2313-2319.
31. Rosiak, Oskar & Krajewski, Krzysztof & Woszczak, Marek & Jozefowicz-Korczynska, Magdalena. (2019). Evaluation of the effectiveness of a Virtual Reality-based exercise program for Unilateral Peripheral Vestibular Deficit. Journal of Vestibular Research. 28. 1-7. 10.3233/VES-180647.
32. Schröder, J., Van Criekinge, T., Embrechts, E., Celis, X., Van Schuppen, J., Truijen, S., & Saeys, W. (2019). Combining the benefits of tele-rehabilitation and virtual reality-based balance training: a systematic review on feasibility and effectiveness. *Disability and Rehabilitation: Assistive Technology*, *14*(1), 2-11.
33. Burdea, G. C. (2003). Virtual rehabilitation–benefits and challenges. *Methods of information in medicine*, *42*(05), 519-523.
34. Cano Porras, D., Sharon, H., Inzelberg, R., Ziv-Ner, Y., Zeilig, G., & Plotnik, M. (2019). Advanced virtual reality-based rehabilitation of balance and gait in clinical practice. *Therapeutic advances in chronic disease*, *10*, 2040622319868379
35. Amorim, J. , Leite, R. C., Brizola, R., & Yonamine, C. (2019). Virtual reality therapy for rehabilitation of balance in the elderly: a systematic review and META-analysis. *Advances in*

rheumatology, *58*, 18.

36. Morel, M,Benoit Bideau, J. Lardy, Richard Kulpa (2015). Advantages and limitations of virtual reality for balance assessment and rehabilitation. Neurophysiologie Clinique = Clinical Neurophysiology, 45 (4-5), pp.315-326. ff10.1016/j.neucli.2015.09.007ff. ffhal-01225506f
37. Henderson, A.; Korner-Bitensky, N.; Levin, M (2007). Virtual Reality in Stroke Rehabilitation: A Systematic Review of Its Effectiveness for Upper Limb Motor Recovery. *Top. Stroke Rehabil. 14*, 52–61.
38. Smits, M.; Staal, J; van Goor, H (2020). Could Virtual Reality play a role in the rehabilitation after COVID-19 infection? *BMJ Open Sport Exerc. Med. 6*, e000943.
39. Massetti, T., Da Silva, T.D., Crocetta, T.B., Guarnieri, R., De Freitas, B.L., Bianchi Lopes, P., Watson, S., Tonks, J. and de Mello Monteiro, C.B., (2018). The clinical utility of virtual reality in neurorehabilitation: a systematic review. *Journal of central nervous system disease*, *10*, p.1179573518813541.
40. Cao, S. (2016). Virtual reality applications in rehabilitation. In *Human-Computer Interaction. Theory, Design, Development and Practice: 18th International Conference, HCI International 2016, Toronto, ON, Canada, July 17-22, Proceedings, Part I 18* (pp. 3-10). Springer International Publishing.