Concept of the Diagnostic Tool for Balance Telerehabilitation of Subjects with Stroke

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Abstract

The number of virtual reality applications in rehabilitation and telerehabilitation medicine is increasing. Unfortunately, without telediagnostics, telerehabilitation requires frequent outpatient clinical testing. This study thus proposes a diagnostic tool for virtual-reality-supported balance training for estimating functional balance progress during telerehabilitation using objective parameters. Four weeks of physiotherapy with assessment before and after the therapy and a follow up 2 weeks after therapy were carried out with 10 sub-acute stroke subjects. Goal-based tasks for standing-frame-supported balance training were designed in a virtual environment. An accelerometer-based tilt sensor not mounted on the subjects was used. The telediagnostics apply the fast Fourier transform (FFT) to movement data and the task time and number of errors committed are analyzed. Additionally the functional progress was estimated with clinical tests (Berg Balance Scale, 10-m walk test, Timed Up & Go test) and correlations with objective data were examined. The area under the FFT curve demonstrated balance improvement and had a moderate correlation with clinical tests, considering that all parameters showed improvement for each individual patient. The proposed tool enables the remote evaluation of the effects of virtual-reality-supported balance training. The tool may decrease the number of outpatient visits and enable the continuation of the rehabilitation process at home. However, to confirm the clinical reliability and practical value of the proposed tool, a further study with a large stroke population and healthcare business models are needed.

Keywords: Virtual reality (VR), Telerehabilitation, Balance training, Home care, Stroke, Diagnostics

1. Introduction

Balance control is one of the most important issues in the stroke population as the loss of balance in most cases results in falls and consequently in severe injuries. Therefore, the restoration of static and dynamic balance is important for the improvement of functional capabilities of subjects with stroke. Research on subjects with stroke has demonstrated that rehabilitation comprising intensive therapy with repetitive and target-based tasks may improve functional capabilities in sub-acute and chronic phases [1]. Nevertheless, conditions for such type of rehabilitation can often be assured only by assistive devices, which also provide maximum safety for the subject. For instance, repeatability and effective goal-based balance therapy in a clinical environment often requires active or passive assistive devices to assure vertical posture and balancing. Active devices comprise actuators (e.g., electric or hydraulic motors) to enable body weight support and trunk and pelvis stabilization, and can control or just help in maintaining a desired posture (e.g., KineAssist[TM], Kinea Design LLC, USA). In contrast, passive devices do not contain any actuators, but instead have springs, dampers, and other mechanical constraints that offer a good adjustable support level (e.g., Balance Trainer, Medica MedizinTechnik, Germany, Goljar *et al.* [2]). In balance training, support includes knee, trunk, and pelvis stabilization and limiting the range of motion. However, passive devices require a certain amount of the subject's voluntary activity. Both active and passive devices are helpful and useful in providing repeatable conditions and physical support for the patient, freeing the therapist from strenuous manual work. The therapist can thus better focus on the patient and assist in simple target-based tasks [2].

Target-based tasks are often carried out in a virtual environment [3,4,5]. Unlike conventional therapeutic tasks, virtual reality (VR) allows the difficulty level of taks to be gradually increased, the repeatability of the rehabilitation process to be supervised, and the virtual environment (VE) to be changed without changing the main goal of the task. The therapist can use VR to modify a complex task scenario to the level that suits the speed and cognitive capabilities of the subject instead of manually assisting the patient. This approach can significantly contribute to the gradual improvement of a

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Table 1. Clinical profile of subjects.

Subject	Age	Topography	Stroke (months)	Affected side	Aphasia	Assisting aid
A	47	bleeding in thalamus, left side putamna	3	R	motor dysphasia	forearm crutch foot orthosis
B	76	ischemic, left hemisphere	6	R	motor dysphasia	crutch
C	61	aneurysm, extensive arterio-venous malformations right-frontoparietal	6	L	-	crutch
D	44	bleeding in right side ganglia region	2	L	-	-
E	56	middle cerebral artery ischemia	2	L	-	crutch foot orthosis
F	67	intra-cerebral hemorrhage in the basal ganglia and right ventricular system	8	R	motor dysphasia	crutch assistance
G	68	ischemic stroke in the brain stem	5	L	-	crutch
H	48	dyslipidemia left sided spastic hemiparesis	1	R	-	crutch foot orthosis
I	39	ischemic stroke in the field lat.medule left and right frontal	1	L	-	walking cane

subject's specific motor functions [6,7,8]. Kim *et al.* performed a double-blind study [7] and found a significant improvement of balance capabilities in hemiparetic subjects with stroke when VR was added to conventional therapy. Yang *et al.* [8] reported improved walking speed and better results for a walking ability questionnaire in stroke individuals practicing VR-supported treadmill walking. Tasks built up in a VE, as computer games [9], also provide additional motivation for subjects [10].

