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Original Article

Is virtual reality training superior to conventional treatment in improving lower extremity motor function in chronic hemiplegic patients?

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ABSTRACT

Objectives: This study aims to examine the effect of virtual reality (VR) training, frequently included in rehabilitation programs, on lower extremity functional status, mobility, balance, and walking speed in chronic stroke patients.

Patients and methods: This randomized, controlled study was conducted with 60 chronic stroke patients (26 males, 34 females; mean age: 64.0 years; range, 33 to 80 years) who presented to the physical therapy and rehabilitation outpatient clinic of the Kütahya Health Sciences University Evliya Çelebi Training and Research Hospital between February 2019 and February 2020. The participants were randomized to the VR group and the control group by simple randomization with 1:1 allocation. The VR group received 30 min of VR training and 30 min of conventional physiotherapy, while the control group received 60 min of conventional physiotherapy. The patients were evaluated before and after treatment using the Fugl-Meyer Assessment-Lower Extremity (FMA-LE), Rivermead Mobility Index (RMI), 10-m walk test (10MWT), and Berg Balance Scale (BBS).

Results: The FMA-LE, RMI, 10MWT, and BBS scores significantly improved in both groups after treatment ($p<0.001$). The post-treatment change in the FMA-LE score was significantly higher in the VR group than in the control group ($Z=-3.560$, $p<0.001$). Similarly, the change in the BBS score was significantly higher in the VR group ($Z=-3.769$, $p<0.001$). Post-treatment changes in the RMI and 10MWT were not significant ($p>0.05$).

Conclusion: Virtual reality training combined with conventional physiotherapy was found to be superior to conventional physiotherapy alone in improving lower extremity functional status in chronic stroke patients; therefore, adding a VR component to rehabilitation programs will have a favorable impact on treatment outcomes.

Keywords: Chronic stroke, lower extremity, motor function, rehabilitation, virtual reality.

Stroke affects millions of people worldwide every year and remains a leading cause of mortality despite improvements in prevention, diagnosis, and treatment.[1] Moreover, two-thirds of stroke patients are left with neurological deficits in the contralateral extremities, such as hemiparesis, muscle weakness, spasticity, joint contracture, laxity, or motor control disorders.[1] These disorders result in the loss of mobility that affects in-bed activities, transition from sitting to standing, walking, and running.[2]

Difficulty or inability to walk is one of the most prominent sequelae of a stroke, and minimizing limitations in activity and participation by restoring mobility is one of the primary goals of rehabilitation.[3] Therefore, functional recovery of the lower extremities is essential in stroke rehabilitation.[4] Neurorehabilitation methods aim to enhance functional recovery by increasing neuronal plasticity, relearning processes, and functional restructuring.[2] However, recovery at the functional

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level can require long-term rehabilitation. Training must be repeated, modified, and combined to increase participation in the rehabilitation process. For this purpose, various approaches, including task-specific training, constraint-induced movement therapy, exercises based on daily activities, motor imaging, mirror therapy, neuroassistive methods, brain stimulation techniques, and technology-assisted rehabilitative training, are used in stroke rehabilitation.[3]

Virtual reality (VR) has become an important rehabilitation technology that enables neuromotor recovery using the mirror neuron system. The purpose of VR training is to provide biofeedback through repetitive exercises and visual feedback. Virtual reality also increases patient participation and motivation while helping retrain neuromotor skills. Therefore, VR exercises are frequently used in rehabilitation programs for stroke patients.[5]

Virtual reality interventions in stroke rehabilitation are well known to have positive effects on upper extremity range of motion, strength, pain, and functionality.[6] Studies examining the impact of VR on the lower extremities have reported that despite evidence of the benefits of VR in walking, balance, and mobility,[5,7,8] more research is needed in this field.[9] Therefore, the present study was designed to examine the effect of VR training on lower extremity functional status, mobility, walking speed, and balance parameters in chronic stroke patients.

