EFFECTS OF VIRTUAL REALITY-BASED TREADMILL TRAINING ON BALANCE AND GAIT IN STROKE PATIENTS: A RANDOMIZED CONTROLLED TRIAL

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Abstract: *Gait and balance impairments contribute significantly to long-term disability after stroke. Modern concepts of stroke rehabilitation recommend a task-specific repetitive approach, such as using treadmill training. The purpose of this study was to investigate the effectiveness of using virtual reality-based treadmill training to improve balance and gait in subacute stroke patients. Twenty-two stroke patients were randomly stratified into two groups: the experimental (n = 11) and the control group (n = 11). Parameters associated with balance and gait were measured using the 6-minute walk test, the 10-meter walk test, the timed "up and go" test, the functional gait assessment, and the four square step test. Gait analysis using the zebris Rehawalk® treadmill system was also performed. Patients in the experimental group received virtual reality-based treadmill training five times a week for a period of four weeks, while those in the control group received treadmill training at the same frequency, duration, intensity, and structure, along with a progressively more difficult task demands. Significant improvements were observed in selected outcome measures in both groups after training. Patients in the experimental group experienced improvements in all of the spatiotemporal gait parameters, but there was a significant difference before and after training in duration of double support and lateral asymmetry. The findings of this pilot randomized controlled trial support the benefits of using a virtual reality-based treadmill training program to improve gait and balance in subacute stroke patients.*

Keywords: *gait training, treadmill system, virtual reality, stroke*

INTRODUCTION

Stroke is reported to be the second most common cause of death and the leading cause of disability worldwide (Murray and Lopez, 1997). Common impairments resulting from stroke include problems with motor control, visuoperceptual disorders, sensory impairments, spasticity, and cognitive function disorders (Carr, 2010). Patients also experience reduced gait stability, resulting in asymmetrical gait patterns such as decreased gait speed, cadence, step length, and stride length (Duncan et al., 2005). Consequently, many stroke survivors experience reduced performance of functional tasks, including mobility, balance, coordination, and activities of daily living (Carr, 2010). Therefore, the recovery of walking ability has been recognized as a major goal of stroke rehabilitation (de Oliveira et al, 2008).

There is increasing evidence that high-intensity, repetitive, task-specific training can improve the outcomes of gait rehabilitation programs (Langhorne, Coupar and Pollock, 2009). One example of such training programs is treadmill training (TT). Several studies have reported that TT can improve walking speed, cardiovascular function, and balance in stroke patients (Yen et al., 2008; Jung, Yu and Kang, 2012), while facilitating the maintenance of a more normal walking pattern (McCain et al., 2008). However, there is still a lack of data on the effects of such training on the recovery of community ambulation ability in stroke patients. Treadmills with an integrated sensor matrix that consists of capacitive force sensors are used for quantitative gait analysis (Reed, Urry and Wearing, 2013). Additionally, TT can be successfully augmented with virtual reality (VR) to train motor-cognitive aspects in individuals who previously experienced stroke. Despite the increasing use of instrumented treadmills and/or VR in gait and balance training for stroke patients, very little information is available regarding the use of a combination of the two methods.

VR has been defined as the "use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real world objects and events" (Lam et al., 2006). VR has the ability to create an interactive and motivational environment, which can be manipulated by the therapist to create individualized treatments. The use of VR encourages a higher number of exercise repetitions and promotes motor learning through immediate feedback about performed tasks (Sveistrup, 2004). Kim et al. (2009) demonstrated that a combination of conventional therapy and VR can have an augmented effect on balance and locomotor recovery in stroke patients. VR-based interventions may have favourable effects on walking speed and the ability to deal with environmental challenges in stroke patients (Lohse et al., 2014). A combination of TT and VR could motivate patients by allowing them to interact with a virtual environment and sending real-time feedback during TT (de Rooij, van de Port and Meijer, 2016). According to the Cochrane systematic review, there is very little evidence about the effects of VR and interactive video gaming on gait speed, balance, and participation in stroke patients (Laver et al., 2017).

RESEARCH QUESTION

In the present study, we aimed to investigate the efficacy of using a combination of TT and VR, rather than TT alone, to help improve gait and balance in stroke patients.