A large problem is that patients receive less therapy or discontinue any activity that could increase their functional capabilities when they are discharged from the rehabilitation center. Only a few patients continue with the outpatient service, while the majority are often left to their own resources and therefore are provided with little or no professional assistance. The continuation of intensive and target-oriented rehabilitation at home can make motor control therapy more effective for stroke survivors in the long term. A supervising physiotherapist can remotely monitor the therapy session taking place in a subject's home, make changes in the treatment program, and provide instructions and encourage the patient. The author has previously demonstrated that telerehabilitation with target-based tasks can be as effective as conventional balance training in a clinical environment [11]. The therapy session consisted of repetitive practice of functional movement and visual feedback. The rehabilitation outcomes were evaluated in a healthcare institution and were carried out by physiotherapists before and after the balance training with a follow-up after 14 days. They used the Berg Balance Scale (BBS) [12], the Timed Up & Go test (TUG) [13], and a 10-m walk test (10MWT) [14], which are the most frequently used clinical tests for functional balance and movement ability evaluation.

However, patients who have been involved in telerehabilitation were requested to visit the outpatient clinic and perform the tests [15]. In principle, clinical tests can be performed at home. However, only a certified expert (e.g., physiotherapist) is entitled to carry out the procedure. Frequent travel to the clinic reduces the convenience of telerehabilitation. Therefore, this study proposes a telediagnostic tool for estimating the functional balance status of a patient in a remote environment using objective kinematic measurements. The concept of telediagnostic tool has foreseen that objective

parameters may also demonstrate correlation with applied clinical tests.

2. Materials and methods

2.1 Subjects

10 subjects (1 person stopped VR therapy due to poor cognitive understanding of the task) with stroke (age: 56.2 years, standard deviation (SD) 12.6 years; weight: 84.8 kg, SD 9.3 kg; height: 176.5 cm, SD 5.6 cm) participated in the clinical and telerehabilitation balance training, diagnostic tool development, and evaluation of the proposed concept (Table 1). The subjects with stroke were selected on the basis of the following inclusion criteria: a) had ability to maintain upright posture and balance during standing in a standing frame, b) passed a cognitive test, c) checked cardiovascular status, d) had not taken any medications, e) had no neglect, f) had no prior experience with the dynamic balance training and standing frame. Clinical examination was carried out by authorized medical staff.

The methodology was approved by the local ethics committee and all subjects gave informed consent in accordance with the ethical standards of the responsible ethics committee on human experimentation and with the Helsinki Declaration of 1975.

2.2 Equipment

In order to ensure upright posture and balance training of subjects with stroke in the sub-acute phase, a commercially available dynamic balance training and standing frame (BalanceTrainer, Medica Medizintechnik, Germany) was used with minor modifications. The standing frame was made of aluminum and fixed to a steel base, which had four wheels to allow relocation where the rehabilitation aids have no dedicated space, e.g., home. The upper frame was fixed to the base with a passive controllable spring, which defined the stiffness of the two degrees of freedom (DOFs) the standing frame. The stiffness of the frame was set up according to the individual's requirements. On the top of the standing frame, a wooden table with a safety lock for holding the subjects at the level of the pelvis was mounted (Fig. 1). The standing frame tilted in the

sagital and frontal planes a maximum of ± 15° and moved together with the subject. Each weight transfer in the medial-lateral direction resulted in a left or right tilt of the balance frame. The tilt in the anterior-posterior and medial-lateral planes was measured using a commercially available three-axis USB tilt sensor (Xsens Technologies, Enschede, The Netherlands). The tilt resulted in the immediate action in the designed VE (modeled in VRML 2.0, running in Microsoft Internet Explorer (IE) with blaxxun contact plug-in, www.blaxxun.com). For teleconferencing, commercial software Skype (Skype Technologies S.A., Luxembourg) was used.

