

Feasibility and Effectiveness of Virtual Reality Training on Balance and Gait Recovery Early after Stroke: A Pilot Study

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Abstract

Objective: To investigate the feasibility and effectiveness of virtual reality training for improving balance and/or gait during inpatient rehabilitation of patients within 12 weeks after stroke.

Methods: Sixteen patients within 12 weeks after stroke and dependent gait as categorised with a Functional Ambulation Category score of 2 or 3 were included in this longitudinal pilot study. Participants received eight 30-min sessions of virtual reality training during four weeks as part of the regular inpatient rehabilitation program. Feasibility was assessed using compliance with the training, adverse events, experiences of the participants and the physiotherapists; and effectiveness with the Berg Balance Scale, centre of pressure velocity, Functional Ambulation Category and 10-meter walking test.

Results: Participants positively evaluated the intervention and enjoyed the training sessions. Also, physiotherapists observed the training as feasible and beneficial for improving balance or gait. Compliance with the training was 88% and no serious adverse events occurred. The Berg Balance Scale, anterior-posterior centre of pressure velocity, Functional Ambulation Category and 10-meter walking test showed significant improvement after four weeks of training ($p < 0.05$).

Conclusion: This study demonstrates that virtual reality training in patients early after stroke is feasible and may be effective in improving balance and/or gait ability.

Keywords: Rehabilitation; Stroke; Virtual reality; Balance; Gait

Introduction

Balance and gait recovery are considered as key aspects in stroke rehabilitation [1-3]. To date, physiotherapy and occupational therapy focus on high intensity, repetitive and task-specific practice, which are important principles of motor learning, to elicit improvements in the early rehabilitation phase [1,4,5]. In addition to high intensity, repetitive and task-specific training, variability in practice is important for motor learning. Also, cognitive involvement, functional relevance and the presence of feedback enhance learning [5]. In current physiotherapy or occupational therapy it is difficult to meet all of these above-mentioned training characteristics as therapy may be tedious and resource-intensive [6-9]. In addition, the frequency and intensity of current therapies have been indicated as insufficient to achieve maximum recovery in the early phase of rehabilitation [8,10]. There is need for engaging, motivating and varied therapy that achieves maximal recovery [11].

In recent years, virtual reality (VR) is introduced in the field of balance and gait rehabilitation after stroke [12]. Since VR training is characterised by individualised, high intensity training in a variety of virtual environments with a high amount of real-time feedback [13-15] it might be valuable in stroke rehabilitation. This is confirmed by recent studies [12,15-18]. However, almost all studies on the effect of VR on balance and/or gait ability were conducted in the chronic phase

after brain injury [9,12,16,17,19-23]. Because of the potential relevant characteristics of VR for motor learning and neuroplasticity [14], VR may be of even more added value during the earlier rehabilitation phase. Three studies [24-26] that investigated the effect of VR in this time period after stroke indicated a positive effect of commercially available VR systems (Nintendo Wii Fit or IREX) on balance and/or gait recovery. However, the results of these studies cannot be generalised to the whole population of patients with stroke because included participants had a relatively high functional level regarding balance and gait at the start of the VR intervention. A lack of studies including patients with lower functional status after stroke might be caused by the idea that the feasibility of using advanced VR technology may be restricted because of visual, cognitive and/or endurance impairments. These impairments are more often present in the more impaired patients early after stroke [27-29]. Because of the expected promising effects of VR training for the recovery of balance and gait in patients with low functional level early after stroke, it is important to investigate the feasibility of this innovative form of training and to determine whether the above-mentioned impairments interfere with the use of VR training early after stroke.

Therefore, the aim of the present study was to investigate the feasibility and effectiveness of VR training for improving balance and/or gait during the inpatient rehabilitation of patients with stroke. The specific research questions were:

- What is the feasibility, from the perspective of patients and physiotherapists, of VR training aimed to improve balance and gait ability?
- What is the effectiveness of VR training, embedded within an inpatient rehabilitation program, on balance and gait ability in people with impaired balance and dependent gait within 12 weeks after stroke?