METHODS

Participants

We included patients who had experienced acute-to-chronic (mostly subacute) stroke and were admitted to the Stroke Department of the University Rehabilitation Institute, Republic of Slovenia – Soča. This study was conducted between January 2017 and February 2018. Inclusion criteria for patients were: first stroke, hemiparesis after stroke, capability to follow instructions (Mini Mental State Examination score ≥ 25) (Tombaugh and McIntryre, 1992), ability to walk independently or with the supervision, with or without aids (Functional Ambulation Category: 4 - 6) (Holden, Gill and Magliozzi, 1986), New York Heart Association Functional Classification I-II (Raphael et al., 2007), ≥ 5 points on the walking motor subscale based on the Functional Independence Measure (FIM; Keith et al., 1987). We excluded all patients who were suffering from other neurological or musculoskeletal diseases, those with a limited range of motion in the lower limbs, those who experienced visuospatial hemineglect or hemianopia, as well as those who went through less than three weeks of planned rehabilitation. This study was approved by the Ethics Committee of the University Rehabilitation Institute and we received written informed consent from all participants for their anonymized data to be collected and analysed for research purposes.

Therapeutic intervention

This study was designed as a prospective pilot randomized controlled trial. Participants were randomly stratified into two groups - experimental (EG) and control group (CG) - by an independent investigator who was not involved in the patient evaluation process. Before the intervention began, the independent investigator chose a sealed envelope corresponding to a participant and randomly assigned that participant to the EG or the CG.

Study participants in both groups were included in a standard rehabilitation program (90 min per day, five times a week for four weeks) consisting of conventional physical and occupational therapy. Conventional motor rehabilitation used a task- and goal-oriented approach that included gait-preparatory manoeuvres and balance exercises that were performed while sitting and standing (Van Peppen et al., 2004; Van Bloemendaal, 2012). Walking aids and orthoses were prescribed based on the individual needs of patients in both groups. Patients in the EG received VR-TT and CG received TT at

Figure 1. *Gait training using virtual reality-based treadmill training.*

the same frequency, duration, intensity, and structure, along with progressively more difficult task demands.

Treadmill training

Training on a treadmill system with or without VR was provided five times a week for four weeks (for a total of 20 sessions). All participants were walking at a self-selected comfortable speed for 13 min per session for the first two weeks (3 min of warm up, 10 min exercise), and for 18 min per session for the next two weeks (3 min of warm up, 15 min exercise). Participants chose to use the handle if they needed additional support. In accordance with safety precautions, patients wore a Polar m31 heart rate monitor (Polar Electro Oy, Kempele, Finland) and defined their perceived exertion rates based on the Borg Rating of Perceived Exertion Scale (Borg, 1982).

Participants in the EG performed walking training with VR exercises included in the zebris Rehawalk® software system (zebris Medical GmbH, Isny im Allgäu, Deutschland). VR feedback training occurred simultaneously with the help of a large monitor mounted in front of the treadmill. Each patient walked in a virtual environment and performed various tasks that required a continuous variation in walking and balance based on observed footprints (*https://www.zebris.de/en/medical/rehawalkr-gait-analysis-and-training-in-rehabilitation*). Obstacles were presented on both sides of the track, which required participants to plan ahead, adapt their steps, and select the correct strategy to avoid a collision (Figure 1). During the first two weeks of training, patients in the EG performed basic exercises. In the third and fourth week of training, there was a gradation of training difficulty with prolonged walking duration, increased walking speed, as well as wider range and frequency of obstacles and cognitive load during walking. Feedback was provided through a cumulative score based on the number of successfully completed tasks (for example, the number of virtual collisions).

Participants in the CG performed walking training without VR on a treadmill system Motion plus (Enraf-Nonius, Rotterdam, Netherlands), along with different tasks, such as moving legs to simulate stepping over obstacles, stepping towards the side to simulate avoiding obstacles, or walking on a narrow surface. At the end of the training, all participants were asked to rate their satisfaction regarding the training on a scale from 0 to 10.

Outcome measurement

Each participant was evaluated before and after the intervention period. First, a medical doctor assessed the FIM, following physiotherapists performed a battery of balance and gait clinical function tests, including the six-minute walk test (6mWT) (Guyatt et al., 1985), the 10 m walk test (10mWT) (Perry, Garrett, Gronley and Mulroy, 1995), the timed “up and go” test (TUG) (Podsiadlo and Richardson, 1991), a functional gait assessment (FGA) (Wrisley et al., 2004), and the four-square step test (FSST) (Dite and Temple, 2002). Additionally, a stance and gait analysis performed on the zebris Rehawalk® system (*https://www.zebris.de/en/medical/rehawalkr-gait-analysis-and-training-in-rehabilitation*). The analysis included spatiotemporal parameters, including step width (SW), duration of double limb support (DS), cadence, and lateral asymmetry (LA) measured when walking on a treadmill. All assessments were performed under the same conditions by the same evaluator who was blinded to group allocation.

