

Telerehabilitation: remote multimedia-supported assistance and mobile monitoring of balance training outcomes can facilitate the clinical staff's effort

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Telerehabilitation can offer prolonged rehabilitation for patients with stroke after being discharged from the hospital, whilst remote diagnostics may reduce the frequency of the outpatient services required. Here, we compared a novel telerehabilitation system for virtual reality-supported balance training with balance training with only a standing frame and with conventional therapy in the hospital. The proposed low-cost experimental system for balance training enabling multiple home systems, real-time tracking of task's performance and different views of captured data with balance training, consists of a standing frame equipped with a tilt sensor, a low-cost computer, display, and internet connection. Goal-based tasks for balance training in the virtual environment proved motivating for the participating individuals. The physiotherapist, located in the remote healthcare center, could remotely adjust the level of complexity and difficulty or preview the outcomes and instructions with the application on the mobile smartphone. Patients using the virtual reality-supported balance training showed an improvement in the task performance time of 45% and number of collisions of 68%, showing significant improvements in the Berg Balance Scale, Timed 'Up and Go', and 10 m Walk Test. The clinical outcomes were not significantly different from balance training with only the standing frame or conventional therapy. The proposed telerehabilitation can facilitate the physiotherapists' work and thus enable rehabilitation to a larger number of patients after release from the hospital because it requires less time and infrequent presence of the clinical staff. However, a comprehensive clinical evaluation is required to confirm the applicability of the concept.

Eine Telerehabilitation kann Schlaganfallpatienten nach ihrer Entlassung aus dem Krankenhaus zu einer anhaltenden Rehabilitation verhelfen bei gleichzeitiger Senkung der Häufigkeit der beanspruchten Einrichtungen dank Ferndiagnose. Hier verglichen wir ein neuartiges System der Telerehabilitation mit virtuellem realitätsunterstütztem Gleichgewichtstraining einerseits mit einem Gleichgewichtstraining nur mit Stehständer und konventioneller krankenhausbasierter Therapie andererseits. Das geplante kostengünstige experimentelle System des Gleichgewichtstrainings für multiple Haussysteme, Echtzeit-Verfolgung der jeweiligen Aufgabe und unterschiedlichen Ansichten der erfassten Daten mit Gleichgewichtstraining umfasst einen Stehständer mit Kippsensor, einen preisgünstigen Computer mit Monitor

und Internetanschluss. Die zielgerichteten Aufgaben für das Gleichgewichtstraining im virtuellen Umfeld motivierten die einzelnen Teilnehmer. Der Physiotherapeut im entlegenen Gesundheitszentrum konnte den Komplexitäts- und Schwierigkeitsgrad per Fernbedienung einstellen oder die Ergebnisse und Anweisungen mit Hilfe der Applikation eines Smartphones kontrollieren. Patienten, die sich einem virtuellen realitätsgestützten Gleichgewichtstraining unterzogen, wiesen bei der Zeit der Ausübung von Aufgaben eine Verbesserung von 45% und bei der Zahl der Kollisionen von 68% auf. Dies sind signifikante Verbesserungen bei der Berg-Balance-Skala, beim Timed Up-and-Go-Test zur Mobilitätsmessung und beim 10 m-Gehtest. Die klinischen Ergebnisse unterschieden sich nicht signifikant vom Gleichgewichtstraining ausschließlich mit Stehständer oder konventioneller Therapie. Die geplante Telerehabilitation kann die Arbeit von Physiotherapeuten erleichtern und die Rehabilitation somit einer größeren Zahl von Patienten nach Entlassung aus dem Krankenhaus zugänglich machen, weil das klinische Personal dabei zeitlich weniger beansprucht wird und weniger häufig anwesend sein muss. Eine umfassende klinische Evaluierung zur Bestätigung der Anwendbarkeit des Konzepts ist jedoch erforderlich.

Los servicios de telerehabilitación pueden ofrecer una rehabilitación prolongada a los pacientes con accidente cerebrovascular tras haber sido dados de alta del hospital, mientras que los diagnósticos a distancia pueden disminuir la frecuencia de los servicios requeridos por los pacientes externos. En este estudio se comparó un novedoso sistema de telerehabilitación para el entrenamiento del equilibrio basado en realidad virtual con la modalidad de entrenamiento del equilibrio donde solo se hace uso de un bipedestador y con el tratamiento convencional administrado en el hospital. El sistema experimental de bajo coste propuesto para el entrenamiento del equilibrio, el cual admite múltiples sistemas domóticos, seguimiento de las tareas a tiempo real y distintas vistas de las capturas de datos con entrenamiento del equilibrio, consiste en un bipedestador equipado con un sensor de inclinación, un ordenador de bajo coste, una pantalla y conexión a internet. Los ejercicios basados en los objetivos para el entrenamiento del equilibrio en el entorno virtual demostraron ser de gran motivación para los participantes. El fisioterapeuta, que se encontraba en el centro de salud a distancia, era capaz de