Figure 1. Diagram of proposed tool. The physiotherapist can supervise, control, and monitor a patient's targeted balance training in the VE in real-time. The physiotherapist and the physician can check the outcomes remotely and provide necessary instructions to the patient via teleconference. The therapeutic goal was the weight transfer from the unaffected to the affected side extremity, and thus the speed of the movement in the VE was proportional to the tilt of the balance frame.

2.3 Interface and task in virtual world

The tilt sensor was mounted on the vertical rod of the balance frame to provide adequate information on anterior-posterior and medial-lateral tilt. The tilt of the balance frame was proportional to the tilt of the subject's body. Every weight transfer from unaffected to the affected extremity resulted in a medial-lateral tilt of the balance frame. The information on tilt was sampled and filtered at 200 Hz and assessed on a computer with hardware-accelerated graphics. Data were downsampled and provided to the VR engine. The tilt angle was proportional to the speed of movement in the VR therapeutic game. A larger tilt angle in the anterior/posterior direction caused higher ahead/backward movement speed in the VE. When the subject stood still in the upright position, there was no movement in the VE. Weight transfer to the left or right extremity consequently tilted the balance frame in the medial-lateral direction and caused rotation of the VR scenery.

The targeted therapeutic task in the VE for this study was a virtual park with a path full of obstacles, a small square, two buildings, and a bar. The physiotherapist suggested a task requiring the subject to move on the path while avoiding collisions with objects (cans, tables, chairs, people, etc.), which required the subject to change the load from/to the affected extremity. When the subject entered the building, the task restarted (Fig. 2). During the activity, the task time, route taken, and number of collisions were detected and recorded. At the end, the data were presented to the subject to provide motivation. The path was the same for all subjects because this was a proof of concept study.
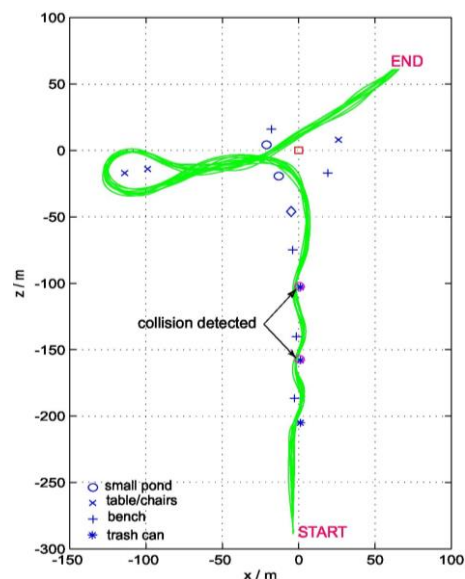

Figure 2. Typical path obtained for VR balance training. Objects/ obstacles and collisions with particular objects are marked.

The subjects standing in the balance frame followed the VE on a 42" screen (LCD monitor/TV). A small multimedia camera with a microphone on top of the screen allowed the physiotherapist to see the subjects during the task. If needed, the physiotherapist provided instructions on how and when to correct posture during the VR-based task. The physiotherapist could also see the task in the VE in real-time over the internet. The subjects could request a teleconference with the physiotherapist at the rehabilitation center at anytime if remote assistance was needed during telerehabiltation (Fig. 1).

2.4 Protocol

Before and after the balance training, clinical tests were carried out. Follow-up clinical tests were additionally carried out 2 weeks after the subjects had finished the balance training. The BBS, a 14-item clinical test consisting of sit, stand, weight transfer, turn, and pick up object from the floor tasks, was used to assess the balance capabilities [12]. The maximum score of the BBS is 56, a score that often only neurologically intact subjects can achieve. TUG [13] and 10MWT [14] are applied to test whether subjects are independently mobile. TUG comprises a number of tasks, such as walking, turning, stopping, standing from a seating position, and sitting down. During TUG and 10MWT, the majority of the subjects used a crutch and an ankle support orthosis and needed additional assistance prior to the therapy. The assessment took place in a clinical environment and each assessment was performed three times to assure data reliability.

The subjects stood in the vertical position with feet parallel to each other in the balance trainer with their hands placed on the wooden table in front of them. The safety lock at the level of the pelvis prevented them from falling backward (Fig. 1). The feet position and the height of the table, which were adjusted for each individual, remained the same for a given subject throughout the study. Before the balance training, the mechanical stiffness of the device was set up to the lowest level that enabled the weakest subject to push the frame. The

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stiffness also remained the same for all subjects throughout the study.

