Virtual Reality Therapy for Balance Training in Aging and Neurological Disorders

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Abstract: Balance training has been applied to compensate and rehabilitate balance dysfunctions in healthy aging and neurological disorders. Technological advances have allowed the development of interactive and feedback systems as an application of virtual reality to balance training.

Research shows encouraging results on the benefits and effects of virtual reality balance training in normal aging and conditions such as acquired brain injury (*e.g.* Stroke, Traumatic Brain Injury) and neurodegenerative disorders (*e.g.* Parkinson, Multiple Sclerosis). However definite conclusions on the efficacy, cost-effectiveness and optimal parameters of virtual reality balance training remain to be established.

We here provide a current perspective on the available evidence for the applications and effects of virtual reality balance training in healthy aging and neurological disorders.

Keywords: Aging, Balance, Balance rehabilitation, Balance training, Neurological disorders, Review, Therapy, Virtual Reality.

INTRODUCTION

Balance is considered a complex motor skill necessary for functional performance of the individual, especially in daily living activities [1, 2].

Balance relies on proprioceptive, vestibular and visual system inputs which are processed by the central nervous system, requiring the integrated functioning of sensory, motor and cognitive systems [3]. Functional or structural brain decay or dysfunction may therefore lead to balance diminishments as observed throughout the aging process [4] and in neurocognitive/brain disorders such as cognitive impairment and Alzheimer's disease [5], Parkinson disease [6] and Multiple Sclerosis [7].

Standard physical therapies have shown some benefit for improving balance in neurological disorders such as Traumatic Brain Injury (TBI) [8].

Technological advancements and cost decrease in Virtual Reality (VR) hardware and software have allowed the expansion of VR application to medical and therapeutic settings also for tackling balance issues in aging and neurological disorders. Virtual reality therapy (VRT) relies on a wide range of technologies and approaches such as CAVE immersive systems, Head Mounted Displays, Haptic systems, and interactive motion sensor devices (*e.g.* Kinect).

In the present review we provide a current perspective on the applications and efficacy of virtual reality as a therapeutic approach and tool for balance training in aging and neurological disorders.

MATERIALS AND METHODS

For the present narrative review a comprehensive literature search was performed on PubMed/MEDLINE, including the terms "balance" AND "virtual" and using the following filters: Clinical Trial and Review, Humans, and Title/Abstract.

Articles were considered to meet inclusion criteria when they focused on virtual reality as a therapy/intervention for balance in aging or neurological disorders. Studies were selected through abstract inspection with reviews and clinical studies being included for further analysis. Additional studies were obtained from references of the retrieved articles during literature search.

RESULTS

Virtual Reality Therapy for Normal Aging

Aging is commonly accompanied by a decline in physical and cognitive functions (*e.g.* attention, executive functioning), with an increased risk of falls and presence of gait impairment (*e.g.* reduced gait speed, stride length, unsteadiness, dysrhythmicity) [9, 10].

Virtual reality, through stimulation of the sensory cues involved in maintaining balance and orientation, is

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considered an effective approach for balance training in aging [10].

Indeed a recent systematic review and meta-analysis found that virtual reality balance training improves static balance, postural control and dynamic balance in normal elderly [11].

Individual studies have also shown the benefits of VR balance training. For example, after bi-weekly sessions of training in the Balance Rehabilitation Unit for 6 weeks, elderly participants showed improvements in balance, and reduced falls and fear of falling [12].

Other studies and systematic reviews support the aforementioned findings [13-15].

Virtual Reality Therapy for Balance in Neurological Disorders

Acquired Brain Injury (Stroke, TBI)

Balance dysfunctions either stemming from central or peripheral causes are a prevalent issue in brain-injured patients, with balance disability being a strong predictor of Activities of Daily Living (ADL's) functioning (in the acute stage) and recovery [16].

Some studies have been conducted assessing the efficacy of VRT for balance in acquired brain injury. Llorens and colleagues [17] evaluated the effectiveness of BioTrak, a virtual reality rehabilitation computerized interactive program, with chronic hemiparesis patients. Improvements were observed in motor scales (BBS and POMA) and posturography parameters, namely in the vestibular index and anterior–posterior control. Effects were also present at 1 month follow-up.

