

Continuation of balance training for stroke subjects in home environment using virtual reality

Imre Cikajlo*, Marko Rudolf, Nika Goljar and Zlatko Matjacic

University Rehabilitation Institute, Ljubljana, Slovenia

Abstract

The objective of telerehabilitation is a continuation of the rehabilitation process in the subjects' home whilst allowing the therapists and physicians the possibility to follow the progress remotely. In this article a pilot project with virtual reality based tasks for dynamic standing, frame supported, balance training is presented. Six stroke subjects participated in the preliminary study. The subjects performed the therapy five times a week, each time for up to 20 min, over a period of 3 weeks. The results were evaluated by objective game parameters as track time, number of collisions and clinical instruments Berg Balance Scale, Timed Up & Go and a 10 m walk test. The outcomes demonstrated a significant improvement of all parameters. However, the follow-up after 2 weeks demonstrated that functional improvement could be possible on a longer term if the subjects continue with targeted tasks for an extended period of time. Additionally, the balance training could be continued at the subject's home instead of the hospital, which would decrease the number of outpatient visits and reduce related costs.

Keywords: balance; stroke; telerehabilitation; virtual reality.

Introduction

One important issue in the stroke population is that of balance control. The loss of balance in most cases results in falls and consequently in injuries. Therefore, the restoration of static and dynamic balance is important for the restoration of functional capabilities of stroke subjects. The outcome of research performed in the US and UK in groups of stroke subjects demonstrated that functional capabilities may improve with rehabilitation in acute and chronic phase, when intensive therapy with repeatable and targeted tasks are applied (1). The therapy in these conditions in a clinical environment is assured by assistive devices that can assure safety. On the other hand these devices are ready for targeted tasks application in repeatable

conditions. A person with severe stroke using assistive devices during hospital treatment requires less physical effort from the medical staff, who can focus on the person and his/her task performance. The improvement of functional status can be achieved by applying target oriented tasks. Among such tasks is a simple ball catching or more complex task requiring person's attention and intervention in a virtual reality (VR) environment (2). The task built up in VR enables a gradual increase of task difficulty level, speed, sensitivity and specific goals, and can be adapted to the subject's cognitive and motor capabilities (3). VR supported therapy can improve balance capabilities in hemiparetic subjects with stroke when combined with conventional therapy (4) and, when presented as computer games, presents an additional motivation for subject (5).

But the main issue remains the limited time dedicated to the rehabilitation due to the financial limits of the health insurance system. It turns out that most of the subjects discontinue with any kind of activity that would enhance their functional capabilities when they are discharged from the rehabilitation hospital. Therefore, it is important to give them an opportunity to continue with the motivating tasks they are familiar with. Nowadays the information-communication technologies (ICT) are capable of transferring video, audio, secure data and graphics in real-time and play a major role in telerehabilitation. VR therapy can continue in remote rehabilitation centers, local hospitals or even in the subject's home. This may lead to a shortening of inpatient hospital treatment and a continuation of the rehabilitation process (e.g., balance training) in the subject's home. Equally, telerehabilitation in combination with telediagnosics may decrease the number of required outpatient visits (6).

We present here a development of a VR supported balance training system using a dynamic standing frame (7), which assures safety with limited range of motion and provides support during vertical posture. The designed task in VR was used in target oriented balance training in the rehabilitation hospital with six subjects with stroke who also continued with the therapy by themselves in the smart home. Only the physiotherapist supervised the therapeutic process occasionally via web browser and video conference. In participating subjects the clinical tests (Berg Balance Scale, Timed Up & Go and 10 m walk test, standing on a single extremity) were also carried out. We expected that the clinical tests would demonstrate rapid improvement of functional balance performance, which would not decline immediately after the therapy.

Methods

Six subjects with stroke (age 58.5 SD 12.1 years, weight 84.3 SD 11.5 kg, height 176.3 SD 5.7 cm) participated in the VR therapy at the Institute's hospital and in the development of a telerehabilitation

*Corresponding author: Imre Cikajlo, University Rehabilitation Institute, Linhartova 51, Ljubljana, Slovenia
E-mail: imre.cikajlo@ir-rs.si

Received November 1, 2010; accepted April 20, 2011

based prolonged therapy. The subjects with stroke were selected on the basis of the following inclusion criteria:

- show minimal ability to maintain upright posture and balance while standing in the standing frame;
- passed the cognitive test;
- checked cardiovascular status;
- subject has not taken any medications; a clinical examination was conducted by authorized medical personnel;
- subject had no prior experience with the dynamic balance and standing frame.

The methodology was approved by the Ethics Committee of the University Rehabilitation Institute, Republic of Slovenia and the subjects gave informed consent.