ajustar mediante control remoto el nivel de complejidad y dificultad o visualizar los resultados y las instrucciones mediante la aplicación de un teléfono móvil inteligente. Aquellos pacientes que utilizaron el sistema de entrenamiento del equilibrio basado en la realidad virtual mostraron una mejora del 45% en el tiempo de ejecución de los ejercicios y un número de caídas del 68%, presentando a su vez mejoras significativas en la Escala de Equilibrio de Berg, la prueba de levantarse y caminar cronometrada y la prueba de la marcha de 10 minutos. Los resultados clínicos no fueron significativamente distintos a los del entrenamiento del equilibrio con bipedestador o los del tratamiento convencional. El sistema de telerehabilitación propuesto puede facilitar el trabajo de los fisioterapeutas y, por lo tanto, permitir la rehabilitación de un número mayor de pacientes tras haber sido dados de alta del hospital, ya que requiere una menor duración y una menor frecuencia de la presencia del personal clínico. Sin embargo, se precisa llevar a cabo una evaluación clínica exhaustiva con el fin de confirmar la aplicabilidad de dicho concepto.

La rééducation à distance peut offrir une rééducation prolongée au patients victimes d'AVC après leur sortie de l'hôpital, les diagnostics à distance pouvant réduire la fréquence de consultation des services externes. Ici, nous avons comparé un système de rééducation à distance d'entraînement à l'équilibre par réalité virtuelle soutenu seulement par un cadre de support à un traitement hospitalier classique. Le système expérimental à bas prix proposé pour l'entraînement à l'équilibre permet le suivi en temps réel de l'exécution des tâches sur plusieurs systèmes à domicile et différentes interprétation des données capturées avec l'entraînement à l'équilibre ; il se compose d'un cadre de support équipé d'un capteur d'inclinaison, d'un ordinateur de faible coût avec écran et

d'une connexion Internet. Les tâches axées sur des objectifs pour l'entraînement à l'équilibre dans l'environnement virtuel se sont avérées motivantes pour les participants. Le kinésithérapeute, situé dans le centre de soins à distance, pouvait ajuster le niveau de complexité et de difficulté ou prévisualiser les résultats et les instructions avec l'application sur un smartphone portable. Les patients utilisant l'entraînement à l'équilibre par réalité virtuelle ont présenté une amélioration de 45% dans l'exécution des tâches dans le temps et un nombre de collisions de 68%, ce qui traduit des améliorations significatives sur l'échelle d'équilibre de Berg, les mesures « Up and Go » temporisées et le test de marche de 10m. Les résultats cliniques n'étaient pas significativement différents de la rééducation à l'équilibre avec seulement le cadre de support ou la thérapie conventionnelle. La rééducation à distance proposée peut faciliter le travail des physiothérapeutes et ainsi permettre la rééducation d'un plus grand nombre de patients après leur sortie de l'hôpital, car elle nécessite moins de temps et une présence moins fréquente du personnel clinique. Toutefois, une évaluation clinique complète sera nécessaire pour confirmer l'applicabilité du concept. *International Journal of Rehabilitation Research* 36:162–171 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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Introduction

Stroke is the leading cause of neurological impairment and serious, long-term disability worldwide. According to the WHO, 15 million individuals survive stroke worldwide each year; 5 million are permanently disabled. Stroke usually affects the neuromuscular system's ability to accurately coordinate muscle groups into postural muscle synergies. This presents a critical aspect of maintaining stability (Shumway-Cook and Woollacott, 2001). The poor coordination of the interaction of each individual with the demand of the functional task and with the constraints of the environment may result in a loss of stability. Poor postural stability or poor balance in most cases results in falls, which may cause fractures or severe injuries. Restoration of static and dynamic balance and postural control is very important for restoration of functional capabilities in patients with stroke. However, such rehabilitation is rather complex, considering that postural control involves various sensory and motor

systems responding in different ways to variable tasks and requirements of the environment. Here, the success of the rehabilitation process also depends on previous experience and learning. Thus, the aim of the task, attention, and motivation of the patient should be considered (Shumway-Cook and Woollacott, 2001). The outcomes of research carried out in a group of patients with stroke showed that improvement in functional capabilities is possible in the acute and chronic phase when intensive physiotherapy with goal-based tasks is applied (Kwakkel *et al.*, 1999). Several studies examined by a systematic review (Hammer *et al.*, 2008), have shown that functional improvement in balance in patients after stroke is also possible by implementing a variety of physiotherapeutic interventions even without the use of extensive technical equipment. However, the inclusion of a feedback in the conventional balance training (CBT) may draw the attention and motivation of the participating individuals. The balance training with force platform