PATIENTS AND METHODS

This randomized, controlled study was conducted with 60 chronic stroke patients (26 males, 34 females; mean age: 64.0 years; range, 33 to 80 years) who presented to the physical therapy and rehabilitation outpatient clinic of the Kütahya Health Sciences University Evliya Çelebi Training and Research Hospital between February 2019 and February 2020. The study included patients who had a stroke at least six months earlier, had a Mini-Mental State Examination (MMSE) score of 21 or higher, were able to walk at least 10 m independently or with aid, did not use any medication that might affect balance, and were medically stable. Patients with stage 4 spasticity in the lower extremity according to the Modified Ashworth Scale, severe musculoskeletal pain, neurological comorbidity in addition to stroke, or any hearing or vision problem that would prevent them from participating in VR were excluded from the study.

The patients receiving inpatient treatment in the rehabilitation center included in the study were assigned to the VR group and control group by simple randomization with a 1:1 allocation ratio according to a list generated by an online randomizer. All assessments were performed by the same investigator who was blinded to the treatment assignment. Blinding of the patients or physical therapist was not possible due to the nature of the treatment. All participants received their assigned intervention five days a week for six weeks. The VR group received a 30-min conservative rehabilitation program plus 30 min of VR training, while the control group received a 60-min conventional rehabilitation program. The conventional rehabilitation program consisted of range of motion exercises and muscle strength (exercise bands and proprioceptive neuromuscular facilitation), activities of daily living, balance (weight-bearing exercises, standing on a narrowing support area, standing against perturbations, walking on a narrowing support area, walking on hard and soft surfaces), and walking training (stance and swing phase exercises). The VR rehabilitation program performed by the VR group consisted of table tennis, football, athletics, and skiing VR games on an Xbox Kinect system (Microsoft©, Redmond, WA, USA) displayed on a 43-inch LCD screen. All four games were played in each session for all patients in the VR group. During the VR training, the patient was asked to stand 2 m in front of the system, and their movements were transferred to the program by the Kinect sensor. Three trial sessions were performed to familiarize and orient the patient to the system. All rehabilitation interventions were performed in a quiet, isolated room of sufficient size and under the supervision of the same physiotherapist.

The patients completed a descriptive information form prepared by the researchers. Assessments included the Fugl-Meyer Assessment -Lower Extremity (FMA-LE) scale to evaluate lower extremity motor functions, the Rivermead Mobility Index (RMI) to evaluate mobility, a 10-m walk test (10MWT) to determine walking speed, and the Berg Balance Scale (BBS) to evaluate balance. The descriptive data form included the affected side, stroke type, time since stroke, the MMSE, and Brunnstrom recovery stage for the lower extremity. All evaluations were performed before the intervention (baseline) and at the end of the intervention (six weeks later) by an evaluator who was blinded to the patient groups.

The lower extremity motor functions of the participants in the study were assessed using the FMA-LE, developed to determine physical recovery

TABLE 1
Descriptive data of the groups

Variables	Study group (n=30)					Control group (n=30)					Z	*p*
	n	%	Mean±SD	Median	Q1-Q3	n	%	Mean±SD	Median	Q1-Q3		
Age (year)				63.50	59-69				64.50	53-73	-0.374#	0.734#
Time since stroke (month)				30	24-63				21	6-60	-1.696#	0.090#
MMSE				24.50	22-25				24	22-24	-2.052#	0.040#
Sex											-1.086*	0.297*
Female	15	50				19	63.3					
Male	15	50				11	36.7					
Affected side											-0.069*	0.793*
Right	18	60				17	56.7					
Left	12	40				13	43.3					
Stroke type											0.001*	1.000*
Ischemic	24	80				24	80					
Hemorrhagic	6	20				6	20					
Brunnstrom stage												
Hand			3.7±1.5					4.0±1.5			-0.550#	0.582#
Upper			4.1±1.6					4.3±1.4			-0.608#	0.543#
Lower			4.3±0.9					4.3±0.9			-0.265#	0.791#
Mean			4.0±1.2					4.2±1.2			-0.500#	0.617#
Lower extremity Brunnstrom recovery stage											-0.265#	0.791#
3												
4	6	20				4	13.3					
5	12	40				4	13.3					
6	10	33.3				13	43.3					
	2	6.7				9	30					

SD: Standard deviation; Q: Quartile; MMSE: Mini-Mental State Examination; χ^2: Chi-square statistic, Z: Statistical coefficient, %: percentage; n: Total number of patients in the group, n: Number of patients, p: Statistical significance level; * Chi-square test; # Mann-Whitney U test.