Equipment

In the last decade we have developed an assistive device for balance training in safe conditions, a dynamic standing frame, which was commercialized by a German company (Medica Medizintechnik, Hochdorf, Germany) and is known as the BalanceTrainer (BT), a simplified passive device for balance training. The balance training standing frame (Figure 1, left) is made of steel base construction placed on four wheels which, when unlocked, enable the apparatus' mobility. The standing frame is made of aluminum and fixed to the base with passive controllable springs defining the stiffness of the two degrees of freedom (2 DOF) standing frame. The stiffness of the frame is set up according to the individual's requirements. On the top of the standing frame a wooden Table 1 with safety lock for holding the subject at the pelvis level was mounted. The standing frame can tilt in sagittal and frontal plane up to $\pm 15^\circ$.

The tilt of the frame is measured by a commercially available three-axis tilt sensor (Xsens Technologies, Enschede, The Netherlands) and the action movement interfaces to the designated virtual environment. The virtual reality based task (modeled in VRML 2.0, running in MS Internet Explorer with blaxxun contact plug-in, blaxxun technologies GmbH, Munich, Germany) required the subject to "walk" by tilting the frame forward and "turn" by tilting the frame left or right. The subject moved through the park to the crossroad and according to the physiotherapist's instructions turned left to the bar, made a circle, returned to the crossroad and continued to the building

Table 1 The protocol timetable.

Clinical assessment			
1st week	2nd week	3rd week	4th–5th week
Activity	Activity	Activity	No activity
VRBT	VRBT	VRBT	No BT
Hospital	Hospital	Smart home	–

and entered, where the task was considered to be accomplished and restarted. Several repetition of the task was accomplished in one session (5 min). The system also registered and counted the number of collisions with VR objects and measured the time that was needed to finish a single task (from START to END point).

Balance training with VR task and clinical assessment

The subject was standing in vertical position in the balance trainer with his hands placed on the wooden table in front of him and secured with safety lock from behind at the level of pelvis, enabling tilting forward, backward, left, right and all combinations, but preventing any backwards fall. The speed of "walk" or "turn" was proportional to the frame tilt angle. The subjects walked through the virtual environment on the path suggested by the therapist and were trying to avoid collision with the objects like bank, pool, tables, chairs, people, etc. At last they entered the building and the task repeated over again. During the activity the task time and number of collisions were detected and at the end presented to the subject. All the subjects needed additional assistance during balancing at the beginning of the task performance in the rehabilitation hospital. After 2 weeks of the VR supported balance training they were set in the smart home environment and performed the task on their own. The tasks were designed to run in a web browser allowing the medical professionals to supervise (Figure 1 right), monitor and control the balance training process remotely through the Internet. Additionally, the videoconference enabled the physiotherapist to give the subject an important advice during the dynamic balance training, e.g., to correct the posture, hand placement, etc.

The subjects performed the therapy [virtual reality balance training (VRBT)] five times a week, each time for up to 20 min over a period

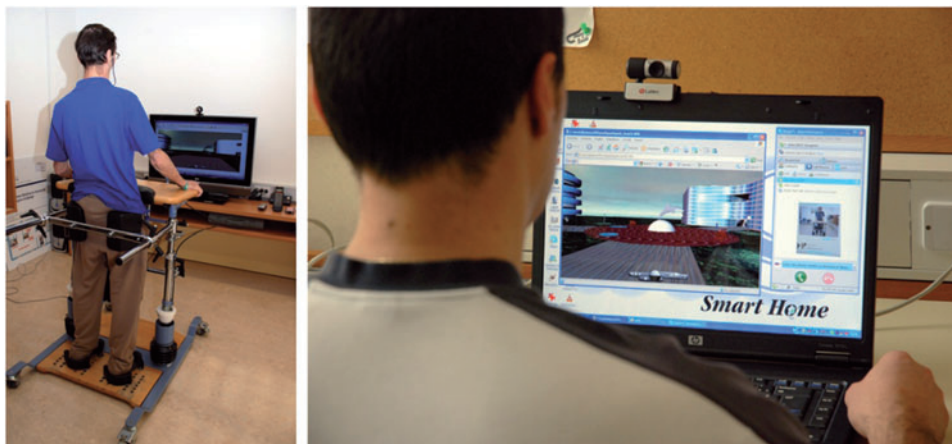


Figure 1 Balance training with task in virtual environment could be continued in subject's home (left). Therapist (right) supervised and advised the subject through the videoconference and followed the task performance in the Internet Explorer.