biofeedback as additional therapy to the conventional therapy in the hospital proved beneficial in improving postural stability and weight bearing on the affected side while walking late after stroke (Yavuzer *et al.*, 2006). Recently, biofeedback has also been provided in the form of tasks in virtual reality (VR). Several studies have reported that individuals with disabilities showed ability of motor learning in virtual environments (Holden, 2005; Yang *et al.*, 2008; Lewis *et al.*, 2011; Wade and Winstein, 2011). The VR represents a suitable tool for a design of simulated, interactive, and multidimensional environments. The value of the VR rehabilitation lies in the experience for the user; both therapists and users can benefit from the ability to design goal-oriented tasks that enable a gradual increase in tasks' difficulty and complexity, speed, and a specific goal (Sveistrup, 2004). The VR tasks could be adapted to the individual's cognitive and motor capabilities to provide neither too much nor too little information to maximize learning (Orsolya *et al.*, 2011; Van Dokkum *et al.*, 2012).

However, sometimes, rehabilitation after stroke requires more time and training than is available for inpatient treatment because of the financial limitations of the healthcare insurance system. One of the possible solutions would be a continuation of the rehabilitation therapy with similar tasks at a remote location within the outpatient service or in a patient's home (Cikajlo *et al.*, 2012). The pilot study (Lai *et al.*, 2004) showed the feasibility, efficacy, and high level of acceptance of telerehabilitation for community-dwelling stroke clients. Here, the participants accepted well the use of videoconferencing for the delivery of the intervention. Kairy *et al.* (2009) reported on satisfaction with telerehabilitation, even higher for patients than therapists. The same review reported on some preliminary evidence of potential cost savings for the healthcare facility. Besides telerehabilitation, a continuous telemonitoring of patients' functional status would be promising for the patient management approach (e.g. decrease in the emergency visits, hospital admissions, average hospital length of stay) (Pare *et al.*, 2007).

The advantages offered by VR tasks may also require additional equipment to enable repeatable conditions for balance training. We have merged the advantages of VR technology, telerehabilitation, teliagnostics, and telecare for the purpose of balance training of patients after stroke, but have also used light equipment to ensure repeatable conditions. A standing frame enabled hands-free and safe standing during balancing, quiet standing, and postural control. Limited range of motion and support provided for upright standing allowed a neurophysiotherapist to focus on accurate and reliable performance of goal-based tasks. While the patient performed a task in VR, the physiotherapist occasionally supervised the progress through web browser and video conference. The client-server application allowed supervision of more than one patient at a time and also enabled an overview of

the results later offline with a terminal, a tablet, or a smartphone. The methodology was compared with the standing frame-supported balance training in hospital without the VR task and the conventional therapy with balance training. All patients were clinically tested using validated clinical tests the Berg Balance Scale (BBS) (Berg *et al.*, 1995) and mobility tests Timed 'Up and Go' (TUG) (Ng and Hui-Chan, 2005) and the 10 m Walk Test (10MWT) (Wade, 1992) before and after the balance training. In addition, a comparison of the time spent and equipment used in all methods was carried out to examine the functional value of the proposed approach.

Methods

Equipment

Architecture

Architecture is client/server with two distinct types of clients and a central database.

Server

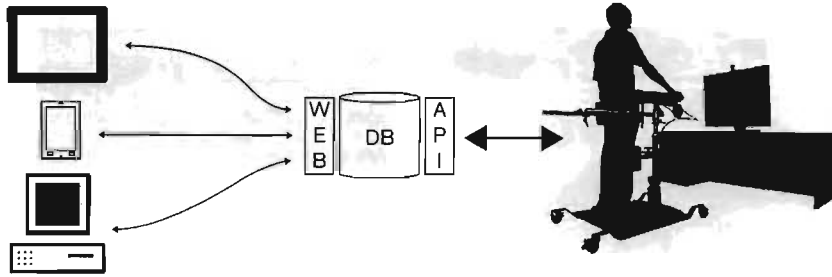
The central server consists of two threaded TCP/IP servers, each being a front end to the database, where all the data were stored (Fig. 1). One of the servers was used to gather data of standing frame movement and to conduct the virtual environment, down to determining the type of task and its difficulty level. The second server was used to present the results of the tasks remotely to a physiotherapist in an accessible form.

Client – home system

As the home system was designed for patients with balance issues, its main component was a standing frame BT (BalanceTrainer; Medica Medizintechnik GmbH, Hochdorf, Germany) (Matjačić *et al.*, 2000), which was used for support and safety – to prevent the patient from falling, and as a supporting frame – to enable an upright posture. A 3-axial tilt/inclination sensor (Oak USB; Toradex AG, Horw, Switzerland) was attached to the standing frame. A USB 2.0 port was used to connect to the computer and was used as an input device to control the movement in the virtual environment (Fig. 2). The proposed system applied a low-cost and a small form factor (Intel Atom-based nettop) computer, equipped with hardware-accelerated three-dimensional capabilities (Nvidia ION, Santa Clara, California, USA).