after stroke. The section assessing lower extremity motor function comprises 17 items and is scored between 0 and 34. A higher score indicates greater motor function.[10] The minimal clinically significant difference for the FMA-LE score was determined as 6.[11]

The patients' mobility levels were evaluated using the RMI, which is an easily applicable scale that can be used to assess rehabilitation outcomes in stroke patients. It consists of 14 questions answered by the patient and one observation made by the evaluator. Each affirmative response receives 1 point. A score of 15 is interpreted as no mobility problem, and all scores below 15 points indicate a mobility problem.[12] The Turkish validity and reliability study for the RMI in the geriatric population was conducted by Akın and Emiroğlu.[13]

The participants' balance was evaluated using the BBS. Originally developed to evaluate balance performance in geriatric patients, the scale is also frequently used in stroke patients. The validity and reliability study of the Turkish version of the BBS in stroke patients was performed by Şahin et al.[14] The 14 tasks in the BBS are rated using a 5-point Likert-type scale to yield a score ranging from 0 to 56. Scores of 0-20 indicate a balance disorder, scores of 21-40 indicate acceptable balance, and scores of 41-56 indicate good balance.[15]

Walking speed was assessed using the 10MWT, which is commonly used in poststroke rehabilitation.[16] The comfortable walking speed was measured by recording the time required to walk to 10 m in a 14-m course. The patient was instructed to walk, and a stopwatch was started when their leading foot crossed the 2-m mark and stopped when it crossed the 12-m mark. No encouragement was given during the test.[17]

Statistical analysis

The sample size calculation was performed with the G*Power version 3.1.9 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) based on the results of Park et al.[18] for FMA-LE. In the study, the mean FMA-LE score for the intervention and control groups were -9.80±4.85 and -6.20±5.22, respectively. The power analysis results were considered for sample calculation using a one-sided hypothesis test with independent samples t-test with a confidence of 95%, power of 80%, alpha of 5%, and effect size of 0.663. As a result of the analysis, 29 patients per group were required.

Statistical analyses were performed using SPSS version 18.0 software (SPSS Inc., Chicago, IL, USA). Group data were summarized using means and percentages. The Shapiro-Wilk test was used to determine whether the data were normally distributed. The Mann-Whitney U test was used as a nonparametric test for comparisons of age, Brunnstrom lower extremity recovery stage, FMA-LE, RMI, BBS, and 10MWT data, and the chi-square test was used to compare sex, affected side, and stroke type. The Wilcoxon signed-ranks test was used for within-group comparisons of pre-and post-treatment data for the non-normally distributed variables, FMA-LE, RMI, BBS, and 10MWT. The nonparametric Brunner-Langer method (F1 LD F1 model) was used to analyze FMA-LE, RMI, BBS, and 10MWT variables of groups for a time, group, and interaction effects using R version 3.3.1 software (R Foundation for Statistical Computing, Vienna, Austria). The level of statistical significance was set at p<0.05.

RESULTS

The groups were found to be similar in age and stroke duration (p>0.05); however, there was a significant difference between the groups in terms of MMSE scores (p=0.040). Descriptive statistics for the patients' age, time since stroke, MMSE scores, sex, affected side, stroke type, Brunnstrom stage, and Brunnstrom recovery stage for the lower extremity are

TABLE 2
Comparison of the groups' FMA-LE, RMI, 10MWT, and BBS scores at baseline

	Study group (n=30)		Control group (n=30)			
Variables	Median	Q1-Q3	Median	Q1-Q3	Z	*p**
FMA-LE	16.5	13.0-27.0	19.50	11.7-28.0	-0.231	0.817
RMI	13.0	8.0-14.0	10.50	6.0-14.0	-0.830	0.407
10MWT (sec)	42.0	30.0-49.0	39.5	29.2-49.0	-0.548	0.584
BBS	35.5	22.5-47.0	31.0	23.0-67.5	0.001	1.000

FMA-LE: Fugl-Meyer analysis-lower extremity; RMI: Rivermead Mobility Index; 10MWT: 10-Meter Walk Test; BBS: Berg Balance Scale; Q: Quartile; Z: Statistical value; * Mann-Whitney U test.

