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RESEARCH PAPER

Telerehabilitation using virtual reality task can improve balance in patients with stroke

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Purpose: The objective of the telerehabilitation is a continuation of the rehabilitation process on patients' home. The study also compares the balance training in clinical environment with the telerehabilitation approach when the physiotherapists and physicians can follow the progress remotely. *Method*: In this paper, the preliminary study of the pilot project with virtual reality (VR)-based tasks for dynamic standing frame supported balance training is presented. Six patients with stroke participated in the study. The patients performed the balance training 3 weeks, 2 weeks in the clinical settings and 1 week in the home environment, five times a week, and each time for up to 20 minutes. Objective effectiveness was demonstrated by parameters as track time, number of collisions and the clinical instruments Berg Balance Scale (BBS), Timed Up & Go (TUG), 10-m walk test and standing on the unaffected and affected extremity. The outcomes were compared to the balance training group without VR and telerehabilitation support. A 2-way ANOVA was used to explore the differences between the both stroke groups. *Results*: In patients who were subject to VR supported balance training, the BBS demonstrated improvement for 15%, the TUG for 29%, the 10-m walk for 26%, stance time on the affected and unaffected extremity for 200 and 67%, respectively. The follow-up demonstrated that the patients preserved the gained functional improvement. The VR task performance time and number of collisions decreased to 45 and 68%, respectively. Besides, no statistical differences were found between the telerehabilitation approach with VR supported balance training and conventional balance training in clinical settings either regarding the overall mean level or regarding the mean improvement. *Conclusions*: The telerehabilitation approach in VR supported balance training improved balance in stroke patients and had similar effect on patients' postural functional improvement as conventional balance training in clinical settings. However, when balance training is continued on patient's home instead of the hospital, it would eventually decrease the number of

Implications for Rehabilitation

- People suffering from stroke have severe problems with posture and balance.
- This study demonstrates that using target based tasks in a virtual environment can improve balance in stroke population.
- Telerehabilitation offers continuation of balance training in the remote centres or at home.
- The longer rehabilitation period improves functionality and therefore the quality of life.

outpatients' visits, reduce related costs and enable treatment of larger number of patients.

Keywords: balance, devices, posture, standing frame, stroke, telemedicine, telerehabilitation, virtual reality

Introduction

Balance control has been one of the important issues in stroke population rehabilitation since ever. The loss of balance in most cases results in fall and consequently in severe injuries. Therefore, the restoration of static and dynamic balance is important for restoration of functional capabilities of subjects with stroke. The outcome of research performed in USA and UK in a group of subjects with stroke demonstrated that rehabilitation in acute and chronic phase may improve functional capabilities when intensive physiotherapy with repeatable and targeted tasks is applied [1]. The physiotherapy in these conditions in clinical environment is assured by assistive devices that can assure safety. Some of these devices, especially active powered devices, can enable execution of specific target-based tasks in repeatable conditions. Most of the assistive devices can be adapted to any person with even severe stroke. Therefore, the treatment of such person requires less physical effort of the physiotherapists, who can now focus more on

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RIGHTSLINK

Table I. Participating subjects: the VRBT group.

Patient	Age	Time after stroke	Stroke side	Aphasia	Neglect	Diagnosis	Assistive aid at baseline
1	47	3 months	R	Motor dysphasia	—	*Hemiparesis* L.dex	Forearm crutch, foot orthosis
2	76	5 months	R	Motor dysphasia	—	*Hemiparesis* L.dex	Crutch
3	61	6 months	L	—	—	*Hemiparesis* L.sin	Crutch
4	44	2 months	L	—	—	*Hemiparesis* L.sin	—
5	56	2 months	L	—	—	*Hemiparesis* L.sin	Crutch, foot orthosis, assistance
6	67	8 months	R	Motor dysphasia	—	*Hemiparesis* L.dex	Crutch, assistance