Methods

Study design

This longitudinal pilot study involved two assessments, one before and one after a four-week VR training intervention, performed within the inpatient rehabilitation program of patients with stroke at (Revant Rehabilitation Centres, Breda, the Netherlands).

Participants

Patients with stroke who were following an inpatient rehabilitation program with a treatment goal to improve balance and/or gait. They received balance and/or gait training with VR as part of their regular rehabilitation program. Besides the VR training, the regular rehabilitation program could include therapy given by a physiotherapist, occupational therapist, speech therapist, psychomotor therapist, psychologist and social worker, depending on the goals of the patient with stroke. Inclusion criteria consisted of hemiplegia resulting from a stroke, a time since stroke of less than 12 weeks, a Berg Balance Scale (BBS) score of at least 20, i.e. the minimum level of balance deemed safe for balance interventions [30], and a Functional Ambulation Category (FAC) score of 2 or 3 out of 5 [31]. Exclusion criteria were patients with stroke with terminal diseases, lower-limb impairments not related to stroke, severe cognitive impairments, severe types of expressive or receptive aphasia, visual impairments, age over 80 years and experiencing epileptic seizures. All participants provided written consent to use data obtained during the rehabilitation program for research, and anonymity was assured. The study procedures follow the principles of the Declaration of Helsinki.

VR training intervention

The intervention consisted of balance and gait training using the recently developed treadmill based Gait Real-time Analysis Interactive Lab (GRAIL, Motekforce Link, Amsterdam, The Netherlands). The GRAIL comprises a dual-belt treadmill with force platform, a motion-capture system (Vicon, Oxford, UK) and speed-matched virtual environments projected on a 180° semi-cylindrical screen (Figure 1) [32].

The VR training program consisted of two 30-min sessions of exercises on the GRAIL per week for four weeks. Participants wore a safety harness that was attached to an overhead suspension system but did not provide weight support. A predefined protocol of VR applications was used during the training sessions of the four-week intervention. This predefined protocol was progressive starting with static balance exercises focussing on shifting weight, followed by training dynamic balance and, if possible, training gait ability. Each application could be individualised to the patient's ability in terms of difficulty, for example by adjusting duration, speed, the amount of simultaneous tasks and the amount of real-time visual, auditory and/or

tactile feedback during the exercises. A physiotherapist, who is certified for working with the GRAIL, decided the progression of the training sessions. The physiotherapist regulated the intensity of the exercises, judged when a new and more difficult application could be used and ensured that safety and quality of movement was maintained during the training.



Figure 1: Illustration of a patient performing exercises on the Gait Real-time Analysis Interactive Lab (GRAIL).

Outcome measures

Feasibility of the VR training intervention: The feasibility of VR training was evaluated through both structured patient interviews and structured questionnaires completed by the physiotherapists. Patients were asked about their experiences in the virtual training environment, the presence of potential side effects and their view on the design and effects of the VR intervention. These interviews were conducted after the last training session. The questions regarding the patients' experiences in the virtual environment included perception and sense of presence in the virtual environment and were partly translated and adapted from the ITC-Sence of Presence Inventory questionnaire of Lessiter et al. [33]. The statements which were covered in the interviews in random order, are displayed in Tables 1 and 2.

Besides the patient interviews, feasibility was evaluated by the physiotherapists using a structured questionnaire. This questionnaire comprised the structure of the training intervention, practicality and added value of the training intervention. Statements consulting these feasibility aspects were scored from 1 (strongly disagree) to 5 (strongly agree). Also, adverse events, e.g. falls, near-falls or epileptic seizures, and compliance with the VR training, i.e. number of sessions completed, were recorded.

Effectiveness of the VR training intervention: The effectiveness of the VR training sessions was determined by measures of static and dynamic balance and gait ability. One researcher who was experienced with the tests conducted all the measurements.

Centre of pressure (CoP) velocity was assessed using the force plates underneath each belt of the treadmill.