The balance training was conducted for almost 4 weeks, 5 days a week, with each treatment lasting 17-20 min. Subjects practiced the task in the VE in the first week with the assistance of the physiotherapist, in the second week alone in the presence of the physiotherapist providing minor help, all in the rehabilitation hospital, and in the third and fourth weeks without any professional assistance at home (Smart Home was used as a substitute for a modern home). The protocol was 5 min of exercise, 1-2 min of rest, 5 min of exercise, 1-2 min of rest, and 5 min of exercise. All subjects also took part in other neuro-therapeutic programs that contributed to the improvement of cognitive function, blood flow, speech, and muscle strength, and functional walking, but performed no execise specific for balance training.

2.5. Data analysis

Data acquired and stored during the balance training consisted of 2-DOF frame movement (anterior-posterior (AP) and medial-lateral (ML) planes), VR object positions, standing frame sensitivity, subject's height, weight, age, and neurological impairment, the path trace (Fig. 2), number of collisions with VR objects (Nr_{coll}), time needed to finish a single track (T_{task}), overall time ($T_{session}$), and the number of tasks completed (Nr_{tasks}). Data assessed from the tilt sensor were sampled at 200 Hz and filtered with a 4th-order low-pass digital Butterworth filter (cut-off frequency: 5 Hz) for presentation.

Data assessed for subjects shows noticable change in ML movement (Fig. 3(a)), i.e., a difference in the load transfer from the unaffected to the affected extremity before and after the VR balance training. It was considered that differences should show significant change in the power spectrum, and thus further examination was conducted in the frequency domain. The ML direction, the fast Fourier transform (FFT) was used to examine the signal characteristics of the average exercise (5 min). However, only the frequency range of 0-0.5 Hz [16] turned out to be relevant and significant. Thus, this frequency range required further examination. The area under each curve (A-ML) (Fig. 3(b)) was calculated using the trapezoid rule (Eq. 1). A comparison was made between the assessments prior to the therapy, during training, and at the end of the VR supported balance training.

$$\int_a^b f(x) \cdot dx \approx (b-a) \cdot \frac{f(a)+f(b)}{2} \tag{1}$$

The developed system also counted and stored the number of detected collisions during VR balance training (Fig. 2). After each training session (5 min), the number of collisions was normalized per single task:

$$Nr_{coll/lap} = \frac{Nr_{coll}}{Nr_{tasks}} \tag{2}$$

2.6. Statistical analysis

Statistical analysis (Matlab 2011, MathWorks, Inc., USA) was performed on measured and calculated data, namely the tilt in the ML direction, A-ML, collisions per lap $Nr_{coll/lap}$, and the mean task time T_{task}. Mean and SD values were calculated and a linear regression and scatter plot analysis were conducted using the collisions per lap $Nr_{coll/lap}$ and mean task time T_{task}.
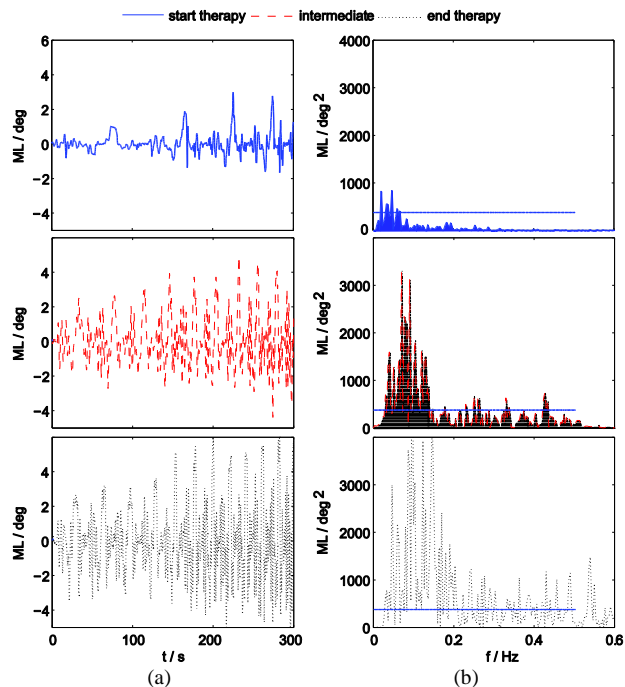

Figure 3. (a) ML movement of the balance frame at the start (solid line), middle of (dashed line), and end (dotted) of therapy. (b) FFT of movement in ML direction. The area under the curve in a frequency range of 0-0.5 Hz proved characteristic and was thus used for estimation.