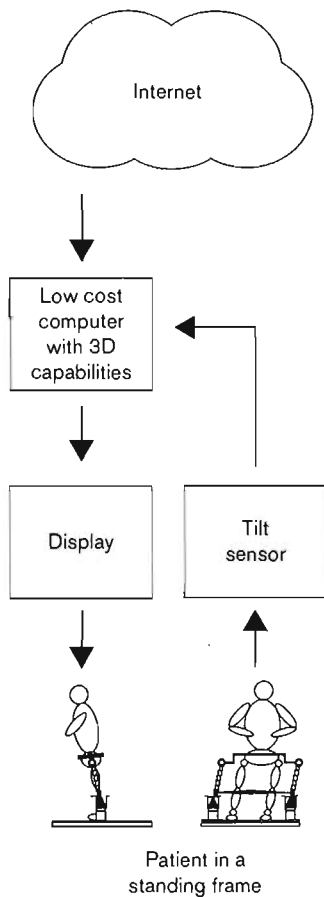
The computer used the Ubuntu (Freeware) operating system, which is a Linux-based distribution and Chromium (open-source browser) browser. The virtual environment was constructed using Panda3D engine (Carnegie Mellon's Entertainment Technology Center, Pittsburgh, Pennsylvania, USA). The web player, installed as a browser plug-in, was used to simplify the distribution of different tasks, their updates, and additions. Another browser plug-in was programmed to make USB sensor data available to the task running in the Panda3D environment.

Fig. 1



The system was based on a central server with a database, serving the data to the two different user interfaces. The right front end provided the set of application interfaces (APIs) needed by remote rehabilitation setup; home system, the left front end was a web server with a data presentation layer designed to the type of device used for access.

Fig. 2



Home system consists of a standing frame, which prevents the patient from falling and provides passive support to maintain an upright posture, a sensor capturing the tilt of the standing frame, a low-cost computer with three-dimensional (3D) capabilities, a display, and an Internet connection.

To achieve an acceptable level of responsiveness, a broadband Internet connection was considered. A bitrate of 150 kb/s was used to ensure smooth transfer of the VR task to the client's browser, real-time data exchange

during the task performance, and to periodically send acquired data back to the server.

Client – therapist's tool

The physiotherapist could access information about the patient, outcomes of the clinical tests, and current and past sessions using any desktop or portable device equipped with a web browser. Outlook was adjusted to the two common portable device form factors: a smartphone (Fig. 3) and a tablet (Fig. 4). The user interface development was based on the jQuery Mobile javascript framework.