Data analysis

Data analysis was performed using SPSS 22.0 (IBM Corp., Armonk, New York, 2010). The Kolmogorov-Smirnov test was used to test for normality of data distribution. Data were presented as mean ± standard deviation, and a p value ≤ 0.05 was considered to indicate statistical significance. The differences between the two groups of patients were analysed using the Mann-Whitney U test and the Wilcoxon rank-sum test.

RESULTS

A total of 22 stroke patients were included in this study. Patients were randomly stratified into two groups for further analysis: EG (n = 11) and CG (n = 11). The baseline characteristics of all included patients are listed in Table 1. There were no significant differences between the two groups with respect to age, sex, etiology of stroke onset, and location of hemiparesis. Furthermore, there were no significant differences between the two groups with respect to baseline measurements associated with the balance and gait clinical function tests (Table 2), as well as spatiotemporal gait parameters (Table 4).

Table 1. *Baseline demographic characteristics of stroke patients in the experimental and control groups.*

Characteristic		**Experimental (n = 11)**	**Control (n = 11)**	**p**
Mean age of patient (years)		59.8 ± 7.7	54.7 ± 6.0	0.227
Post stroke duration (months)		5.0 ± 2.4	4.5 ± 2.0	0.591
Sex	Male	7	8	0.647
	Female	4	3	
MMSE score		28.3 ± 1.4	28.0 ± 1.7	0.638
Location of hemiparesis	Left side	3	4	0.565
	Right side	8	7	
Etiology of stroke onset	Ischemic	10	10	0.383
	Haemorrhagic	1	1	
Walking aid	None	9	10	0.261
	Crutch	2	1	
	Ankle foot orthosis	1	2	

MMSE, Mini-Mental State Examination. Values are mean ± standard deviation, or numbers.

Table 2. *Comparison of balance and gait clinical function tests performed before and after the intervention.*

Clinical measures	**Experimental (n = 11)**		**Control (n = 11)**		**Mann-Whitney U test**	
	Before	**After**	**Before**	**After**	**p1**	**p2**
FIM	108.9 ± 10.2	113.9 ± 7.7	106.2 ± 9.5	110.1 ± 7.0	0.576	0.450
FGA	15.5 ± 7.5	19.4 ± 6.5	14.5 ± 5.8	18.3 ± 6.3	0.869	0.921
TUG (s)	11.3 ± 8.6	9.8 ± 8.3	10.2 ± 3.3	8.2 ± 2.2	0.818	0.718
10mWT (s)	8.9 ± 6.7	7.8 ± 5.9	8.2 ± 2.3	6.7 ± 1.3	0.374	0.392
6mWT (m)	382.3±110.5	420.0 ± 122.8	354.2 ±104.2	434.1 ± 73.9	0.393	0.843
FSST (s)*	12.2 ± 3.3	9.9 ± 2.5	12.4 ± 3.0	9.3 ± 1.4	0.885	0.540

*FGA, functional gait assessment; FIM, functional independence measure; FSST, four square step test; TUG, timed "up and go" test; 6mWT, 6 min walk test; 10mWT, 10 m walk test. * With respect to FSST, the experimental group consisted of six patients and the control group had nine patients.*

Both groups of patients showed significant improvements in the selected outcome measures (FIM, FGA, TUG, 10mWT, 6mWT, and FSST) after the intervention (Table 3). However, there were no significant differences between the two groups in parameters related to gait and balance (Table 2).

Table 3. *Results of Wilcoxon rank-sum test comparing clinical outcomes measured before and after the intervention.*

Measurement tool	Experimental (n = 11)	Control (n = 11)
	p	p
FIM	0.008	0.005
FGA	0.007	0.007
TUG	0.005	0.003
10mWT	0.008	0.008
6mWT	0.005	0.005
FSST*	0.012	0.011

FGA, functional gait assessment; FIM, functional independence measure; FSST, four square step test; TUG, timed "Up and Go" test; 6mWT, 6 min walk test; 10mWT, 10 m walk test.

* With respect to FSST, the experimental group consisted of six patients and the control group had nine patients. The p values in bold indicate statistically significant differences at $p < 0.05$.

Additionally, there were significant improvements in the spatiotemporal gait parameters (SW, duration of DS, LA, and cadence) in both groups after the training (with the exception of SW and LA while walking with side rails) (Table 4). Patients in the EG experienced an improvement in all spatiotemporal gait parameters after training, along with statistically significant differences in duration of DS and LA when walking with side rails before and after training.

No adverse events occurred during training, and none of the patients reported any side effects, including motion sickness symptoms such as nausea, disorientation, dizziness, or headache. The physiotherapists did not report any significant problems with respect to handling the zebris Rehawalk® software system. Overall, patients in the EG who received VR-TT were more satisfied than those in the CG (Table 6).