Additionally, a statistical analysis (SPSS v14., Lead Technologies, Inc., USA) was carried out on data obtained from clinical test TUG, BBS, and 10MWT, with the mean, SD, and confidence interval (CI) calculated. It was hypothesized that the clinical status of the subjects would change rapidly during VR-supported balance training and hopefully the improvement would remain the same after 2 weeks. Therefore, a paired t-test was applied to explore the differences between each test before and after the balance training and the follow up.

In order to check the relationship between the objectively measured data and extracted information, a linear regression and scatter diagrams were used. A comparison was made between the area under the FFT curve A-ML and mean time T_{task}, and the area under the FFT curve A-ML and clinical outcomes for TUG, BBS, and 10MWT.

3. Results

The balance frame tilt in the ML plane coincided with the subjects' weight transfer and body movement in that plane. Figure 3(a) shows that the movement in the ML plane was low-amplitude motion (average of $\pm 0.7°$ per session) prior to the balance training. Often the inability to tilt to the affected side of the body resulted in an inability to avoid collisions with

obstacles in the VE. This functional limitation has significantly improved, with higher amplitude, in the 2nd week (average of $\pm 2.1°$ per session) of balance training and further improved in the beginning of the 3rd week (average of $\pm 3.6°$ per session). The subjects achieved much better scores at the end of the balance training (fewer collisions with obstacles, 2.9 (SD 1.7) vs. 7.2 (SD 5), and faster task times, 48.2 s (SD 15.1 s) vs. 91.8 s (SD 27.1 s)). The task time was shorter by 47% and the subjects had on average 60% fewer collisions.

Figure 3(b) shows the FFT of the movement in the ML plane. The peak power spectrum of the ML movement at the beginning of the balance training was very low (921 deg^2), as was the area under the curve (A-ML) shaded (33 deg^2/s). A-ML was significantly larger in the 2nd week (intermediate, 76 deg^2/s), with a peak at 3202 deg^2, and even larger at the end of the balance training (111 deg^2/s), with a peak at 4008 deg^2. The majority of the spectrum power was concentrated in the frequency range of 0-0.5 Hz.

Figure 4 shows the outcomes of the performed clinical tests (10MWT, TUG, BBS). The mean and 95% CI values for the subjects prior and after the training and the follow up are presented. The mean BBS score improved from 36 (SD 12.8) to 44 (SD 12.4) and futher to 48 (SD 9.5) in the follow up. The range of the BBS prior to the therapy varied from 17 up to 50. However, all subjects managed to improve their BBS, with one improving it by 26 points. They improved their TUG time from 29.0 s (SD 16.8 s) to 20.7 s (SD 11.7 s) at the end of the therapy. In the follow up, the TUG time remained practically the same 20.4 s (SD 10.8 s). The time of the 10MWT before the therapy was 18.9 s (SD 10.1 s), and that after the therapy was 15.1 s (SD 6.8 s). In the follow up, the changes were negligible (14.3 s (SD 6.5 s)). All subjects improved their score in all mobility and balance tests after the therapy. The changes were also significant ($p < 0.05$), but those between the time after the therapy and the follow up were not ($p > 0.86$).

Figure 5 shows that the mean time required to finish the task significantly decreased for all subjects. 67% of the subjects (B, C, D, F, G, I) managed to improve their task time rapidly (in the first and second weeks), and maintained their improvement until the end of the therapy. For all subjects except D, the area under the frequency curve, A-ML, increased (Fig. 5(a)). Subject A demonstrated very similar objective results in all three assessment periods (his BBS prior to therapy was 50). However, the linear regression with task time was relatively high ($R^2 = 0.63$) despite the small number of persons involved, demonstrating that improvement in task performance also resulted in higher A-ML. Similar results, but with better task time scores, could mean fewer collisions per task committed. The correlation between the task time and number of collisions committed per task was $R^2 = 0.72$ (Fig. 5(b)).