In a randomized controlled single blind trial of eBaViR (easy Balance Virtual Rehabilitation), 9 patients trained for 20 one-hour-sessions [18]. When comparing with the standard therapy group, the eBaViR group showed significant improvements in static balance.

McClanachan and colleagues [19] conducted a feasibility study of Wii-Fit exergaming in addition to standard therapy. Wii-Fit plus standard therapy led to similar benefits in endurance, gait and balance when compared to standard therapy alone.

Other studies also support findings that commercially available virtual reality exergaming systems might show similar, although not superior, results in static and dynamic balance outcomes when comparing to standard physical therapy [20]. However, a recent systematic review shows that there is little evidence supporting the use of Nintendo Wii in stroke patients regarding balance and functional independence (although motor function benefits can be observed) [21].

In another review [22] on stroke, the authors concluded that while evidence exists for superior member rehabilitation using virtual reality in stroke, there is a scarcity of virtual reality studies focusing on gait and balance training.

Nonetheless studies have been conducted. For example, Kim and colleagues [23] conducted a double-blind randomized controlled trial in chronic stroke patients comparing standard physical therapy to combined virtual therapy plus physical therapy. They found that virtual reality increased balance improvement and also led to enhancements in ambulation parameters such as cadence, velocity, and stride length.

In a different approach, Walker and colleagues [24] conducted a preliminary trial in stroke patients of body weight-supported treadmill training plus virtual reality simulating walking down a city street. Patients underwent 12 sessions and showed improvements in gait/walking ability and balance.

Cho and Lee [25, 26] used a similar approach (treadmill training plus video recordings) and found significant beneficial effects on gait and balance.

Ustinova and colleagues [27] developed a first person 3D view immersive videogame (Octopus) comprising motion analysis and real-time hand avatars synchronized with the environment simulation. Training consisted of a single session divided in 10 trials of 90 seconds each. TBI patients improved game performance, arm movement time, and precision. 10 patients (out of 13) increased arm forward reach and single-leg stance time.

Ustinova and colleagues [28] also conducted a study of virtual reality therapy consisting of interactive and tailored games and scenarios, using a Kinect sensor. TBI patients underwent 15 sessions (50-55 minutes each, with a frequency of 2-3 per week, 5–6 consecutive weeks). Improvements in static and dynamic postural stability, gait and arm movements were observed.

Neurodegenerative Disorders

Parkinson's disease

There has been a recent spur in innovative assessment and rehabilitation approaches to Parkinson's disease [29-31], with complementary physical therapies being considered as useful for mobility and quality of life [32, 33].

A valuable number of trials of virtual reality applied to balance training has been conducted on Parkinson's disease. For example, Dowling and colleagues reported that a therapeutic computer-based video game directed at improving gait and balance was feasible for use with PD patients [34].

Regarding efficacy, virtual reality-based exercise has also been found to be superior to standard exercise intervention leading to increased performance in dynamic balance and sensory organization test [35]. Similarly, Lee and colleagues found beneficial effects of virtual dance exercise in balance, activities of daily living, and depressive disorder, when comparing with a control group [36].

Although the compared efficacy of commercially available software to professional tools is unclear, exergaming tools might also be useful. For example, Pompeu and colleagues reported performance improvement in game scores balance, gait, cardiopulmonary parameters and quality of life, after 14 sessions (1hour, 3 times/week) of Kinect Adventures!™ [37]. In another study participants were enrolled in 14 sessions of Nintendo Wii exercises (40 min, 2 times/week), leading to increased stride length and gait speed, reduction of rigidity and flexibility improvement of the lower limbs, and higher functional independence [38].

Nonetheless it is important to note that "negative findings" regarding a possible superiority of the efficacy of virtual reality in comparison to standard balance training do exist. Yang and colleagues specifically addressed this issue and found that home-based virtual reality training was as effective as standard home balance training [39].

Yen and colleagues evaluated an interactive training system combining virtual reality and dynamic balance board compared to traditional balance training. They found that both types of training lead to better sensory integration (for postural control) as measured by computerized posturography [40].