Statement	Disagree (%)	Neutral (%)	Agree (%)
I would have liked the GRAIL training sessions to be longer*	50	0	50
I felt entirely surrounded by the displayed virtual environment of the GRAIL*	7.1	7.1	85.7
I vividly remember some parts of the GRAIL training sessions*	0	0	100
I felt involved in the virtual environment of the GRAIL*	0	21.4	78.6
I paid more attention to the virtual environment than I did to my own thoughts*	7.1	0	92.9
The content of the GRAIL training sessions appealed to me*	7.1	0	92.9
I could judge well whether I performed the exercises during the GRAIL training sessions correctly	0	14.3	85.7
The GRAIL training sessions stimulated me to move during the sessions	0	7.1	92.9
My movements during the GRAIL training sessions felt realistic*	7.1	7.1	85.7
I enjoyed the GRAIL training sessions*	0	7.1	92.9
I am motivated to attend the GRAIL training sessions	0	7.1	92.9
Experienced side effects			
I felt disorientated during the GRAIL training sessions*	100	0	0
I felt dizzy during the GRAIL training sessions*	92.9	7.1	0
I felt nauseous during the GRAIL training sessions*	100	0	0
I had a headache because of the GRAIL training sessions*	100	0	0
I felt physically tired at the end of the GRAIL training sessions*	28.6	7.1	64.3
The environment on the screen was visually well tolerated	7.1	0	92.9

Table 1: Results of the patient interviews regarding the experiences in the virtual training environment and the experienced potential side effects (n=14), *Based on the ITC-Sence of Presence Inventory questionnaire of Lessiter et al. [33].

Statement	Disagree (%)	Neutral (%)	Agree (%)
The schedule and duration of the GRAIL training sessions were good	7.1	7.1	85.7
The training with the GRAIL helped me to achieve (part of) my rehabilitation aims	0	7.1	92.9
Because of the training sessions with the GRAIL I perform more activities in daily life	7.1	42.9	50
My balance was improved after the GRAIL training sessions	0	7.1	92.9
I would like to continue training on the GRAIL for a longer time period	14.3	0	85.7
Things I learned during the GRAIL training sessions have an added value for my daily functioning	0	14.3	85.7
The GRAIL training sessions are of added value to my other therapies	0	0	100

Table 2: Results of the patient interviews regarding the design and effects of the intervention (n=14).

CoP velocity measurements are commonly used in studies focussing on balance in the stroke population [34-36]. Participants were asked to stand on the treadmill in most stable standing position with their head straight. Force plate data was recorded twice over 10 seconds with an analogue frequency of 1000 samples per second. Data was down sampled to 100 Hz and then filtered using a low pass fourth order Butterworth filter with a cut-off frequency of 5 Hz. CoP velocity was measured in medio-lateral (CoPX) and anterior-posterior direction (CoPZ) [37,38].

The BBS was used to measure dynamic balance. This scale contains 14 actions from daily life to evaluate a person's ability to maintain positions or movements of increasing difficulty as the base of support is decreased [39,40]. The items of the BBS were performed without the use of walking aids, but the use of an ankle-foot orthosis, bandage or sling was permitted.

The FAC score measured functional ambulation status and distinguishes six levels (0-5) of gait ability on the basis of the amount

of physical support required [31]. This scale has shown to be a reliable and valid measurement that is responsive to change over time [41]. Besides the FAC, the 10-meter walking test was included to measure gait ability. Participants were asked to walk three times 10 meters at their own comfortable speed as described by Salbach et al. [42] and the time needed was measured with a digital stopwatch. The mean of three measurements was considered as the comfortable walking speed. Participants that were unable to walk 10 meters without physical assistance (FAC 2) scored 0 m/s.

All assessments were performed before the start of the intervention and after the four-week intervention.