person itself and his/her task performance. The choice and application of adequate target oriented tasks can improve the person's functional status. Among such tasks, one may find a simple ball catching or more complex task requiring person's attention and intervention in virtual reality (VR) environment [2]. The tasks designed in VR enable a gradual increase of task's difficulty level, speed, sensitivity, specific goal and can be adapted to the subject's cognitive and motor capabilities [3]. VR supported rehabilitation [4] can improve balance capabilities in hemiparetic subjects with stroke when combined with conventional physiotherapy [5] and on top of that when built up as computer games presents an additional motivation for the subject [6]. However, the main issue remains a limited time dedicated to the rehabilitation due to the financial limits of the health insurance system. It turns out that most of the patients discontinue with any kind of activity that would enhance their functional capabilities when they are discharged from the rehabilitation hospital. Therefore, it is considered important to offer the patients the possibility to continue with the familiar task. Nowadays, the information-communication technologies are ready to offer services like video, audio, secure data and graphics in real-time and play a major role in telerehabilitation [4]. The VR physiotherapy can be continued in a remote rehabilitation center, local hospital or even at the patient's home. This may lead to the shortening of inpatient hospital treatment and continuation of rehabilitation process (e.g., balance training) at patient's home. Besides, the telerehabilitation in combination with telediagnostics may decrease the number of required outpatient visits [7].

Hereby, we present a development of the VR supported balance training using the dynamic standing frame [3,8], which assures safety with limited range of motion and provides support in an upright standing. The designed task in VR was used in target-based balance training in the rehabilitation hospital in six patients with stroke who also continued with the physiotherapy all by themselves in the smart home. The physiotherapist occasionally supervised the progress of the training process via web browser and videoconference. Beside VR task performance in participating patients, the validated clinical tests (Berg Balance Scale (BBS [9]), Timed Up & Go (TUG [10]) and 10-m walk test, standing on a single extremity [11]) were carried out to demonstrate the functional value of the approach. However, we also hypothesized that the presented approach can achieve comparable functional progress with conventional and standing frame supported balance training in patients with stroke [12] and therefore emphasize the importance of the telerehabilitation approach.

Methodology

Subjects

Six patients with stroke (58.5 SD 12.1 years) participated in the VR balance training at the rehabilitation hospital and in the development of telerehabilitation–based, pro-longed physiotherapy (Virtual Reality Balance Trainer-VRBT group). The patients with stroke (Table I) were selected on the basis of the inclusion criteria: (i) first stroke, no recurrent stroke, (ii) can maintain upright posture and walk at least 10 m using cane, crutch or walker without assistance, (iii) show minimal ability to balance while standing in the balance standing frame, (iv) fully oriented, performed well on simple tests of short-term memory and able to follow 2-step directions, (v) stable medical condition, no other neurological or musculoskeletal impairments or heart failure (New York Heart Association (NYHA) Classification Class I and II), (vi) without psychotropic medications and (vii) willing to participate and had no prior experience with the dynamic balance and standing frame. Patients with neglect were excluded from the experimental group. The majority of the patients (with low BBS) could not stand on the affected extremity prior to the physiotherapy and needed assistance or/and used a crutch. The control group for this study was shared with our previous study [9,12] and consisted of 22 (2 subject gave up due to medical problems) subacute stroke subjects (61.0 SD 7.4 years and at baseline 14 subjects needed assistance, 1 walker user, 2 single crutch users and 1 cane user, 2 without any assistive aid). The in(ex)cluding criteria for the control group was the same as above. The subjects in control group also practiced balance with balance standing frame, but without VR support (Balance Trainer-BT group). The study was approved by ethics committee of the University rehabilitation institute, Republic of Slovenia and the patients provided informed consent.