DISCUSSION

As far as we know, this is the first study comparing two groups of stroke patients who went through a similar exercise rehabilitation program that differed only in one aspect: patients in the EG received VR-TT rather than conventional TT. Another unique aspect of this study is that we included both balance and gait clinical function tests, as well as instrumental spatiotemporal gait parameters as outcome measures.

Our study showed positive effects of both types of training on spatiotemporal gait parameters (such as narrower SW, shorter DS duration, and decreased LA). Furthermore, after the training changes in DS duration and LA were more pronounced in VR-TT group. Dunsky et al. (2008) performed a home-based motor imagery gait training program for chronic stroke patients and observed a significant

Table 4. *Results of Wilcoxon-signed rank test comparing spatiotemporal gait parameters before and after the intervention.*

Experimental (n = 11)	Control (n = 11)					
Parameter	Before	After	p	Before	After	p
SW rails 2-1 (cm)	10.5 ± 3.5	8.6 ± 4.6	0.018	11.4 ± 3.9	9.8 ± 2.2	0.205
SW without side rails 2-1 (cm)	14.7 ± 3.5	11.6 ± 4.1	0.005	14.7 ± 3.0	12.5 ± 2.8	0.007
DS rails 2-1 (%)	43.3 ± 7.3	40.2 ± 5.2	0.012	47.7 ± 6.2	44.5 ± 3.8	0.003
DS without side rails 2-1 (%)	47.8 ± 8.9	44.4 ± 7.7	0.003	50.4 ± 7.0	47.2 ± 5.2	0.016
LA rails 2-1 (mm)	16.4 ± 14.3	9.2 ± 7.7	0.010	16.0 ± 7.7	16.1 ± 6.4	0.248
LA without side rails 2-1 (mm)	22.2 ± 14.7	16.0 ± 11.0	0.005	20.0 ± 7.1	15.1 ± 6.2	0.026
Cadence rails 2-1 (steps/min)	72.1 ± 9.0	62.9 ± 13.1	0.005	68.3 ± 14.2	59.8 ± 11.8	0.021
Cadence without rails 2-1 (steps/min)	87.3 ± 5.6	71.5 ± 9.9	0.003	81.1 ± 18.1	66.0 ± 10.3	0.008

All parameters were measured at a comfortable self-selected walking speed. The p values in bold indicate statistically significant differences at $p < 0.05$. DS, duration of double limb support; LA, lateral asymmetry; SW, step width

Table 5. *Results of Mann-Whitney U test evaluating the differences between the experimental and the control group in each parameter.*

Parameter	Experimental (n = 11)	Control (n = 11)	p
SW rails 1 (sel)	10.5 ± 3.5	11.4 ± 3.9	0.644
SW rails 2 (sel)	8.6 ± 4.6	9.8 ± 2.2	0.183
SW without side rails 1 (sel)	14.7 ± 3.5	14.7 ± 2.3	0.790
SW without side rails 2 (sel)	11.6 ± 4.1	12.5 ± 2.8	0.304
SW without side rails 2 (max)	11.0 ± 4.1	12.0 ± 2.8	0.234
SW rails 2 (max)	7.9 ± 3.6	9.4 ± 2.3	0.155
DS rails 1 (sel)	10.5 ± 3.5	11.4 ± 3.9	0.108
DS rails 2 (sel)	8.6 ± 4.6	9.8 ± 2.2	0.042
DS without side rails 1 (sel)	14.7 ± 3.5	14.7 ± 3.0	0.273
DS without side rails 2 (sel)	11.6 ± 4.1	12.5 ± 2.8	0.293
DS without side rails 2 (max)	11.0 ± 4.1	12.0 ± 2.8	0.491
DS rails 2 (max)	7.9 ± 3.6	9.4 ± 2.3	0.200
LA rails 1 (sel)	43.3 ± 7.3	47.7 ± 6.2	0.491
LA rails 2 (sel)	47.3 ± 5.2	44.5 ± 3.8	0.015
LA without side rails 1 (sel)	47.8 ± 8.9	50.4 ± 7.0	0.870
LA without side rails 2 (sel)	44.4 ± 7.7	47.2 ± 5.2	0.974
LA without side rails 2 (max)	39.8 ± 7.3	43.0 ± 6.5	0.450
LA rails 2 (max)	38.7 ± 4.7	41.2 ± 4.6	0.017
Cadence rails 1 (sel)	72.1 ± 9.0	68.3 ± 14.2	0.339
Cadence rails 2 (sel)	62.9 ± 13.1	59.8 ± 11.8	0.793
Cadence without rails 1 (sel)	87.3 ± 5.6	81.1 ± 16.1	0.292
Cadence without rails 2 (sel)	71.5 ± 9.9	66.0 ± 10.3	0.212
Cadence without rails 2 (max)	87.0 ±13.1	82.0 ± 13.0	0.393
Cadence rails 2 (max)	74.8 ± 15.2	74.5 ± 11.9	0.922