(a)

(b)
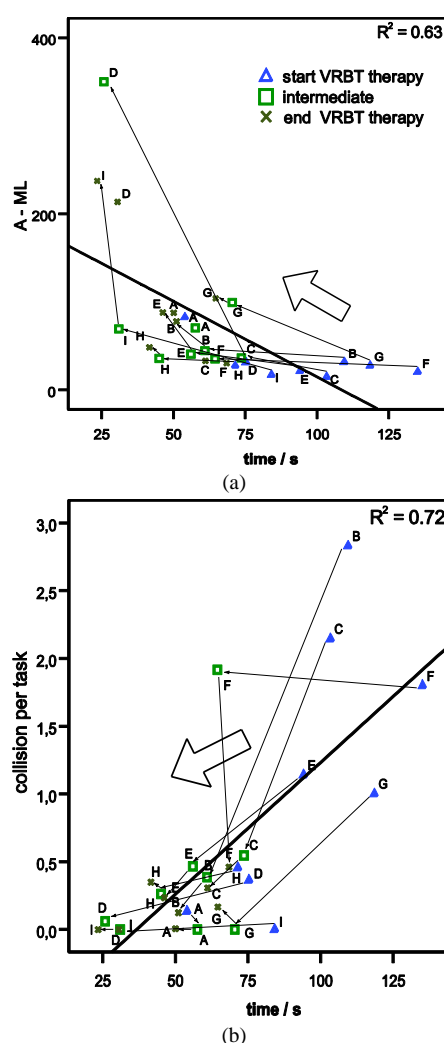
Figure 5. (a) All subjects (B, C, D, E, F, G, H, I) except subject A (with BBS 50 prior to therapy) demonstrated an increase in the area under the frequency curve (A-ML) and faster task performance after therapy. Despite the small number of participants, a linear correlation between the task time and A-ML was found ($R^2 = 0.63$). (b) When the subjects learned the task and improved their task time, they committed fewer collisions with obstacles in the VE ($R^2 = 0.72$). Most of the subjects managed to improve their performance very early (2nd week).

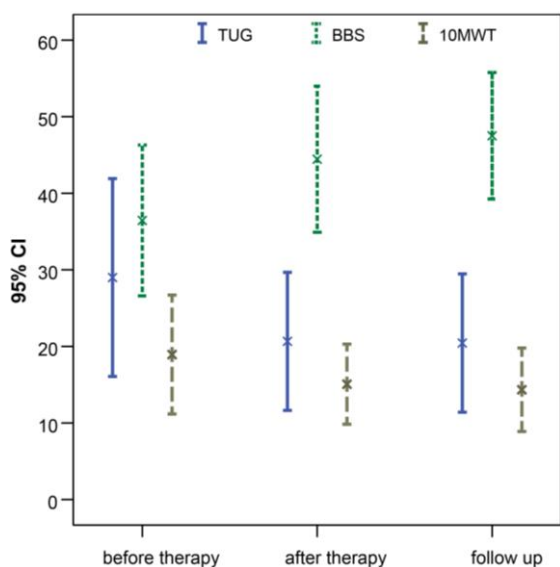Figure 4. All clinical outcomes before and after the balance training demonstrated a significant ($p < 0.05$) improvement of functional ability. Data are 95% CI values of all subjects. The clinical tests in the follow up demonstrated that the functional status of the subjects did not change.

Figure 6 shows data assessed at the beginning of the balance training and at the end of the balance training. The objective test A-ML demonstrated a mild linear correlation with 10MWT ($R^2 = 0.44$), but for all subjects, the A-ML value increased after therapy (Fig. 6(a)). Very similar results were found for TUG (Fig. 6(c)). A medium linear correlation was found between A-ML and TUG ($R^2 = 0.46$). The A-ML value increased and the TUG time decreased after therapy for all subjects. The linear regression and the scatter plot between the A-ML and BBS values show moderate linear correlation ($R^2 = 0.56$). The A-ML and BBS values increased after therapy for all subjects (Fig. 6(b)). Only for two subjects (D, I), larger differences in the A-ML values were found. However, for both subjects, the A-ML value increased and 10MWT and TUG values decreased after therapy, as with the other subjects. Same improvement was found when comparing the A-ML and BBS values.