Equipment

We have developed an assistive device for safe balance training in clinical conditions [8], a dynamic standing frame. Now, a simplified passive device for balance training is commercially available from the German company, Medica Medizintechnik GmbH, under the commercial name Balance-Trainer (BT). The BT standing frame (Figure 1) 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 spring defining the stiffness of the two degrees of freedom standing frame. The stiffness of the frame is set up according to the individual's requirements. On the top of the standing
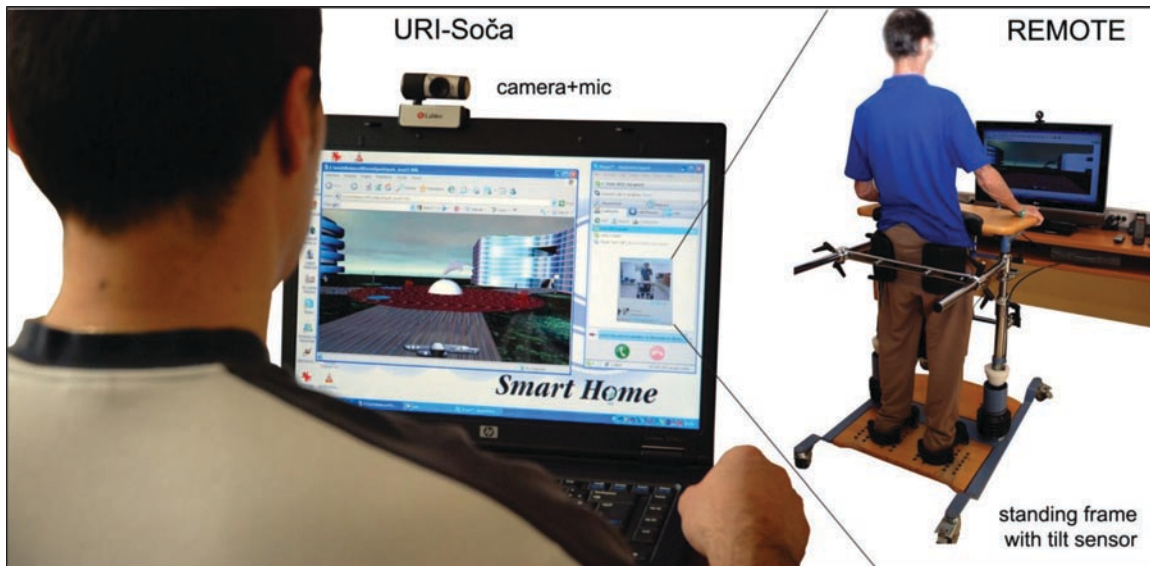
Figure 1. Balance training with task in virtual environment could be continued on patient's home (right). Therapist (left) supervised and advised the patient through the videoconference and followed the task performance in the Internet Explorer.
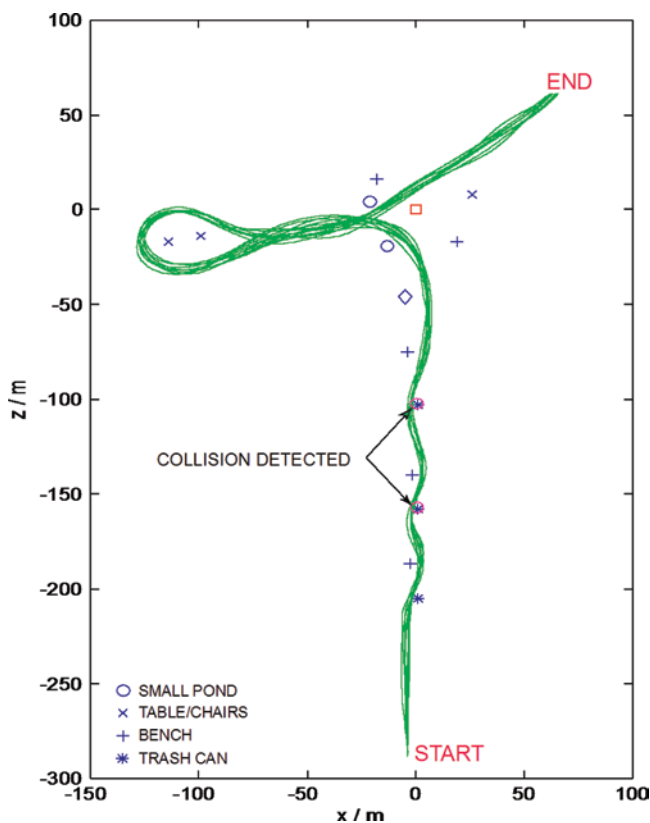