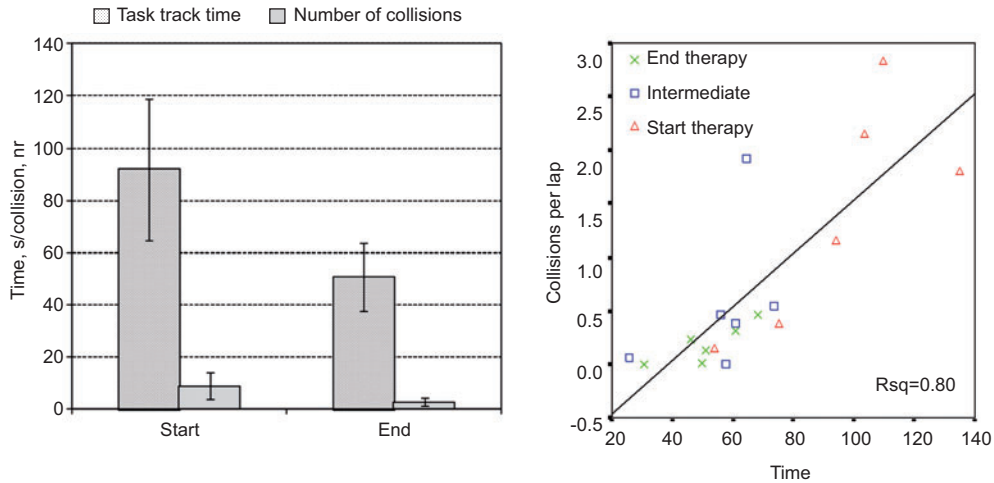


Figure 2 Measured outcomes (left). The subjects accomplished the VR task significantly faster with fewer collisions with objects after therapy. The “score” was also considered a motivation factor for each individual. Number of collisions normalized per task (lap) correlated well with the task time (right).

of 3 weeks. The results were evaluated by objective game parameters, such as track time, number of hits and the clinical instruments Berg Balance Scale, Timed Up & Go (TUG), and a 10 m walk test.

Results

Over the course of the training, the task time was reduced by 42.7 s (45%) and the subjects committed in average of six (68%) fewer collisions (Figure 2). The collisions with objects were averaged on single VR task (“lap”) and a linear regression (Pearson’s coefficient) with the VR task time demonstrated high level of agreement, $R=0.80$ (Figure 2). This confirmed our observations that subjects who managed to accomplish the task faster, also collided with fewer obstacles.

Figure 3 shows clinical outcomes (10 m test, TUG, BBS, standing on affected extremity (AE), standing on the healthy

extremity (HE)) of the participating subjects. The mean and standard deviation (SD) values for all subjects prior, after the training and the follow-up are presented. All observed parameters have improved with training, although the assessment of the AE and also of the HE was not possible prior to the therapy for all subjects due to the impairment. Some subjects also used an additional walk aid and/or needed therapist’s assistance (a reason for a higher SD). The BBS score improved from 37/56 to 42/56, standing on one leg was longer for HE by up to 10 s and AE up to 4 s. The subjects also improved their TUG time in average for 10.0 s and 10 m walk time in average for 4.6 s.

Discussion

All participating subjects were able to accomplish the VR task faster at the end than at the beginning of the therapy and

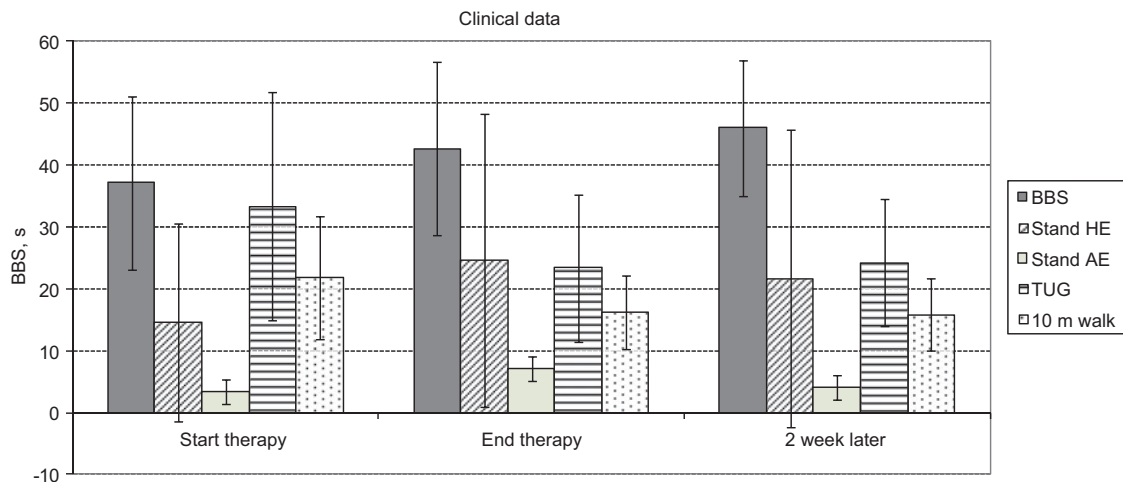


Figure 3 Clinical outcomes in subjects who participated in balance training with virtual reality tasks and the follow-up after 2 weeks.