Values are mean ± standard deviation. The p values in bold indicate statistically significant differences at p < 0.05. All parameters were measured at a comfortable self-selected walking speed (sel) or at a maximum self-selected walking speed (max). DS, duration of double limb support; LA, lateral asymmetry; SW, step width

Table 6. *Comparison of satisfaction and during training.*

	Experimental (n = 11)	Control (n = 11)	p
Satisfaction	8.7 ± 0.8	7.2 ± 0.8	0.001*

*Values are mean ± standard deviation. * indicates p < 0.05.*

increase in affected lower limb support time and a decrease in DS time. Cho et al. (2014) also reported a shorter duration of DS in a real-world based video recording of a VR-TT group compared to that of a non-VR-TT group. This decrease of DS time is considered as advantageous because an increase in this parameter can lead to difficulties associated with balance, as well as decreased velocity and energy efficiency during ambulation (Lee et al., 2013). When patients in the present study were walking at their maximum self-selected speed, the duration of DS was shorter than when they were walking at their comfortable self-selected speed. It is known that fast walking induces a decrease in proportion of stance duration, along with shorter double-support and longer single-support phases (Lamontagne and Fung, 2004). When patients used side rails for support, their spatiotemporal gait parameters showed significant improvement, which could be due to unmasked latent locomotor behaviour and their capability to walk faster. Slow walking after a stroke may be a behavioural adaptation to poor endurance, poor balance, and an individual's perceived limits of stability (Murray et al., 1984).

Gait asymmetry is highly prevalent in independent ambulators following stroke and it is correlated with higher energy expenditure, musculoskeletal imbalance, as well as reduced speed and stability during walking. Previous studies have not addressed the effects of VR-TT on LA in stroke patients. In the present study, we found that patients who received VR-TT had lower LA than those who received only TT. Malone and Bastian (2014) reported that gait symmetry can be temporarily (up to 3 months) improved in stroke patients through split-belt TT. Rehabilitation targeting gait symmetry with VR-TT is an important consideration since previous findings confirm that repetitive, task-oriented training can help transfer body mass on to the paretic side and decrease LA (Hase et al., 2011).

Our findings also show that the differences between the two groups of patients with respect to spatiotemporal gait parameters did not transfer into the timed gait and balance clinical function tests that we performed. Ramakrishnan et al. (2019) also showed a weak correlation between the 6mWT, the DS, and ground reaction force asymmetries. Our study, however, did show that both groups (VR-TT and non-VR-TT) experienced significant improvement based on the clinical gait and balance assessment after four weeks of training, suggesting improved functional mobility that was confirmed with the FIM scores. Previous studies also reported positive effects of TT on the improvement of gait and balance function (Cho et al., 2014; Pohl et al., 2002; Ada et al., 2003; Cho et al., 2015) and positive effects of VR-based rehabilitation on improving walking speed, lower limb function, balance, and mobility in stroke patients (Corbetta, Imeri and Gatti, 2015; Cano Porras et al., 2019). Comparable effects of VR-TT and TT on balance and functional mobility outcomes in subacute stroke patients are in accordance with results of a meta-analysis that compared VR to conventional physiotherapy in acute/subacute stroke patients (Gibbons et al., 2016). On the other hand, Jung et al. (2012) reported that there was a statistically significant trend towards improved results of the TUG test in the VR group, however patients in this study were in chronic stroke phase. Similar to our study, Fritz et al. (2013) found no statistically significant differences between chronic stroke patients receiving VR-based training and those receiving conventional rehabilitation with respect to walking and balance outcomes such as the Fugl-Meyer Assessment, the Berg Balance Scale, the TUG test, and the 6mWT. Jaffe et al. (2004) also found that there were no significant changes in chronic stroke patients based on the 6mWT after VR-TT compared to conventional therapy.

Very few studies have addressed the effects of a combination of VR and TT and could be compared to the methodology of our study. Although these studies provide evidence of the positive effects of VR-TT on balance and gait in stroke patients, it is difficult to generalize their results: some studies lack a comparison group with random assignment of conditions (Heeren et al., 2013), while others are based on a small sample (Walker et al, 2010), or lack subject homogeneity, which was considered in the protocol of our study. Furthermore, many of these studies compared VR-TT with conventional therapy (Kim et al., 2009; Cho et al., 2014). Kang et al. (2012) compared the effects of conventional therapy with VR-TT, as well as the effects of conventional therapy with non-VR-TT and had the same training period as our study. They showed that the VR-TT group showed significantly improvements in the TUG, 10mWT, and 6mWT than the non-VR-TT group. These results were different from our study, where patients in the non-VR-TT group performed additional exercises with obstacles on the treadmill track. Jung et al. (2012) compared VR-TT with non-VR-TT and showed an improved TUG test in VR-TT group after 3 weeks of training: these results are a trend towards improved TUG test in VR-TT group, however similar to our study it was not statistically significant. In the present study, patients had baseline TUG results below 12 s, which is considered almost normal for the elderly population.