4. Discussion

An improvement of an individual's functional abilities indicates changes of postural control. The recovery of postural control allows better load transfer from healthy to affected extremities [17]. The subjects were able to increase the task speed already in the 2nd week when they mastered the VR task. As the subjects increased the speed, the task required higher dynamics of movement in the ML plane. The dynamics made it easier for the subjects to avoid collisions with obstacles in the VE. Consequently, the subjects achieved greater range of motion, and thus put much more load on the affected extremity. This was evident from the FFT signal analysis; the areas under the frequency curve (A-ML) and the peak spectral power increased with ML movement dynamics in the frequency range of 0-0.5 Hz [16]. There was also an acceptable rate of correlation between the A-ML values and the mean time required to finish the task. For all participating subjects, the A-ML increased in the first 2 weeks of balance training and all of them also improved the task times. A similar correlation was found between the collisions per task and task time. The reduction of collisions with obstacles at higher speed can be attributed to the improved postural control in the ML direction. Our findings are in line with reports on improved ML trajectory during balance-frame-supported training [2], frequency responses at quiet standing [18], and changes in the center of pressure frequency spectra area after rehabilitation of subjects with stroke [19].

All participating subjects demonstrated improvement of balance and functional mobility, as evaluated by 10MWT, BBS, and TUG clinical tests, after the therapy and a follow up after 2 weeks. However, the changes were significant only between before and immediately after the therapy. The differences at the follow up were not significant, meaning that the clinical status of the subjects did not significantly changed in the time after the therapy. All observed clinical parameters improved after balance training and rehabilitation, although some subjects still needed additional walking aid or/and a therapist's assistance (this was also a reason for higher dissemination). In the first 2
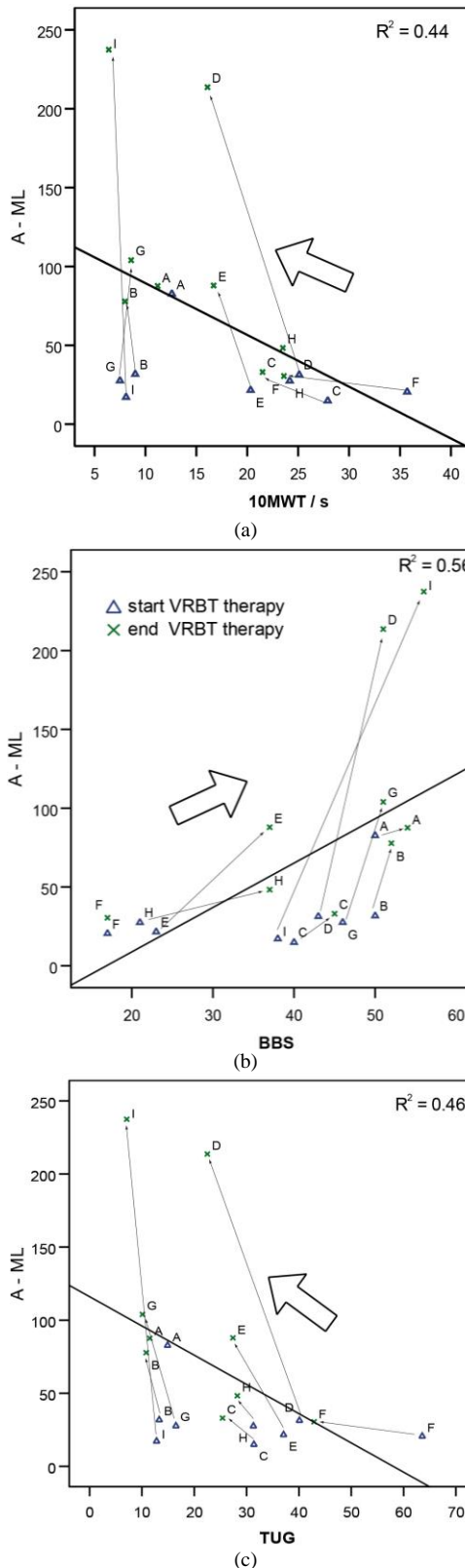

(a)

(b)

(c)

Figure 6. All subjects (A, B, C, D, E, F, G, H, I) demonstrated improvement in 10MWT, BBS, and TUG and an increase of the A-ML value. (a) A-ML had a mild linear correlation with 10MWT ($R^2 = 0.44$). (b) Linear regression between the A-ML and BBS values had a higher linear correlation ($R^2 = 0.56$). (c) Medium linear correlation between A-ML and TUG values ($R^2 = 0.46$) was found, but the A-ML value increased and TUG time decreased after therapy for all subjects.

weeks of therapy, the subjects became functionally independent and were later able to accomplish the task all alone. However, if any help was needed, the subjects could have had a teleconference on request. After the therapy, the mean BBS was above 45, which is the cutoff score between fallers and non-fallers [20]. The TUG results also demonstrated major improvement in the first 2 weeks. 10MWT is more a general walking test than a balance test, but as walking activity requires dynamic balance, it was considered appropriate. The high SD values in the clinical tests are a consequence of the diversity of the participating subjects; prior to the therapy, some subjects with BBS < 20 could not stand on the healthy extremity only. This clinical status variety was necessary to test the sensitivity of the proposed concept.