Figure 2. Path accomplished during the VR supported physiotherapy.

frame, a wooden table with safety lock for holding the patient at the level of pelvis was mounted. The tilt of the standing frame is mechanically limited to ±15° in sagittal and frontal plane. The tilt of the frame was measured by the three-axis tilt sensor (Xsens Technologies, Enschede, The Netherlands) and the action movement immediately resulted in the designated virtual environment (modeled in VRML 2.0, running in MS Internet Explorer with blaxxun contact plug-in). The movement speed in the VR was proportional to the standing frame tilt. The VR environment was built in 3D rendering program (V-Realm builder, Integrated data systems, Inc., USA).

Protocol

The patient was standing in vertical position in the BT 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 combination, but preventing to fall backward. The patient's leaned forward in the pelvis, consequently tilted the frame in the anterior direction, which caused a movement in the virtual environment. Transferring his weight from one side to another and tilting the standing frame right or left caused a turn in the virtual environment. Applying these movements, the patient moved through the virtual environment on the virtual path. The path was determined by the physiotherapist in advance and in the way subject would perform weight transfer, rapid turns and accurate movements and such path remained the same for all participating subjects. The speed of "walk" or "turn" in the VR was proportional to the frame tilt angle. The task required from the patients to avoid collision with VR objects like can, bank, pool, tables, chairs, people etc. At last, they entered the building and the task started over and over again. During the activity, the VR task performance time and number of collisions were detected and at the end presented to the patient. All the patients needed additional assistance during balancing at the beginning of the VR task-based physiotherapy in rehabilitation hospital. After 2 weeks of the VR supported balance training in the clinical environment, they were set in the smart home [13] environment, a good substitute for modern home, and performed the task on their own. The tasks were designed to run in a web-explorer allowing the physiotherapist to supervise (Figure 1), monitor and control the balance training process remotely through the World Wide Web. Besides, the videoconference enabled the

physiotherapist to give the patient an important advice during the dynamic balance training, e.g., to correct the posture, hand placement, etc. The patients in the VRBT group performed the VR supported balance training five times a week, each time for up to 20 minutes for about 3 weeks, a bit more than 2 weeks in the clinical settings and 1 week in the smart home environment. The path in Figure 2 was accomplished in several repetition of the VR task in one session (5 minutes) and was defined by physiotherapist in advance in the way that patients would often transfer the weight to the affected extremity, but also preserve enough dynamics in movement. The system counted the number of collisions with VR objects, measured the time and calculated the time required for finishing the single task (from START to END point). The time required to finish the single track was defined as VR task performance time. During the hospitalization period, the patients received cognitive therapy, speech therapy, general motor therapy and hydrotherapy.

The subjects in the BT control group performed the balance training without VR task for 20 minutes, five times a week for almost 4 weeks [9,12] in the clinical environment only. Before and after the physiotherapy, the clinical status of each participating patient was evaluated with validated clinical tools BBS [9], TUG [10] and 10-m walk and standing on the unaffected or affected extremity (SAE [11]). A follow-up assessment was carried out 2 weeks later in the experimental VRBT group.

Data analysis

The results were evaluated by objective game parameters such as VR task performance time and a number of collisions in the first, second and third week of balance training. All assessed data (path, VR task performance time, number of collisions) were averaged within patients using Matlab software (Mathworks, Natick, MA, USA). The t-test was used to verify the differences between means for VR task performance time and number of collisions per task. The data from clinical tests for both VRBT group and BT control group were analyzed using SPSS 14.0 (SPSS Inc., LEAD Technologies Inc., USA). Descriptive statistics were calculated for all variables. A two-way mixed-model analysis of variance (ANOVA) was used with group (VRBT vs. BT) as between-subjects and time (either beginning or end of the study) as within-subjects factor.