Data analysis

Given the relatively small sample size of the present study nonparametric analyses were used. Descriptive data were reported as median with interquartile range (IQR=1st, 3rd quartile). The Wilcoxon's signed-rank test was performed to determine changes between baseline and post-intervention values. Results were considered significant when P-values were <0.05. Participants who completed less than 75% of the training sessions were excluded from the data-analysis (patient interviews and balance and gait measures). Extreme outliers, defined as values below 1st quartile-3(IQR) or above 3rd quartile +3(IQR), were also excluded from the analysis [43]. The questionnaires regarding feasibility from the perspective of patients or physiotherapists consisted of five scores per statement (strongly disagree, disagree, neutral, agree and strongly agree). Results were analysed by combining the scores for strongly (dis)agree and (dis)agree resulting in three scores (disagree, neutral, agree) and were reported as percentage per score. All statistical analyses were performed using SPSS version 20.0 (IBM Corp., Armonk, NY).

Results

Participant characteristics

Sixteen patients with stroke participated in the study (twelve males and four females) with a median age of 61 (IQR 56, 71) years. Table 3 shows the demographic data and baseline clinical characteristics of the participants. Median time since stroke onset was 42 (25, 65) days and median USER (Utrecht Scale for Evaluation of Clinical Rehabilitation) [44] mobility score was 9 (7, 12) at admission for inpatient rehabilitation.

Characteristics	Median (1 st , 3 rd quartile)
Age (years)	61 (56, 71)
Gender (male/female)	12/4
Type of stroke	
Haemorrhage	3
Infarction	13
Side of stroke (left/right)	5/11
Time since stroke onset (days)	42 (25, 65)
FAC score (2/3)	9/7
Admission USER	

Mobility	9 (7, 12)
Self-care	19 (14, 23)
Cognitive functioning	42 (38, 48)
Pain	0 (0, 20)
Fatigue	50 (30, 60)
Mood	40 (0, 170)
FAC=Functional Ambulation Categories, USER=Utrecht Scale for Evaluation of Clinical Rehabilitation.	

Table 3: Demographic and baseline clinical characteristics of the participants (n=16).

Feasibility of the VR training intervention

The patients with stroke answered positively regarding their experiences in the virtual environment (Table 1). 93% of the participants enjoyed training in the virtual environment and were motivated for the training sessions. In addition, the participants answered that the training sessions simulated realistic movements (86%). They also felt engaged by the virtual environment and indicated that they could properly judge, based on the given feedback, whether exercises were performed correctly (86%). Participants experienced no major side effects during the training intervention, except for physical fatigue at the end of a training session which was experienced by 64% of the participants (Table 1).

The majority of the participants were positive about the four-week training intervention (Table 2). The participants were satisfied with the frequency of two times per week and the duration of 30 min VR training; however 86% of the participants would have liked to train longer than four weeks. Also, 93% of the patients with stroke felt that their balance improved after four weeks of training and 86% thought that the VR training positively influenced daily functioning. According to all participants, the VR training is of added value to the conventional rehabilitation program. Furthermore, 50% of the patients with stroke had the impression that they performed more activities in daily life because of the virtual training intervention.

Statement	Disagree (%)	Neutral (%)	Agree (%)
Training on the GRAIL has added value for balance recovery in inpatients	0	0	100
The frequency and duration of the GRAIL training sessions are good	0	50	50
A progression of applications focusing on static balance to dynamic balance and applications focusing on walking is good	0	0	100
The GRAIL training sessions can be properly guided	0	0	100
One clinician for the GRAIL training sessions is enough	0	50	50
The stairs in front of the GRAIL caused problems during the training sessions	50	0	50
A lot of manual support is necessary during the GRAIL training sessions	100	0	0

Training on the GRAIL has added value in daily life of the inpatients	0	0	100
The GRAIL training sessions are a valuable addition to the other therapies of inpatients	0	0	100
The GRAIL training sessions for inpatients are feasible	0	0	100

Table 4: Results of the structured questionnaires completed by the physiotherapists.

