Virtual and augmented reality based balance and gait training

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The use of virtual and augmented reality for rehabilitation has become increasingly popular and has received much attention in scientific publications (over 1,000 papers). This white paper aims to summarize the scientific background and efficacy of using virtual and augmented reality for balance and gait training. For many patients with movement disorders, balance and gait training is an important aspect of their rehabilitation process and physical therapy treatment. Indications for such training include, among others, stroke, Parkinson’s disease, multiple sclerosis, cerebral palsy, vestibular disorders, neuromuscular diseases, low back pain, and various orthopedic complaints, such as total hip or knee replacement. Current clinical practice for balance training include exercises, such as standing on one leg, wobble board exercises and standing with eyes closed. Gait is often trained with a treadmill or using an obstacle course. Cognitive elements can be added by asking the patient to simultaneously perform a cognitive task, such as counting down by sevens. Although conventional physical therapy has proven to be effective in improving balance and gait, there are certain limitations that may compromise treatment effects. Motor learning research has revealed some important concepts to optimize rehabilitation: an external focus of attention, implicit learning, variable practice, training intensity, task specificity, and feedback on performance. Complying with these motor learning principles using conventional methods is quite challenging. For example, there are only a limited number of exercises, making it difficult to tailor training intensity and provide sufficient variation. Moreover, performance measures are not available and thus the patient usually receives little or no feedback. Also, increasing task specificity by simulating everyday tasks, such as walking on a crowded street, can be difficult and time consuming. Virtual and augmented reality could provide the tools needed to overcome these challenges in conventional therapy. The difference between virtual and augmented reality is that virtual reality offers a virtual world that is separate from the real world, while augmented reality offers virtual elements as an overlay to the real world (for example virtual stepping stones projected on the floor). In the first part of this paper we will explain the different motor learning principles, and how virtual and augmented reality based exercise could help to incorporate these principles into clinical practice. In the second part we will summarize the scientific evidence regarding the efficacy of virtual reality based balance and gait training for clinical rehabilitation.

Motor learning principles

Focus of attention
During rehabilitation, physical therapists will need to explain the different exercises to the patient. The specific instructions that are given will influence the focus of attention, which can affect the movement execution and therapy outcome. Physical therapists often refer to body parts or movements in their instructions (“keep your knees behind your toes”). In motor learning literature this is described as an instruction promoting an internal focus of attention. Such internal focus induces more conscious movements, interfering with automatic motor control. Recent research indicates that instructions promoting an external focus, i.e. directing attention to the effect of the movement on the environment (“squat down to the box”), result in better motor learning. Studies in sports and balance training have consistently shown better motor performance after a learning period with external versus internal focused instructions. The evidence favoring instructions promoting an external focus of attention is thus quite convincing, and it should be recommended to practitioners to avoid instructions which focus the attention on body parts or movements. However, in practice, finding the right instructions to induce an external focus of attention is difficult. One advantage of augmented reality is, therefore, the ability to provide external cues in order to facilitate gait adjustments, such as stepping stones projected on the walking surface or auditory beeps. Augmented reality using such external cues directs the attention of the patient to the virtual world instead of to his body, which therefore promotes an external focus of attention and likely improves the therapy outcome.

Implicit learning
Traditionally, new motor skills are taught by giving explicit instructions, resulting in conscious control of movement. However, movement control is usually based on implicit knowledge. We know how to make the movement, but are not consciously aware of how we control our muscles and cannot express it in words. Recent literature suggests that explicit learning may limit or interfere with such automatic processes, leading to worse performance, especially when subjects have to perform under pressure. Rehabilitation may therefore benefit from using implicit learning, i.e. learning without awareness of what is being learned. For example, in stroke
patients, performance on a dynamic balance task was worse after a period of explicit learning versus implicit learning.\textsuperscript{17} In the previous paragraph we described one way to promote implicit learning, namely by giving instructions or tasks inducing an external focus of attention. Alternative ways are to use a concurrent cognitive task\textsuperscript{13} or to provide variation in the tasks so that it is impossible to learn by explicit rules. Virtual and augmented reality based exercise games often promote implicit learning through one or more of these principles.