Results

The VR performance task time was shorter for 42.7s (45%, $p = 0.006$) and the patients committed in average 6 (68%, $p = 0.019$) collisions less (or 1.4 collision per task less) at the end of the third week of VR balance training than at the beginning (Figure 3). The 95% confidential interval for the collisions per task has significantly decreased in the third week of balance training. Figure 4 shows clinical outcomes (10-m walk test, TUG, BBS, SAE, SUE) of the participating patients. The mean and 95% confidence interval values for the VRBT group prior, after the training and the follow-up are presented. All observed parameters have improved with training, although the assessment of the SAE was possible prior to the physiotherapy only for some patients due to the impairment. The BBS score improved from 37/56 to 42/56, standing on one leg lasted longer for SUE up to 10 seconds and SAE up to 4 seconds. The patients also improved their TUG time in average for 10.0 seconds—from 33.4 to 23.4 seconds—and 10-m walk time in average for 5.6 seconds—from 21.8 to 16.2 seconds. These values remained practically the same or within standard deviation or improved in the case of BBS (46/56) in the follow-up (Figure 4).

Similar improvement was also demonstrated by clinical test prior and after the physiotherapy in the BT control group which performed balance training but without VR (Table III). The BBS score in the BT group improved from 21.6 to 33.6 ($p < 0.001$), TUG time decreased from 42.8 to 34.2 seconds ($p < 0.001$) and 10-m walk test showed improvement from 32.5 to 27.9 seconds. The BT group also managed to improve standing on the affected extremity from 2.2 to 6.3 seconds in average (Table III).

However, both groups demonstrated improvement in BBS, TUG test and 10-m walk test as well as standing on affected or unaffected extremity (Table III). However, we found no differences in the applied clinical tests between the two groups in the overall mean (no significant group effect in the ANOVA), or the overall mean improvement (no significant interaction effect).

Discussion

All participating patients were able to accomplish the VR task faster at the end than at the beginning of the balance training
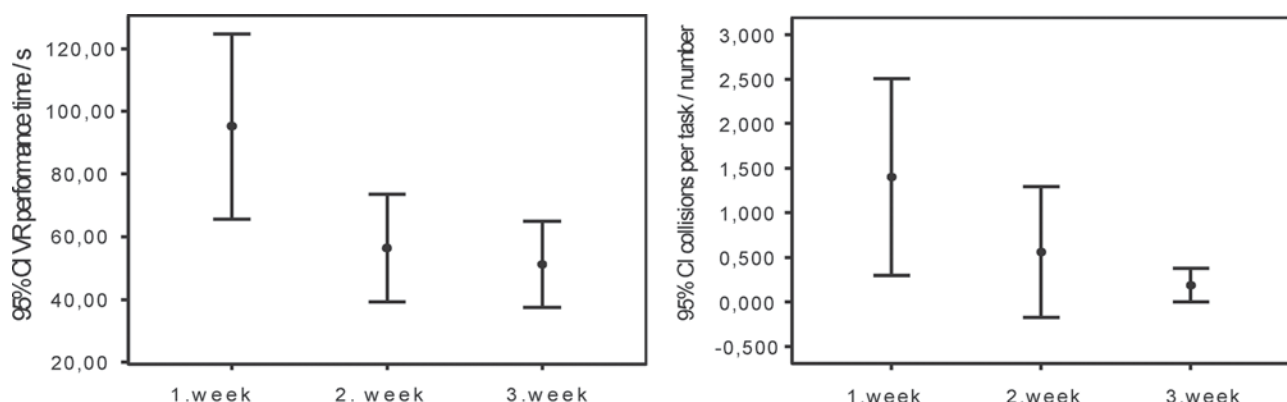