From the perspective of the physiotherapists the VR training intervention was evaluated positively and observed as feasible (Table 4). During the VR training sessions, the majority of the participants needed short rest periods because of endurance limitations. In some cases, extra manual support was needed during the training sessions, to provoke correct movement while performing exercises, to help participants with climbing the steps to get on the treadmill and to get participants seated on a stool that was temporarily placed on the treadmill during a short break. With little manual support of the physiotherapists all participants were able to climb the steps to get on the treadmill. The physiotherapists did not report adverse events including falls or epileptic seizures during the course of the intervention, although three near-falls occurred for two participants. These near-falls were due to tripping of the paretic leg. Because the participants were wearing the safety harness and immediately grabbed the handrails, no actual fall or injury occurred. Furthermore, compliance with the VR training sessions was 88%, with 113 of the 128 training sessions completed. Fifteen training sessions were missed because of illness of the patient or physiotherapist (n=2), injuries of the patient not related to VR training (n=2), early discharge (n=6), technical issues with the GRAIL (n=1) or unknown reasons (n=4). Two participants did not complete 75% of the training sessions and were therefore not included in the analysis. One participant was

discharged two weeks earlier than expected and the other participant missed three training sessions because of unexpected absence of the participant or the physiotherapist. In total 14 participants were included in the final analysis. Overall, the physiotherapists agreed on the benefit of the VR training intervention for balance recovery as part of the rehabilitation program. In their opinion, the benefit of the challenging training in a safe VR environment is particularly expressed in more confidence during daily life activities. Lastly, the physiotherapists advised to extend the training period because they expected that patients with stroke would still benefit VR training after four weeks.

Effectiveness of the VR training intervention

Table 5 presents the median (1st-3rd quartile) of the balance and gait measures before intervention and after the four weeks of VR training. Dynamic balance significantly improved represented by an increase of 14 (13, 17) points of the median BBS scores. In addition, static balance measured with CoPZ velocity was significantly improved by a median decrease of 0.56 (-1.34, -0.02) mm/s, although CoPX velocity did not significantly change over time. For the CoP velocity measurements one extreme outlier was observed, which was excluded in the analysis. Participants significantly improved functional ambulation with one point on the FAC. Twelve participants used the same walking aid during the FAC measurements before and after the training intervention. One participant changed a 4-point stick into a cane and one person walked without a walking aid at the end of the intervention instead of using a walking frame. Furthermore, walking speed improved significantly with a median of 0.20 (0.03, 0.46) m/s. The use of a walking aid during the 10-meter walking test before and after intervention was the same for majority of the participants, except for two participants who walked with a walking frame at start of the intervention and without a walking aid at the end of the four-week intervention period.

Measure	Before intervention	After intervention	Change in score	P-value
BBS	32.00 (26.75, 36.50)	45.50 (40.25, 52.00)	14.00 (12.75, 17.25)	0.001*
CoPX velocity (mm/s)#	1.83 (1.32, 3.50)	1.45 (0.68, 2.44)	-0.53 (-1.56, -0.36)	0.084
CoPZ velocity (mm/s)#	2.39 (1.59, 3.75)	1.81 (1.42, 2.56)	-0.56 (-1.34, -0.02)	0.023*
FAC	2 (2.0, 3.0)	3 (3.0, 4.0)	1 (0.8, 1.0)	0.002*
10MWT (m/s)◆	0.00 (0.00, 0.32)	0.46 (0.19, 0.81)	0.20 (0.03, 0.46)	0.003*

All measures are presented as median (1st, 3rd quartile). BBS=Berg Balance Scale, FAC=Functional Ambulation Categories, 10MWT=10-meter walking test, CoPX=Centre of pressure in medio-lateral direction, CoPZ=Centre of pressure in anterior-posterior direction.
*P-value<0.05 according to the Wilcoxon signed rank test.
#n=12, ◆n=13

Table 5: Balance and gait measures before and after the intervention (n=14).

Discussion

This pilot study demonstrates that VR training on the GRAIL as part of the regular inpatient rehabilitation program is feasible in patients within 12 weeks after stroke. Also, our results indicate that balance and gait ability improved after four weeks of VR training. VR training is a potential powerful intervention for motor learning after stroke, therefore it is important to be sure that it is safe and feasible even in patients early after stroke, as shown in this study.