Some reflections are needed concerning the aforementioned findings in the field of Parkinson. Despite some favorable data regarding commercially available software for balance training in PD, it is important to note that the cognitive demands greatly influence learning, retention and transfer of improvements [41], and therefore should be incorporated in a professionally guided selection of adequate therapeutic exercises.

Other approaches such as virtual visual cueing googles have also been used aiming at reducing freezing of gait based on the *kinesia paradoxa* phenomenon, with Kaminsky and colleagues pointing that this approach might lead to reduced length and number of freezing episodes [42].

Multiple Sclerosis

Considering that balance and postural control are often impaired in Multiple Sclerosis [43] (MS), trials have been conducted in aims of assessing the efficacy of balance training in this pathology.

Using the Biodex Balance System SD, Eftekharsadat and colleagues showed that a relatively short duration virtual reality balance training program (24 sessions) can lead to improved fall risk and postural stability performance [44].

Lozano-Quilis and colleagues compared a Kinect VR-based rehabilitation exercise program to standard rehabilitation showing that it led to greater improvement in balance and anterior reach test scores. Participants also accepted this approach considering it usable and safe [45].

Other studies also found increased specific balance benefits of Kinect based telerehabilitation over standard rehabilitation [43, 46], although both approaches led to improved general balance.

A preliminary study also shows promising findings for MS patients of combined training using body weight supported treadmill and over ground walking and virtual reality balance training [47].

Interestingly, recent research [48] suggests brain changes related to virtual reality balance training in Multiple Sclerosis patients. Namely, Prosperini and colleagues found that a 12 week video game (Nintendo Wii) balance board training may lead to micro structural changes of superior cerebellar peduncles, although these were reverted 12 weeks after [48].

Other Conditions

Research has also been conducted on the role of virtual reality therapies in other disorders/pathologies.

A recent practice guideline states the existence of sufficient evidence for the use of virtual reality therapy in children and adolescents (ages 4 to 18) with cerebral palsy, based on a review which suggested benefits in balance, postural control, gait, upper limb function and selective joint control [49].

Regarding motor conditions/impairments, intensive VR-augmented lower limb training has recently shown promising findings in chronic incomplete spinal cord injured patients. Namely, an intensive VR-augmented training of limb control led to improvements in balance, walking speed, ambulation, and muscle strength accompanied by increased volume in left middle temporal, occipital gyrus, left temporal pole, fusiform gyrus, hippocampi, cerebellum, corpus callosum, and brainstem [50].

Another systematic review on virtual reality therapy for cerebellar ataxia highlights the need for further research [51].

A trial with older adults with diabetes mellitus suggests benefits from virtual reality balance therapy with intervention effects such as balance and gait speed improvements [52]. Moreover, other studies show that this approach might be efficacious for balance and postural stability in diabetic neuropathy [53, 54].

Concerning cognitive disorders, a recent case study suggests that virtual reality training is a feasible and safe approach for exercise engagement in dementia despite no improvements in balance and mobility measures [55].

VR therapy has also been explored in Metachromatic Leukodystrophy, with a case study reporting improvements in balance, walking speed, mobility and functionality [56].

DISCUSSION

The present study reviewed the existing literature on virtual reality therapy for balance training in aging and neurological disorders.

Findings globally suggest that virtual reality therapy may be an easy to implement, practical, engaging and effective complement or substitute to traditional balance training in aging and neurological disorders (main findings are summarized in Table **1**). However it is important to note that evidence is still scarce in many disorders, especially for conditions such as diabetic neuropathy and incomplete spinal cord injury.

These findings are in agreement with results from other fields reporting benefits of VR application to therapeutic setting and conditions such as burn/pain [57] and anxiety disorders [58].

There is evidence that VR balance training improvements, at least task related, are possible after a brief focused training [27].