Goal-based balance training

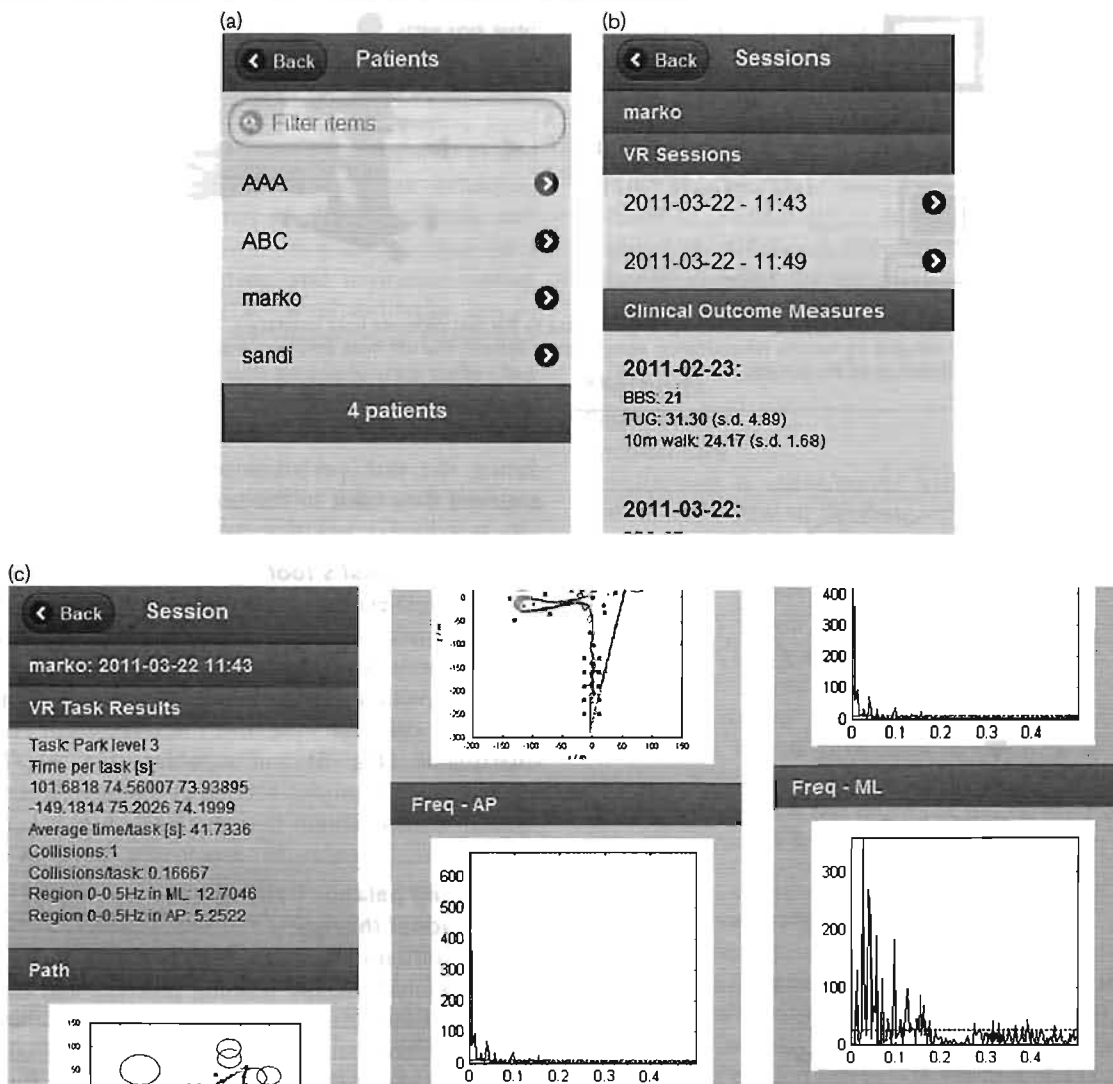
Conventional therapy

The rehabilitation program of the hospital also comprised a conventional therapy training protocol and the participating patient group received balance training as an extension. The patients were encouraged through verbal and tactile cues to increase weight bearing to the affected lower limb and thus achieve a symmetrical weight distribution. The CBT envisaged balance training exercises during standing in the parallel bars. Patients held the parallel bars and gradually increased the weight bearing to the affected lower limb. Among the exercises were also leaning forward, backward, and gradual addition of arm activities. Task became difficult with holding a ball during weight shifting from unaffected to affected extremity in left–right or forward–backward directions.

Balance training using a standing frame

The patients used the BT standing frame that provided a fall-safe balancing environment for patients with balance problems. BT could stabilize forces acting at the level of pelvis in the sagittal and frontal planes and thus helped the patients maintain stability. The forces were generated by passive spring and compliant materials and could be varied from zero up the level without balance activity. The participating patient stood vertically in the standing

Fig. 3



User interface to review the results of performed tasks in the form factor of a contemporary smartphone. After the selection of a patient (a), the physiotherapist was presented a list of sessions with clinical information for a particular patient (b). Details of a single session consist of task results and graphs of path taken in the virtual environment and tilts of a supporting frame in the frequency space for the anterior-posterior and mediolateral directions (c). AP, anterior-posterior; BBS, Berg Balance Scale; ML, mediolateral; TUG, Timed 'Up and Go'; VR, virtual-reality.

frame and practiced balance by reaching the target as requested by the physiotherapist and thus shifted the weight to the affected lower limb. This task was made even more difficult when the patients held the ball. The entire range of anterior-posterior and mediolateral activities as well as the evaluation program on the BT device and its predecessor device were published by Matjačić *et al.* (2000).

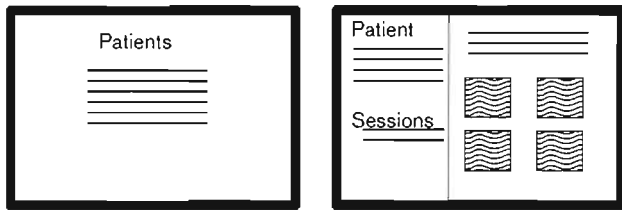
Virtual reality feedback and telerehabilitation-supported balance training using a standing frame

VR technology has been applied here to build a goal-based task that could provide clear goals, enable day-to-day repeatability, control over the complexity and

difficulty level, and that would motivate the patients. The basic idea of balance training remained the same: gradually increase the weight bearing to the affected lower limb. Therefore, each task in the VR was directly connected to the weight shifting.

The participating patients were standing in the same BT standing frame, equipped with the three axial tilt/inclination sensor providing data on anterior-posterior and mediolateral tilt to the computer running VR. The information on tilt was transformed into the movement velocity of VR; the greater the tilt, the faster the movement of the VR: $v_{mov} \sim \alpha \cdot \text{tilt} (\text{°})$. The patients tilted the standing frame in the anterior direction (Fig. 2) and made a controlled movement in the VR environment

Fig. 4



Mock-up user interface in the form factor of a tablet. After the patient was chosen from the list, his personal details, outcomes of clinical tests, and sessions performed were listed. A particular session could then be selected for details in the main view.