The patients with stroke that participated in this study were all inpatients within 12 weeks after stroke. A substantial part of these patients had severe limitations following stroke. This can be confirmed by the median values of the USER mobility and USER self-care at admission in the rehabilitation centre, which were 9 and 19 out of 35 points, respectively. These scores represent relatively poor functional status, as compared to a recent large study, including 1310 inpatients after stroke, in which a mean physical independence (mobility plus self-care) score of 42.9 was reported [45].

The positive findings for enjoyment and motivation, and the high compliance, indicate that the severely impaired participants could enjoy a challenging intervention like the VR training. The results for enjoyment and motivation in this study are consistent with previous studies regarding feasibility of VR in patients early after brain injury for upper [46,47] and lower extremity recovery [48]. The high level of enjoyment and motivation may have been reached because of a good balance between the difficulty of the training and the abilities of the patient with stroke [46]. Exercises on the GRAIL can easily be adjusted to the abilities and demands of the patient with stroke by changing the type of exercise, difficulty level, amount of feedback and the amount of tasks within a game. These adjustable settings provide the therapists the opportunity to search for the individual limits during the training, which is of importance for effective rehabilitation after stroke. Physical fatigue at the end of a training session was reported in 64% of the participants. The presence of fatigue indicates that participants indeed trained on high intensity with the proper amount of physical demand. This suggests that an appropriate training level could be realised for the severely impaired patients after stroke. The physiotherapists reported that in some cases extra support was needed for the participant to climb the steps to get on the treadmill, to provide manual support during the exercises or to let participants rest on a stool on the treadmill. In these cases the training sessions were more labour-intensive for the physiotherapist.

When focussing on the experienced effects of the training, both the participants and physiotherapists evaluated the training intervention as beneficial for improving balance or gait. The patients with stroke reported that balance improved after the intervention and that they experienced the VR training of added value for improving their daily functioning. Although the majority of the participants answered that the VR training provokes improvement on functional level, 50% of the patients with stroke could not confirm that the training intervention resulted in improvements on activity and participation level.

The objective results of the present study confirm the subjective results of the VR training intervention reported by the patients with stroke. After the four weeks of training on the GRAIL dynamic balance, walking speed and functional ambulation improved. Median BBS and median comfortable walking speed improved with 14 points and 0.20 m/s respectively, which is substantially more than the smallest detectable change of 5.8 points for the BBS [30] and 0.15 m/s for comfortable walking speed [49]. Merely two of the thirteen participants in this study increased less than the minimally detectable change in walking speed. Other, frequently used, physiotherapy interventions for improving balance or gait, such as circuit training, functional strength training and body weight supported treadmill training, showed comparable increases for gait speed in patients within three months after stroke [50-52]. It is important to notice that the VR training intervention, just like the interventions described above, was part of the regular rehabilitation program. Spontaneous recovery may have occurred in the first months after stroke [53].

To investigate the effect of the VR training intervention on the recovery of balance and gait in patients with subacute stroke more thoroughly, the VR training needs to be compared with a dose-matched control intervention using a randomised controlled trial with a large sample size. Since the present study concerned a pilot study in which the main aim was to study the feasibility, the sample was relatively small. When conducting a controlled trial it might be considered to extend the training period beyond four weeks since participants indicated that they prefer a longer training period, and

physiotherapists also suggest a longer training period to achieve a maximal learning effect for motor recovery. Also, it would be interesting to measure the effect of VR training on daily activity and participation level because participants in this study could not confirm whether the improvement of performance on functional level was also present on daily activity and participation level. With the use of outcome measures on participation level it can be investigated whether potential improvements induced by VR training translate to real life. In the available literature the effect of virtual training on daily life activity and participation level is not yet established [15].

Overall our results show that even for the severely impaired patients with stroke, an appropriate training level on the GRAIL could be realised, which was experienced as motivating and challenging and did not lead to lower levels of participation. Potential visual, cognitive and endurance impairments often seen in more impaired patients after stroke did not interfere with the use of VR technology for the recovery of balance and gait in patients with stroke. In addition, our results indicate that substantial effects on dynamic balance and gait ability can be realised after a four-week integrated VR training intervention. These results are a valuable contribution for both further research and clinical practice.

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