Figure 3. Measured outcomes (mean VR performance task time and normalized number of collisions per task with the 95% confidence interval). The patients accomplished the VR task significantly faster with fewer collisions with objects after physiotherapy. The "score" was also considered a motivation factor for each individual.
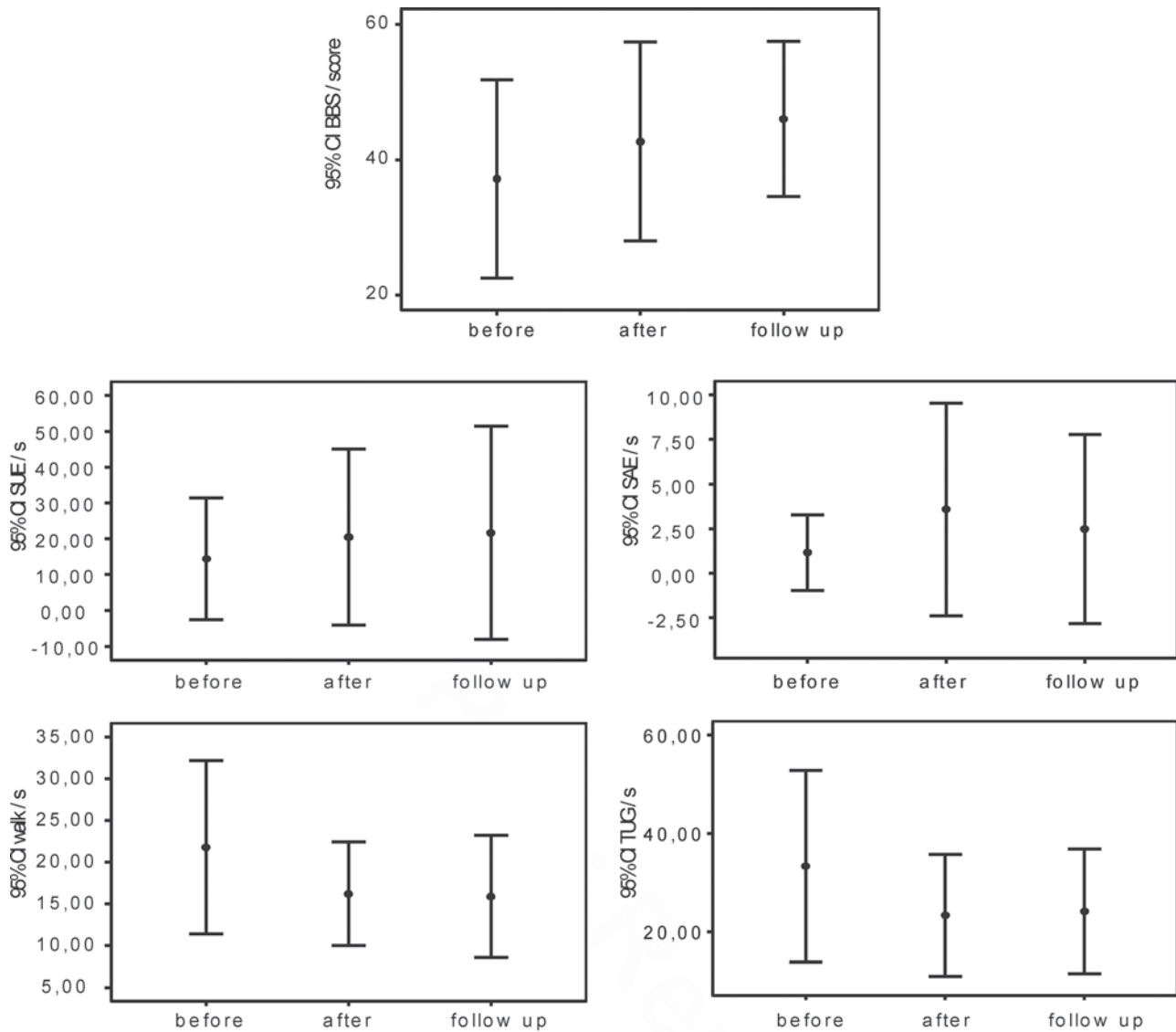
Figure 4. Clinical outcomes in patients who participated in balance training with virtual reality tasks and the follow-up after 2 weeks (mean, 95% confidential interval).