Fig. 5



The virtual environment contains a model of a hotel resort with objects carefully placed as obstacles to form a path that encouraged the patient to shift the load from the unaffected to the affected lower limb. The view was augmented with the map of the virtual environment.

(Fig. 5), and when returned to the upright position, the movement in the VR stopped. Shifting the weight from one side to another and consequently tilting the standing frame in the mediolateral direction caused a turn in the VR environment. The patients used the combination of these movements to navigate through the VR environment and remain on the virtual path as requested by the physiotherapist. The virtual path contained several obstacles such as cans, bins, benches, pool, chairs, and table, which needed to be timely avoided. At the end of the path, the patients virtually entered the building and restarted the task. The VR task was displayed on the screen in front of the patient standing in the BT standing frame and available in real time through the internet browser to the physiotherapist on a remote location. The web access enabled the physiotherapist supervision, monitoring, and control of the balance training remotely. All the parameters, virtual path, task time, and number of collisions with the obstacles were recorded simultaneously and were also available offline (Figs 3 and 4).

Assessment protocol

The control group participated (CBT) in the conventional rehabilitation program of the rehabilitation hospital mainly on the basis of manual therapy. Within this therapy, the balance training program was carried out. The physiotherapist held the individual patient and assisted during the balance training with various objects (e.g. ball). The program lasted 4 weeks, 5 days a week, and 45 min/day.

The first experimental group (BT) used the passive balance training device BT and performed simple tasks. The patient stepped in the balance frame BT and relaxed his/her arms while placing his/her hands on the table. The table moved together with the standing frame. The physiotherapist fixed the safety lock at the level of the pelvis to ensure 100% safety. The tasks consisted of holding a ball and leaning in the major direction, left, right, forward, backward, while standing in the standing frame (Fig. 2). Among the main goals of balance training was also increasing the weight bearing to the affected

limb, which is one of the most difficult tasks for patients with stroke. This balance training also lasted 4 weeks, 5 days a week, but only 20 min/day.

The second experimental group [Tele-virtual reality balance training (VRBT)] participated in the telerehabilitation program, comprising balance training with tasks in VR and telediagnosics from a remote computer, tablet, or smartphone. The patient stepped into the balance frame BT in the same way as described above, but focused on the large screen in front of the BT. On the screen, the task in VR was displayed together with the instructions. Besides, the patients could make a video call to the physiotherapist anytime and also the physiotherapist made a call to provide verbal instructions on how to perform the task or how to correct the posture, place the hand, etc. In the first 2 weeks, the patient had a physiotherapist's physical assistance, whereas in the last week, he/she could rely only on him/herself or nonprofessional assistance. One of the main goals of VR balance training was also to unconsciously increase weight bearing to the affected lower extremity, while being focused on the VR task. The balance training program lasted 3 weeks, 5 days a week, but around 15 min/day. These 15 min included three repetitions of the task, each lasting 5 min and less than a minute's rest between the sessions.

All sessions were carried out within the rehabilitation hospital, except the last week of the telerehabilitation program, which was performed in the modern Smart Home (Dom Iris: IRIS Smart Home, 2008). The Smart Home was adopted to the patients' needs, enabled independent living, and was equipped with communication technologies. Although the CBT group and BT group trained under the supervision of the two senior neuro-

physiotherapists, only one skilled neurophysiotherapist supervised the VRBT group.

The overall balance and mobility capabilities of all three groups were evaluated before and after the treatment. A skilled physiotherapist carried out the balance test BBS and two relevant mobility tests: 10MWT and TUG. The BBS is a 14-item test that uses the five-point scale (0–4) to evaluate each individual test. The test was validated in acute patients with stroke with high intrarater and inter-rater reliability (Berg *et al.*, 1995). The maximal score indicating a good balance is 56. In the 10MWT, the relevant information was the measured time needed to walk a 10 m distance. The participating patients were allowed to use walking aids, orthoses, and even seek the assistance of the physiotherapist. The TUG is considered a physical agility test, which measured the time needed to stand up from the sitting position, walk around the obstacle 8 ft far from the chair, and return to the initial position and sit again. In this test, walking aids, orthoses, and even the assistance of the physiotherapist were also allowed.

Participants

Participants were randomly selected from the 262 subacute stroke patients. Those who fulfilled the inclusion criteria and were willing to participate were randomized into groups. Conventional therapy with physiotherapist-assisted balance trainer was carried out in 11 patients, balance training with a BT device was carried out in nine patients, and balance training with BT and tasks in the virtual environment with telerehabilitation (Cikajlo *et al.*, 2012) support was performed in six patients with stroke (Tele-VRBT) (Tables 1 and 2). In addition, two patients with stroke also tested the telerehabilitation system presented with mobile telediagnosics. The patients with stroke were selected on the basis of the following inclusion criteria: (a) show minimal ability to maintain an upright posture and balance while standing in the standing frame, (b) fully oriented, performed well on simple tests of short-term memory and able to follow two-step directions, (c) stable medical condition, no other neurological or musculo-skeletal impairments or heart failure (New York Heart Association Classification Class I, II), (d) without psychotropic medications, and (e) willing to participate and had no previous experience with the dynamic balance

and standing frame. Patients suffering for neglect were excluded.