**Variation**
The importance of variation in exercises is another new insight from motor learning research. Instead of training the exact same movement over and over, small movement variations will result in more robust motor learning.\textsuperscript{18} Also, variation in the sequence of exercises (random versus blocked) will improve motor learning, especially retention and transfer.\textsuperscript{19} Although studies consistently favor variable practice, most studies have focused on laboratory tasks\textsuperscript{19,20} or applications in sports.\textsuperscript{18,21–23} When applying these principles to balance training, reduced postural sway during standing after fifteen minutes of varied balance exercises was reported (weight shifting and reduced base of support exercises), whereas no differences were found after repetitive training of standing as still as possible.\textsuperscript{24} It therefore seems that variable practice can also improve rehabilitation. By using virtual or augmented reality, variation can easily be created by the numerous exercise parameters, such as target placement, context, and speed requirements. Virtual or augmented reality based rehabilitation thus enables variable practice with little or no effort for the practitioner, thereby increasing efficiency and reducing costs.

**Training intensity**
It is well established that the intensity of the training (number of repetitions, training frequency, task difficulty) is an important determinant of therapy outcome.\textsuperscript{25–27} High intensity training is recommended in order to maximize treatment effects. Virtual reality can aid in achieving high training intensities by increasing patient motivation and adherence, improving training efficiency, and providing an adequate challenge. Clinical rehabilitation or physical therapy often requires repetitive training of relatively simple movements. Such monotone exercises quickly become boring, thereby making it difficult for the patient to stay focused and motivated. One of the key benefits of virtual rehabilitation is being able to use gaming techniques, which makes the therapy more fun and enjoyable.\textsuperscript{28–30} Because of this, the patient is more engaged in the therapy session and therapy adherence is higher.\textsuperscript{31–34} Also, the number of repetitions reached and the active training time are both greater with virtual and augmented reality based training than with conventional therapy.\textsuperscript{35–37} For example, twice as many steps were taken during an augmented reality based treadmill training when compared to conventional gait training.\textsuperscript{35} Increased motivation is surely one factor to explain this, but it’s not the only one; practical aspects such as the fact that there is no need to physically set out different walking tracks also factor in to the increased output. Lastly, virtual and augmented reality enable the maximization of training intensity by challenging the patient to the limits of his or her abilities. The difficulty of the game can easily and gradually be adjusted by changing settings, such as speed and target distance.

**Task specificity**
Another important recommendation for rehabilitation is to include task-specific training.\textsuperscript{26,38} To improve the transfer of progress in motor function to activities outside of therapy, the therapy should include practice of everyday challenges. Virtual and augmented reality can be used to simulate such challenges in a safe environment. For example, virtual and augmented reality could help train gait under difficult circumstances. This is essential because everyday walking is more than setting one foot in front of the other; it also requires the ability to adjust your walking pattern to different situations. You may need to lift your leg up higher to avoid tripping over a loose tile, or slow down to avoid bumping into someone. Gait adaptability, defined as the ability to adjust gait to environmental circumstances, is therefore a crucial element of walking at home or in the community. Augmented reality can be a helpful tool to train gait adaptability by projecting stepping targets or obstacles on the walking surface.\textsuperscript{10,39} In addition, virtual reality can be used to create optical flow when walking on a treadmill in order to enhance the feeling of natural walking.\textsuperscript{40,41} Further examples of everyday challenges are activities comprising both physical and cognitive tasks, such as crossing a street while watching traffic or walking while remembering your groceries list. When doing two tasks simultaneously it is often the case that performance of one or both tasks decreases. This so-called dual-task interference becomes more pronounced with age\textsuperscript{42} and with neurological disorders, such as stroke\textsuperscript{43} or Parkinson’s disease.\textsuperscript{44} Dual-task interference has been shown to be a predictor of falls.\textsuperscript{45} Since dual-task training is more effective in reducing dual-task interference than single-task training,\textsuperscript{46–49} fall prevention programs should always include dual-tasking.\textsuperscript{1} With virtual reality it is relatively simple to add cognitive elements to the training, and therefore, to train dual-tasking. One way to do this is to include a cognitive task that is not related to the motor task, such as counting backwards or a memory task. Another way is to incorporate the cognitive task in the virtual reality game, for example, games that require planning or strategy development. Lastly, cognitive elements can be added by actually simulating real-life dual-task challenges like walking through a virtual supermarket while putting items in a basket,\textsuperscript{50} crossing a street while avoiding obstacles\textsuperscript{51} or, for militaries, walking on unstable terrain while identifying and shooting military targets.\textsuperscript{52}