commit fewer collisions with obstacles. This can be attributed to the fact that the subjects mastered the exercise, as well as their balance abilities improving. The latter is evident from fewer collisions which force the participating subject to transfer the load to the medial extremity and overcome a VR obstacle; otherwise the collision would be unavoidable. The improved balance abilities were evident from the BBS improvement and also from the fact that most of them could stand on the affected extremity, which was not possible for all subjects prior to the therapy. The gait clinical tests 10 m walk and TUG also demonstrated significant improvement, which resulted in better overall mobility. Summarizing the outcomes we may claim that the functional status of the participating subjects has significantly improved and remained practically the same after 2 weeks during which they had no balance training. Also we have not noticed any postural instability or VR sickness as a consequence of immersions in dynamic VR environment, thus we are aware of subjective physical experience of moving. The limitation in field of view may also have had impact on performance (8) as well as the problems in cognitive processing due to conversion of tilting into “walking”. Also the VR supported learning may not be always transferable to the real world applications or be effective immediately in the real world (9).

Conclusions

Telerehabilitation presents a novel approach in treatment of subjects with neuromuscular injuries or diseases (10). The proposed approach is not based only on teleconsulting which is indeed indispensable, but also supervised control and guidance of the therapy process remotely via the Internet. The clinical outcomes are comparable with conventional therapy and passive device supported balance training, but allows the patients more independence and an earlier return home. Additionally, physiotherapists are relieved from strenuous manual work. The proposed approach also takes into consideration an economic view (11) since the number of outpatient visits could be reduced. Besides that the return home had positive effects on the motor performance of the subjects and one of the most important issues was that the subjects expressed personal satisfaction (12).

Acknowledgments

The authors would like to acknowledge the financial support of the Slovenian Research Agency (Grant Nr. P2-0228).

Conflict of interest statement

Authors' conflict of interest disclosure: The authors stated that there are no conflicts of interest regarding the publication of this article. Research funding played no role in the study design; in the collection, analysis, and interpretation of data; in the writing of the report; or in the decision to submit the report for publication.

Research funding: None declared.

Employment or leadership: None declared.

Honorarium: None declared.

References

1. Kwakkel G, Wagenaar RC, Twisk JW. Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *Lancet* 1999;354:191–6.
2. Holden MK. Virtual environments for motor rehabilitation: review. *Cyberpsychol Behav* 2005;8:187–219.
3. Cikajlo I, Matjacic Z. Advantages of virtual reality technology in rehabilitation of people with neuromuscular disorders. In: Naik, Ganesh R, editors. *Recent advances in biomedical engineering*. Vienna: In-Tech, 2009:301–20.
4. Kim JH, Jang SH, Kim CS, Jung JH, You JH. Use of virtual reality to enhance balance and ambulation in chronic stroke: a double-blind, randomized controlled study. *Am J Phys Med Rehabil* 2009;88:693–701.
5. Rizzo AA, Strickland D, Bouchard S. The challenge of using virtual reality in telerehabilitation. *Telemed J E Health* 2004;10:184–95.
6. Cikajlo I, Matjacic Z. Directionally specific objective postural response assessment tool for treatment evaluation in stroke patients. *IEEE Trans Neural Syst Rehabil Eng* 2009;17:91–100.
7. Matjacic Z, Johannesen IL, Sinkjaer T. A multi-purpose rehabilitation frame: a novel apparatus for balance training during standing of neurologically impaired individuals. *J Rehabil Res Dev* 2000;37:68–91.
8. Nyberg L, Lundin-Olsson L, Sondell B, Backman A, Holmlund K, Eriksson S, et al. Using a virtual reality system to study balance and walking in a virtual outdoor environment: a pilot study. *Cyberpsychol Behav* 2006;9:388–95.
9. Rose FD, Attree EA, Brooks BM, Parslow DM, Penn PR, Ambihapahan N. Training in virtual environments: transfer to real world tasks and equivalence to real task training. *Ergonomics* 2000;43:494–511.
10. Lai JC, Woo J, Hui E, Chan WM. Telerehabilitation – a new model for community-based stroke rehabilitation. *J Telemed Telecare* 2004;10:199–205.
11. Dhurjaty S. The economics of telerehabilitation. *Telemed J E-health* 2004;10:196–200.
12. Piron L, Turolla A, Tonin P, Piccione F, Lain L, Dam M. Satisfaction with care in post-stroke patients undergoing a telerehabilitation programme at home. *J Telemed Telecare* 2008;14:257–60.