The zebris instrumented treadmill has been used as a valid and reliable measuring instrument for the assessment of ambulation capabilities in patients with multiple sclerosis (Kalron, Dvir, Frid and Achiron, 2013). There are no similar studies available for stroke patients. In the present study, we confirmed that the use of this device is feasible and appropriate for goal-directed gait and balance training, as well as for treadmill gait analysis in subacute stroke patients during the rehabilitation period, especially since patients did not experience adverse events such as motion sickness symptoms during VR-TT. Patients in the EG also reported significantly higher satisfaction rates with the training compared to those in the CG. Such VR programs that can be individually tailored to accommodate adjustable features that maintain a patient's enjoyment, safety, and motivation are extremely useful (Morone et al., 2014). It is therefore reasonable to consider a VR-based approach using the zebris device since it offers standardized and complex training in an enriched environment without realistic physical danger of injury (Fung et al., 2006). Additionally, this system also incorporates cognitive aspects of training (Chen and Shaw, 2014).

One possible limitation in our pilot study was a relatively small sample. Therefore, further randomized-controlled clinical studies with a larger study population should be performed. In addition, this study included only high-functioning patients after a stroke, therefore results cannot be generalized to all stroke patients. Long-term effects of VR-TT were not assessed and further studies should also include a long-term follow-up. Furthermore, a standardized training protocol using VR-TT for stroke patients in varying stages of the disease should also be developed. It is also important to perform a gait analysis study with the zebris instrumented treadmill to compare healthy subjects and stroke patients, since there are no such studies available in the literature.

CONCLUSION

The findings of this pilot study support the benefits of the VR-TT program in terms of improvement of gait and balance in subacute stroke patients. Although both training methods were effective in improving gait parameters, the addition of VR to TT had a significant effect on spatiotemporal gait parameters, such as duration of DS and gait symmetry. Patients who received VR-TT also reported higher satisfaction with the training. The VR-based approach could also enhance the feedback received by the physiotherapists during training, which can consequently help them offer more effective individualized training sessions in a safe environment. Further research must be conducted with larger samples and longer follow-up times to evaluate the sustainability of the effects of such interventions.

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REFERENCES

Ada, L., Dean, C. M., Hall J. M., Bampton, J., & Crompton, S. (2003). A treadmill and overground walking program improves walking in persons residing in the community after stroke: a placebo-controlled, randomized trial. *Archives of Physical Medicine and Rehabilitation,* 84, 1486–91.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*, 14, 377-81.

Cano Porras, D., Sharon, H., Inzelberg, R., Ziv-Ner, Y., Zeilig, G., & Plotnik M. (2019). Advanced virtual reality-based rehabilitation of balance and gait in clinical practice. *Ther Adv Chronic Dis,* 10:2040622319868379.

Carr, J. H. (2010). *Neurological rehabilitation: optimizing motor performance.* 2nd ed. Edinburgh: Churchill Livingstone.

Chen, J. C., & Shaw, F. Z. (2014). Progress in sensorimotor rehabilitative physical therapy programs for stroke patients. *World J Clin Cases*, 2, 316-26.

Cho, K., Lee, K., Lee, B., Lee, H., & Lee, W. (2014). Relationship between Postural Sway and Dynamic Balance in Stroke Patients. *J Phys Ther Sci,* 26, 1989-92.

Cho, K. H., Kim, M. K., Lee, H. J., & Lee, W. H. (2015). Virtual Reality Training with Cognitive Load Improves Walking Function in Chronic Stroke Patients. *Tohoku J Exp Med,* 236, 273-80.

Corbetta, D., Imeri, F., & Gatti, R. (2015). Rehabilitation that incorporates virtual reality is more effective than standard rehabilitation for improving walking speed, balance and mobility after stroke: a systematic review. *J Physiother,* 61, 117-24.

de Oliveira, C. B., de Medeiros, I. R., Frota, N. A., Greters, M. E., & Conforto, A. B. (2008). Balance control in hemiparetic stroke patients: main tools for evaluation. *J Rehabil Res Dev*, 45, 1215–26.

de Rooij, I. J., van de Port, I. G., Meijer, & J. G. (2016). Effect of Virtual Reality Training on Balance and Gait Ability in Patients With Stroke: Systematic Review and Meta-Analysis. *Phys Ther*, 96, 1905-1918.