In the concept the A-ML parameter demonstrated moderate correlation with clinical tests BBS, TUG, and 10MWT. The scatter plot reveals that all compared parameters improved for each of the subjects. However, it was not necessary that subjects with higher BBS prior to the therapy achieved larger A-ML change. All subjects with good cognitive abilities and motivation achieved short task times and demonstrated positive changes in the A-ML values. This confirms our assumption that the A-ML is an indicator of the functional balance and mobility capabilities in the ML direction in patients with stroke. Potentially a higher correlation may be achieved for a long-term study with a larger group of participating subjects. However, the clinical tests are not sensitive and specific enough to provide clean results, which are often limited to clinical settings [21]. The clinically tested physiological changes were accompanied by recorded balance functional changes; therefore, a neurological recovery had taken place [22].

However, it cannot be concluded that VR-supported training contributed the most to the overall functional recovery as all subjects received full rehabilitation treatment. However, it certainly played an important role in balance recovery as the VR provides target-oriented exercises with visual feedback, repetitive tasks, and motivation [23,24,25]. Additionally it helps to assess and contribute to the improvement of cognitive abilities [26]. For the sub-acute patients, the emphasis was on the recovery of normal function, whereas for the chronic patients, the emphasis was on maximizing function through compensatory strategies [21]. No postural instability or VR sickness as a consequence of immersions in dynamic VE was noticed [27], thus we are aware of subjective physical experience of moving. The limitation in the field of view may have had an impact on performance [28], as well as the problems in cognitive processing due to the conversion of tilting into "walking". Also the VR-supported learning may not be always transferrable to real-world applications or be effective immediately in the real world [29]. However, VR technology provides repeatability, target-oriented rehabilitation, adjustable difficulty levels, and remote activity, making rehabilitation comparatively effective. Therefore, a VR task can be considered as a complementary therapeutic balance training tool for in- and outpatient treatment. This approach provides rehabilitation to more patients and frees physiotherapists from strenuous manual work. Additionally, the approach can be extended to long-term rehabilitation in a patient's home. Patients' functional status can be regularly or occasionally estimated remotely using a decision tool. A return home has a positive effect on stroke subjects' motor performance and personal feeling [29]. In this context, this study demonstrated that telerehabilitation service can be as effective as the prolonged inpatient balance training [11]. Lai *et al.* [15] also demonstrated the feasibility, efficacy, and high level of acceptance of telerehabilitation in subjects with stroke living at home.

5. Conclusion

The VR technology has brought many novelties in rehabilitation of subjects with stroke and has significantly facilitated the therapists' work. Nowadays almost every personal computer or net-top computer can handle complex graphics and support the home based VR system [31], therefore we have already proposed a VR task oriented balance training and demonstrated the advantage of the telerehabilitation approach [11]. This study proposed a novel concept of remote functional balance estimation and monitoring of the progress of subjects' balance abilities. The validation of the proposed approach was limited to a small number of available subjects. However, this study managed to demonstrate that the concept of objective data assessment and information extraction from the frequency curve of the ML tilt can be used to estimate clinical balance and mobility. While the patients residing far from the rehabilitation hospitals may not continue the outpatient treatment, in the future we may expect that knowledge and some services would be transferred from hospitals to remote medical centers and patients' homes using telerehabilitation service and available technology [32]. The proposed tool may be used to decide whether an outpatient visit is necessary. The advantages of the objective approach are also supported by Meyer *et al* [33] reporting that telemedicine was more appropriate for decision-making as telephone consultations.

Telerehabilitation approach certainly takes in consideration an economic view [34] as the number of outpatient treatments can be reduced and a larger number of patients can benefit from the service. Practically the outpatient visit to a rehabilitation center would be necessary only when requested by physicians and physiotherapists, which may reduce costs and thus attract the attention of medical insurance companies.

Acknowledgment

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