**Feedback**
In order to improve our motor performance, we require at least some information on our current performance. This feedback often comes from intrinsic sources, such as vision or proprioception. Intrinsic feedback can also be augmented...
by providing information that would normally be inaccessible for the patient, such as exact joint angles or moments (biofeedback). Using virtual reality, biofeedback can be shown to the patient or even incorporated into an exercise game. Providing biofeedback can be useful for both balance and gait training. Balance training with feedback usually consists of weight shifting exercises supported by feedback on the patient’s center-of-pressure (CoP) position. In a systematic review, the effectiveness of feedback-based balance training in old adults was evaluated and it was concluded that such training can result in reduced postural sway, improved weight-shifting ability, reduced attentional demands in quiet standing and increased scores on the Berg Balance Scale. There is also some evidence suggesting that adding biofeedback to balance training can be beneficial for stroke patients.

A large body of literature shows the effectiveness of biofeedback for gait retraining in different patient populations. For example, training with feedback can reduce the knee adduction moment or increase the toe-out angle for the prevention of knee osteoarthritis. Also, it can enhance forward propulsion during push-off in healthy old adults, making their gait pattern more similar to that of young adults. Feedback can help people with Parkinson’s disease or incomplete spinal cord injury to take longer steps and improve gait performance following transfemoral amputation. Knee hyperextension patterns in young women can be corrected using feedback in order to prevent knee problems due to excessive loading of knee structures.

Training with feedback has also been shown to reduce impact loading while running thus helping to prevent running-related injuries, and it has been shown to help modulate various gait parameters in both typically developing children and children with cerebral palsy. Future experiments are planned to test the ability to use the feedback protocol for diagnostic purposes in cerebral palsy. Together, these examples show that biofeedback is an effective and versatile tool that enables patients to adapt specific aspects of their gait.

In conclusion, the ability to provide biofeedback is one of the great assets of virtual reality training. By incorporating augmented feedback in a game, one can ensure patient motivation and engagement.

Efficacy

Numerous studies have examined the efficacy of virtual reality balance and gait games. Most of the balance training studies have used commercially available exercise games using the center of pressure as measured by a balance board. When compared to no intervention, virtual reality balance games were shown to be effective in improving balance in the elderly. When compared to conventional balance training, some studies report greater improvements in the virtual reality group, whereas others report similar improvements. Comparable findings were reported in patients with stroke, Parkinson's disease and multiple sclerosis. Similarly for these same populations, the addition of virtual reality training to conventional physical therapy or no therapy was consistently found to improve balance. When training duration was matched between the experimental and control group, some studies found greater improvement in the virtual reality training group, yet other studies found no differences between the groups. Virtual reality games have thus proven to be at least as effective, and maybe even more effective, in improving balance than conventional treatment. It should be noted that most games examined in these studies were not designed for rehabilitation, therefore greater improvements may be possible when games are specifically developed for patients.

Studies investigating the effect of virtual reality during gait training are consistently positive. A large six-week randomized control trial (RCT) with 282 subjects defined as fallers compared virtual reality based treadmill training with regular treadmill training. Only in the virtual reality group was the fall rate significantly reduced, with half as many falls in the following six months as compared with values from before training. Additionally, physical performance on several gait and balance tasks improved more in the virtual reality group. Similar RCTs with 25 multiple sclerosis patients and 20 stroke patients also showed the added value of virtual reality. Greater improvements were reported in walking speed, hip range of motion and hip generated power during walking, and clinical balance tests. Lastly, the transfer of ankle movement training to overground walking was greater using a virtual environment coupled with a robot than with the robot alone.

Conclusion

Overall, we can conclude that virtual and augmented reality are powerful tools for balance and gait training in clinical rehabilitation. The therapy outcome is optimized because virtual and augmented reality training follow the motor learning principles: an external focus of attention, implicit learning, variable practice, high training intensity, task specificity, and feedback. With the introduction of gaming elements, patients will experience the training as more enjoyable, resulting in greater motivation, engagement, and training adherence. By combining cognitive and physical aspects, rehabilitation exercises can more closely resemble real-life challenges, but in a safe environment. Moreover, real-time feedback on the screen can facilitate balance training and the retraining of specific gait parameters. Numerous studies have proven the added value of virtual and augmented reality for balance and gait training. Virtual and augmented reality, therefore, may well be the future of rehabilitation.
References