Dite, W., & Temple, V. A. (2002). A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch Phys Med Rehabil*, 83, 1566-71.

Duncan, P. W., Zorowitz, R., Bates, B., Choi, J. Y., Glasberg, J. J., Graham, G. D., et al. (2005). Management of adult stroke rehabilitation care: a clinical practice guideline. *Stroke*, 36, 100-143.

Dunsky, A., Dickstein, R., Marcovitz, E., Levy, S., & Deutsch, J. E. (2008). Home-based motor imagery training for gait rehabilitation of people with chronic poststroke hemiparesis. *Arch Phys Med Rehabil,* 89, 1580-8.

Fritz, S. L., Peters, D. M., Merlo, A. M., & Donley, J. (2013). Active video-gaming effects on balance and mobility in individuals with chronic stroke: a randomized controlled trial. *Top Stroke Rehabil*, 20, 218-25.

Fung, J., Richards, C. L., Malouin, F., McFadyen, B. J., & Lamontagne, A. (2006). A treadmill and motion coupled virtual reality system for gait training post-stroke. *Cyberpsychol Behav*, 9, 157-62.

Gibbons, E. M., Thomson, A. N., de Noronha, M., & Joseph, S. (2016). Are virtual reality technologies effective in improving lower limb outcomes for patients following stroke - a systematic review with meta-analysis. *Top Stroke* Rehabil, 23, 440-457.

Guyatt, G. H., Sullivan, M. J., Thompson, P. J., Fallen, E. L., Pugsley, S. O., Taylor, D. W., et al. (1985). The 6-minute walk: a new measure of exercise capacity in patients with chronic heart failure. *Can Med Assoc J*, 132, 919-23.

Hase, K., Suzuki, E., Matsumoto, M., Fujiwara, T., & Liu, M. (2011). Effects of therapeutic gait training using a prosthesis and a treadmill for ambulatory patients with hemiparesis. *Archives of Physical Medicine and Rehabilitation,* 92, 1961–6.

Heeren, A., van Ooijen, M., Geurts, A. C., Day, B. L., Janssen, T. W., Beek, P. J., et al. (2013). Step by step: a proof of concept study of C-Mill gait adaptability training in the chronic phase after stroke. *J Rehabil Med*, 45, 616-22.

Holden, M. K., Gill, K. M., & Magliozzi, M. R. (1986). Gait assessment for neurologically impaired patients. Standards for outcome assessment. *Phys Ther*, 66, 1530-9.

Jaffe, D. L., Brown, D. A., Pierson-Carey, C. D., Buckley, E. L., & Lew, H. L. (2004). Stepping over obstacles to improve walking in individuals with poststroke hemiplegia. *J Rehabil Res Dev*, 41, 283–292.

Jung, J., Yu, J., & Kang, H. (2012). Effects of virtual reality treadmill training on balance and balance self-efficacy in stroke patients with a history of falling. *J Phys Ther Sci*, 24, 1133–6.

Kalron, A., Dvir, Z., Frid, L., & Achiron, A. (2013). Quantifying gait impairment using an instrumented treadmill in people with multiple sclerosis. *ISRN Neurol*, 867575.

Kang, H. K., Kim, Y., Chung, Y., & Hwang, S. (2012). Effects of treadmill training with optic flow on balance and gait in individuals following stroke: randomized controlled trials. *Clin Rehabil*, 26, 246-55.

Keith, R. A., Granger, C. V., Hamilton, B. B., & Sherwin, F. S. (1987). The functional independence measure: a new tool for rehabilitation. *Adv Clin Rehabil*, 1, 6-18.

Kim, J. H., Jang, S. H., Kim, C. S., Jung, J. H., & You, J. H. (2009). Use of virtual reality to enhance balance and ambulation in chronic stroke: a double-blind, randomized controlled study. *Am J Phys Med Rehabil,* 88, 693-701.

Lam, Y. S., Man, D. W., Tam, S. F., & Weiss, P. L. (2006). Virtual reality training for stroke rehabilitation. *NeuroRehabilitation,* 21, 245-53.

Lamontagne, A., & Fung, J. (2004). Faster is better: implications for speed-intensive gait training after stroke. *Stroke,* 35, 2543-8.

Langhorne, P., Coupar, F., & Pollock, A. (2009). Motor recovery after stroke: a systematic review. *Lancet Neurol*, 8, 741-54.