Table II. The protocol timetable.

Clinical assessment	Activity			Clinical assessment	No activity	Clinical assessment
	1. week	2. week	3. week		4–5 weeks	
	VRBT[H]	VRBT[H]	VRBT[SH]		No (VR)BT	
	BT[H]	BT[H]	BT[H]*		—	

*25 days of balance training; [H]hospital; [SH]Smart home.
VRBT-virtual reality supported balance training with standing frame; BT-balance training with standing frame.

Table III. Results and comparison of VR supported with only standing frame supported balance training.

	Beginning				End				*p*-value time effect*	*p*-value group effect	*p*-value for interaction
	BT group	SD	VRBT group	SD	BT group	SD	VRBT group	SD			
Age	61,0	7,4	58,5	12,1							
BBS	21,6	9,8	37,2	14,0	33,6	12,3	42,7	14,0	<0,001	0,068	0,485
SUE (s)	2,2	3,0	14,7	15,9	6,3	7,1	24,6	23,6	<0,001	0,127	0,910
SAE (s)	0,0	0,0	1,2	2,0	0,7	0,8	3,6	5,7	<0,001	0,266	0,904
TUG (s)	42,8	16,2	33,4	18,5	34,2	15,9	23,4	11,8	<0,001	0,312	0,842
10-m walk (s)	32,5	13,5	21,8	9,9	27,9	14,0	16,2	5,9	0,011	0,133	0,393

*Significant *p* < 0,05

and commit fewer collisions with obstacles. This could be attributed to the fact that the patients mastered the exercise, as well as their balance abilities improved. The latter was evident from fewer collisions which forced the participating patient to transfer the load to the affected extremity and overcome the VR obstacle; otherwise, the collision would have been unavoidable. The improved balance and postural abilities were evident from the BBS improvement and from the fact that standing on the affected extremity became possible for patients after the physiotherapy. The gait clinical tests 10-m walk and TUG also demonstrated significant improvement. Both tests are mobility test and demonstrated better overall mobility in all participating patients. Summarizing the outcomes, we may claim that the functional balance status of the participating patients also improved in functional terms, the patients could transfer the load to the affected extremity while standing, they became more confident in turning around, picking and placing objects, had less fear of falling and demonstrated faster walking. Besides, the participating patients' functional status remained practically the same after 2 weeks despite they had no further balance training. We also 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 movement. The limitation in field of view may also have had impact on performance [14] as well as the problems in cognitive processing due to conversion of tilting into "walking". In addition, the VR supported learning may not be always transferrable to the real world applications or be effective immediately in the real world [12,15].

Although we have included a smaller number of patients in the preliminary study, we demonstrated a successful attempt of telerehabilitation approach which gave similar outcomes as balance training with the same mechanical device in clinical environment. There were no significant differences between both groups neither for group effect nor for interaction. Besides, Goljar et al. [9,12] did not find a significant difference even between the balance training group and the conventional physiotherapy without any balance training device. On the basis of these findings, we may claim that the proposed telerehabilitation approach should be considered as effective as balance training in clinical environment. However, the proposed telerehabilitation approach proposes a new issue, an economic view [16] since the number of outpatient visits could be reduced as data can be monitored and patient's functional status can be estimated remotely. Besides the positive effects on the functional motor performance, the patients also expressed personal satisfaction at the return home [17.]

Conclusions

The telerehabilitation presents a novel approach in treatment of patients with neuromuscular injuries or diseases [18]. The proposed telerehabilitation approach is not based only on teleconsulting which is indeed indispensable, but it enables a physiotherapist to supervise and guide the training process remotely via Internet. The clinical outcomes of the proposed VRBT with telerehabilitation demonstrated improved postural and gait performance [19] and were comparable with balance training with standing device and indirectly also with conventional physiotherapy without any balance training device [12]. However, the telerehabilitation approach allows the patients more independence and earlier return home and even continuation of balance training at home. Besides, the physiotherapists were relieved from direct manual contact and physical effort.

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