The methodology was approved by the local ethics committee and the participants provided informed consent.

Statistical data analysis

For each participating patient in the Tele-VRBT group, the task performance was evaluated by VR task time and the number of collisions with the obstacles in the VR environment. Statistical analysis (mean and 95% confidential interval) before and after the balance training was carried out using Matlab software (MathWorks Inc., Natick, Massachusetts, USA). For all three groups of participating patients, a statistical analysis (mean, SD) of the outcomes of clinical test BBS, TUG, and 10MWT before and after the balance training program was carried out. In addition, differences between the outcomes before and after the balance training in all three groups (conventional therapy, BT, and Tele-VRBT) were explored using a two-way mixed-model analysis of variance statistical tool SPSS v.17 (SPSS Inc., Chicago, Illinois, USA).

Results

Outcomes of the clinical tests showing improvement in balance and mobility capabilities in all the groups are presented in Table 2. The CBT group showed an improvement on average in their BBS by 54%, the BT group by 55%, and the Tele-VRBT group by 15%. Similar improvements were found in mobility tests TUG for CBT, 20.4%, for BT, 20%, and for Tele-VRBT, 29.9%, and 10MWT 16.9, 13.9, and 25.7% for the CBT, BT, and Tele-VRBT groups, respectively. The changes in time were significant despite the high variance in all clinical tests. However, the interaction between groups showed that the changes were not significant (Table 2).

The Tele-VRBT group showed an improvement in task performance; the average VR task time had decreased for 45% and the number of collisions with VR obstacles had decreased for 68% (Fig. 6).

The analysis of the resources required for the balance training of all three groups showed that telerehabilitation required less time and effort of physiotherapists. For the balance training in the CBT and BT groups, two skilled neurophysiotherapists were required, whereas the telerehabilitation required only one physiotherapist for the time a patient spent in the hospital (Table 3). However, the telerehabilitation required more equipment and a dedicated space.

Discussion

Clinical tests carried out in this proof-of-concept study confirmed that all groups showed improvements in balance and mobility capabilities (Table 2). Similar

Table 1 Participating patient groups in the telerehabilitation-telediagnosics proof of concept

Groups	Age (years)	After stroke (months)	Sex (M/F)	Affected side (L/R)
CBT	63.0 (8.5)	2–10	6/5	6/5
BT	61.0 (7.4)	1–10	4/5	4/5
Tele-VRBT	58.5 (12.1)	3–8	5/1	3/3

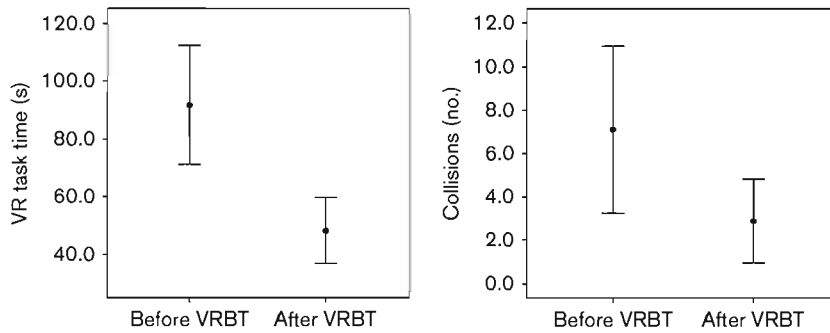
BT, BalanceTrainer; CBT, conventional balance training; F, female; L, left; M, male; R, right; VRBT, virtual reality balance training.

Table 2 Participating patients before the balance training for each type of therapy [conventional therapy, BalanceTrainer, and Telerehabilitation with BalanceTrainer (Tele-virtual reality balance training)]

Groups	BBS (score)		TUG (s)		10MWT (s)		P-value time effect	P-value for interaction
	Before	After	Before	After	Before	After		
Conventional therapy	23.0 (11.4)	35.55 (12.4)	32.8 (18.8)	26.1 (12.8)	24.8 (14.2)	20.6 (11.0)	0.007*	0.957
BT	21.6 (9.8)	33.6 (12.3)	42.8 (16.2)	34.2 (15.9)	32.4 (13.5)	27.9 (13.9)	0.018*	0.988
Tele-VRBT	37.2 (14.0)	42.7 (14.0)	33.4 (18.5)	23.4 (11.8)	21.8 (9.9)	16.2 (5.9)	0.006*	0.697

BBS, Berg Balance Scale; BT, BalanceTrainer; 10MWT, 10m Walk Test; TUG, Timed 'Up and Go'; VRBT, virtual reality balance training.