Table 1: Main Findings of VR Balance Therapy for Aging and Neurological Conditions

Conditions	Summary of Main Findings
Normal Aging	Improvements in balance [10, 11, 12]; reduction of falls and fear of falling [12]
TBI, Stroke	Improvements in static [18] and dynamic postural stability [20, 28], gait and balance [23, 24, 25, 26, 28]
Parkinson's disease	Improvements in mobility [32,33, 38], gait and balance [34, 35, 36, 37, 38], quality of life [32, 33]; reduction of freezing of gait [42]
Multiple Sclerosis	Reduction of fall risk [44]; improvements in postural stability [44], balance [43, 45, 46]; microstructural brain changes [48]
Cerebral Palsy	Preliminary evidence of benefits in balance, postural control, gait, upper limb function and selective joint control [49]
Incomplete Spinal Cord Injury	Improvements in balance, walking speed, ambulation, and muscle strength; brain changes [50]
Cerebellar Ataxia	Further research is needed [51]
Diabetes Mellitus - Diabetic neuropathy	Improvements in balance, gait speed and postural stability [52, 53, 54]
Dementia	Further research is needed [55]
Metachromatic Leukodystrophy	Improvements in balance, walking speed, mobility and functionality [56]

Preliminary findings also suggest VR balance training, even short-duration programs, may lead to neural changes, perhaps related to the systematic training, functional and biological activation they allow [48].

VRT for balance benefits include systematic and continuous quantitative registration and monitoring of training effects and evolution tracking.

Nonetheless, definite conclusions on the efficacy, cost-effectiveness, optimal system and parameters of VR balance training remain to be established. Also, perceptions about the prompt availability of systems to clinicians, cost and other implementation barriers (*e.g*. trained and specialized staff) of complex systems may still remain as obstacles to the widespread use of VR therapy. Moreover, VR is a tool requiring a trained health professional for correct exercise performance and patient safety (*e.g*. fall risk during exercise cannot be excluded with VR systems, like conventional approaches, and should be prevented). Since VR balance training systems are mostly based on visual feedback, for specific populations with risk of seizure (*e.g*. TBI [59]) the inclusion of such patients should be thoroughly evaluated and monitored.

Future research should take into account the following aspects:

- Inclusion of larger samples;
- Clarification of the optimal type of VR system and best training parameters regarding the number of sessions, frequency, duration and intensity;
- Determination of the compared adherence, completion and efficacy of low-cost commercial setups vs. professionally/clinically designed systems;
- Understanding of short-term and long-term effects and their differential neural/biological mechanisms, correlates and bases; through the use of flexible brain monitoring technologies (*e.g*. EEG, fNIRS). This might also advance the rehabilitation field [60];
- Inclusion of comprehensive outcome protocols [61] including functional tests/tasks, quality of life scales, symptom, specific disease scales, balance tests, computerized posturography, functional connectivity and other brain measures (*e.g*. EEG, sMRI, fMRI, fNIRS);
- Increased research evaluating the feasibility and effects of VR balance training in other neurocognitive disorders such as Alzheimer's disease;
- Evaluation of the efficacy of combined VR balance training with other emerging approaches such as bodyweight treadmill training, anti-gravity treadmill training, haptic floor systems and TMS/tDCS;
- Determination of cost-effectiveness when comparing to traditional balance therapy.

CONCLUSION

Balance dysfunctions are often present in normal aging and in several neurological disorders. This review shows that is there evidence for VR-based balance training efficacy in aging and other disorders, although additional research is needed to elucidate the potential and specific existence of effects in each condition. Additionally, optimal intervention parameters (*i.e*. frequency, duration and intensity) remain to be established as well as the compared effectiveness of different systems. Interestingly, preliminary evidence suggests potential neural effects of VR balance training, though the underlying mechanisms and nature (*i.e*. compensatory vs. restorative) of such observations remain to be clarified.

VR is a present emerging approach to balance training in normal aging and many neurological conditions which should be considered as a current therapeutic tool for the rehabilitation professional, although keeping in mind the supporting evidence (or lack thereof) for each specific disease application. Combining it with simultaneous monitoring technologies (*e.g*. EEG, fNIRS) and/or brain stimulation (*e.g*. tDCS) might lead to improvement in the understanding of the underlying mechanisms of VR balance training, better clinical practice and increased therapeutic effects in balance outcomes.

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