Laver, K. E., Lange, B., George, S., Deutsch, J. E., Saposnik, G., & Crotty, M. (2017). Virtual reality for stroke rehabilitation. *Cochrane Database Syst Rev*, 11, CD008349.

Lee, N. K., Son, S. M., Nam, S. H., Kwon, J. W., Kang, K. W., & Kim, K. (2013). Effects of progressive resistance training integrated with foot and ankle compression on spatiotemporal gait parameters of individuals with stroke. *J Phys Ther Sci*, 25, 1235–7.

Lohse, K. R., Hilderman, C. G., Cheung, K. L., Tatla, S., & Van der Loos, H. F. (2014). Virtual reality therapy for adults post-stroke: a systematic review and meta-analysis exploring virtual environments and commercial games in therapy. *PLoS One*, 9, e93318.

Malone, L. A., & Bastian, A. J. (2014). Spatial and temporal asymmetries in gait predict split-belt adaptation behavior in stroke. *Neurorehabil Neural Repair*, 28, 230-40.

McCain, K. J., Pollo, F. E., Baum, B. S., Coleman, S. C., Baker, S., & Smith, P. S. (2008). Locomotor treadmill training with partial body-weight support before overground gait in adults with acute stroke: a pilot study. *Arch Phys Med Rehabil,* 89, 684-91.

Morone, G., Tramontano, M., Iosa, M., Shofany, J., Iemma, A., Musicco, M., et al. (2014). The efficacy of balance training with video game-based therapy in subacute stroke patients: a randomized controlled trial. *Biomed Res Int,* 580861.

Murray, C. J., & Lopez, A. D. (1997). Mortality by cause for eight regions of the world: global burden of disease study. *Lancet,* 349, 1269-76.

Murray, M. P., Mollinger, L. A., Gardner, G. M., Sepic, S. B. (1984). Kinematic and EMG patterns during slow, free, and fast walking. *J Orthop Res,* 2, 272–280.

Perry, J., Garrett, M., Gronley, J. K., & Mulroy, S. J. (1995). Classification of walking handicap in the stroke population. *Stroke,* 26(6), 982-9.

Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatrics Soc*, 39, 142-8.

Pohl, M., Mehrholz, J., Ritschel, C., & Ruckriem, S. (2002). Speed-dependent treadmill training in ambulatory hemiparetic stroke patients: a randomized controlled trial. *Stroke*, 33, 553–8.

Ramakrishnan, T., Kim, S. H., & Reed, K. B. (2019). Human Gait Analysis Metric for Gait Retraining. *Appl Bionics Biomech*, 1286864.

Raphael, C., Briscoe, C., Davies, J., Ian Whinnett, Z., Manisty, C., Sutton, R., Mayet, J., & Francis, D. P. (2007). Limitations of the New York Heart Association functional classification system and self-reported walking distances in chronic heart failure. *Heart,* 93, 476-82.

Reed, L. F., Urry, S. R., & Wearing, S. C. (2013). Reliability of spatiotemporal and kinetic gait parameters determined by a new instrumented treadmill system. *BMC Musculoskelet Disord*, 14, 249.

Sveistrup, H. Motor rehabilitation using virtual reality: review. *J NeuroEng Rehabil*. 1, 10-18.

Tombaugh, T. N., & McIntyre, N. J. (1992). The mini-mental state examination: a comprehensive review. *J Am Geriatr Soc,* 40, 922-35.

Van Bloemendaal, M., van de Water, A. T., & van de Port, I. G. (2012). Walking tests for stroke survivors: a systematic review of their measurement properties. *Disabil Rehabil,* 34, 2207-21.

Van Peppen, R. P., Kwakkel, G., Wood-Dauphinee, S., Hendriks, H. J., Van der Wees, P. J., & Dekker, J. (2004). The impact of physical therapy on functional outcomes after stroke: what's the evidence? *Clin Rehabil*, 18, 833-62.

Walker, M. L., Ringleb, S. I., Maihafer, G. C., Walker, R., Crouch, J. R., Van Lunen, B., et al. (2010). Virtual reality-enhanced partial body weight-supported treadmill training poststroke: feasibility and effectiveness in 6 subjects. *Arch Phys Med Rehabil,* 91, 115-22.

Wrisley, D. M., Marchetti, G. F., Kuharsky, D. K., & Whitney, S. L. (2004). Reliability, internal consistency, and validity of data obtained with the Functional gait assessment. *Phys Ther*, 84, 906-18.

Yen, C. L., Wang, R. Y., Liao, K. K., Huang, C. C., & Yang, Y. R. (2008). Gait training induced change in corticomotor excitability in patients with chronic stroke. *Neurorehabil Neural Repair*, 22, 22-30.