*Significant $P < 0.05$.

Fig. 6

Performance in the virtual reality task before and after the Tele-virtual reality balance training (VRBT) balance training shown with 95% confidence intervals. VR, virtual reality.

Table 3 Requirements of the balance training programs applied

	Conventional balance training	Balance training with a BalanceTrainer	Tele-VRBT
Session time (min/day)	45	20	15
Days/week	5/7	5/7	5/7
Weeks	4	4	3
Number of physiotherapists	2	2	1/0
Place	Hospital	Hospital	Hospital/home
Equipment	Ball manual therapy	BalanceTrainer	BalanceTrainer VR tasks, LCD nettop, USB tilt sensor

VR, virtual reality; VRBT, virtual reality balance training.

findings with additional clinical tests (standing on the unaffected and standing on the affected lower extremity only) have been reported in the randomized study (Goljar *et al.*, 2010). However, they also found no significant difference between the standing frame group and the conventional therapy group. The participating patients were in the acute or the subacute phase after stroke; therefore, the fact that the most spontaneous recovery after stroke occurs in the first 3 to 6 months should be considered. In this period, the patients were provided special care in the specialized rehabilitation center. Although the natural recovery may not be neglected, the outcomes of such a targeted treatment after stroke suggest better results in terms of functional abilities than treatment in general medial wards; Walker *et al.* (2000) reported on the importance of the nature of treatment.

We have shown previously that the targeted task for balance training in patients after stroke may also be equally efficient if the tasks are implemented with contemporary technologies of VR environments (Cikajlo *et al.*, 2012). The VR technology brings into the rehabilitation the repeatability, accuracy, and possible modifications of the hardware or software to create an individualized rehabilitation program without changing the strategy. VR systems enable sensory feedback to the patients, in most cases visual or/and audio feedback, that improves the patient's cognitive and motor functions (Yang *et al.*, 2008). Our results also showed that patients managed to master the VR task and, at the end of the balance training, significantly improved their task time performance and collision score. Additional tactile feedback information can be provided through the haptic

technology, providing the sense of touch, feel by applying forces, torque vibrations, or motion to the patients. For example, in VR-supported balance training, the patients can 'feel' the collision with the object through the haptic floor (Cikajlo *et al.*, 2011). Haptic technology in connection with a VR environment may augment the conventional therapy in patients with motor disabilities and improve motor performance, and also reduce the rehabilitation time. In addition, it can provide objective parameters for the evaluation of a patient's functional performance (McCue *et al.*, 2010).

Despite the fact that the differences in the clinical effects of individual treatments were not statistically significant, we found that a standing frame support allows the same therapeutic effect with shorter treatments. Obviously, standing frame-supported balance training with goal-based tasks in VR required less time for the same clinical effect. Besides, within the telerehabilitation program, the VRBT balance training required the assistance of only one neurophysiotherapist when the therapy was performed in the hospital and occasional remote assistance when the balance training took place at home. However, the optimal time for training should be explored further. More long-term researches with a follow-up are required to confirm the outcomes related to the functional improvement of balance and consequently also the reduction of fall risk. Also, participation in the society should not be neglected (Lubetzky-Vilnai and Kartin, 2010).

Patients also expressed satisfaction with the continuation of therapy at home (Piron *et al.*, 2008). Besides the positive effect of the home environment, the society may also influence patients' health and this may be stimulating or inhibiting (McCue *et al.*, 2010). In other words, there are numerous studies that clearly show evidence of successful telerehabilitation, especially that this therapy improves functional performance, indicate potential problems with integration, increased patient satisfaction (Piron *et al.*, 2008), and autonomy, which is of course linked to the quality of life (McCue *et al.*, 2010). However, broadband connections at home and mobile access have a wide set of users worldwide (DSL and fiber US 80%, DSL and fiber EU-15 93%, DSL EU-27 88%, mobile 3G 79% according to the Broadband Coverage in Europe Final Report 2009 Survey, 2008); therefore, this kind of therapeutic approach and monitoring through telerehabilitation applications are realistic in the near future.

Conclusion

We found that a contemporary rehabilitation approach using goal-based tasks in virtual environments relieve physiotherapists from manual labor, enable rehabilitation to a larger number of patients, and may result in the same effect in less time. At the same time, the tasks in VR present an additional motivation for the patient. Tele-rehabilitation allows the patient to maintain contact with

medical professionals, doctors, and therapists from a comfortable home environment, while also enabling the continuation of long-term rehabilitation for higher functional efficiency. Telediagnosics enables a transmission of messages, monitoring of patient outcomes and functional progress, as well as changes in the rehabilitation strategy and planning of outpatient visits. Thus, it may have a significant impact in reducing the number of outpatient visits required. All this may, in the future, affect the funding of rehabilitation programs after stroke.

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Conflicts of interest

There are no conflicts of interest.

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