TABLE 3
Comparison of FMA-LE, RMI, 10MWT, and BBS scores within and between the groups

	Study group (n=30)				Control group (n=30)						
	Baseline		After treatment		Baseline		After treatment		Group	Time	Interaction
	Median	Q1-Q3	Median	Q1-Q3	Median	Q1-Q3	Median	Q1-Q3	*p**	*p**	*p**
FMA-LE	16.5	13.0-27.0	27.0	14.0-28.0	19.5	11.7-28.0	22.0	11.7-28.0	0.568	0.001	0.001
RMI	13.0	8.0-14.0	14.0	10.7-14.0	10.5	6.0-14.0	12.0	6.7-14.0	0.141	0.001	0.046
10MWT (sec)	42.0	30.0-49.0	52.5	33.7-56.0	39.5	29.2-49.0	42.5	30.5-53.2	0.339	0.001	0.001
BBS	35.5	22.5-47.0	29.0	16.0-39.0	31.0	23.0-67.5	25.5	19.0-60.0	0.347	0.001	0.001

FMA-LE: Fugl-Meyer analysis-lower extremity; RMI: Rivermead Mobility Index; 10MWT: 10-m walk test; BBS: Berg Balance Scale; Q: Quartile; Z: Statistical value; * The Brunner-Langer method.

presented in Table 1. Baseline FMA-LE, RMI, BBS, and 10MWT data of the groups are shown in Table 2. The groups were similar in all four parameters at baseline ($p>0.05$). Time, group, and interaction effects of FMA-LE, RMI, BBS, and 10MWT data of groups are displayed in Table 3. Interaction effects of the groups were statistically significant in all parameters ($p<0.05$). The within-group and between-group comparisons of FMA-LE, RMI, BBS, and 10MWT data are demonstrated in Table 4. Between-group comparisons revealed that the changes in FMA-LE and BBS were significantly higher in the VR group compared to the control group ($p<0.001$).

DISCUSSION

The results of this study demonstrate that both conventional physiotherapy and a combination of VR and conventional physiotherapy are effective in improving motor function, mobility, balance, and walking speed, whereas conventional treatment combined with VR is superior to conventional treatment alone only in improving motor function and balance.

Virtual reality interventions have been shown to be superior to conventional physiotherapy for improving upper extremity motor function.[19] However, there have been few studies investigating the effect of VR on lower extremity motor functions. This may be due to many stroke patients having balance problems that prevent them from independently participating in VR and VR games requiring quick responses. To the best of our knowledge, there is only one study in the literature examining the effect of VR exercises on lower extremity motor function, in which VR games were reported to be superior to conventional physiotherapy in improving motor function.[18] This is consistent with our finding that the VR group showed greater improvement in motor function than the control group. This may be owing to VR games leading to relatively more load transfer to the hemiplegic side and increased selective activity and balance reactions on the hemiplegic side compared to conventional physiotherapy. In addition, the feedback provided by VR may have further enhanced motor function development.

Mobility was also assessed using RMI in the present study. The post-treatment results demonstrated significant increases in mobility scores in both groups with no statistical difference between the groups. The literature search yielded only one VR study that used mobility indices. This study, which included 24 chronic stroke patients, reported that RMI increased significantly in both the control group and the VR group after treatment and that the VR intervention was superior to conventional physiotherapy in improving mobility.[20] The discrepancy between our results and those in the study of Calabrò et al.[20] might be attributable to their small sample size.

Studies investigating the effects of VR with conventional physiotherapy on walking speed have shown similar increases in walking speed in the VR and control groups at the end of treatment.[21-23] Kim et al.[24] determined that VR was superior to conventional treatment alone in their study. However, the VR group in their study received more treatment than the control group, which may have affected their results. In another study, Singh et al.[25] observed no significant increase in walking speed in either group. In the present study, both groups showed statistically significant increases in walking speed at the end of treatment, but the extent of this increase did not differ between the groups. We believe that the main reason for the conflicting

TABLE 4
Comparison of FMA-LE, RMI, 10MWT, and BBS scores within and between the groups

	Study group (n=30)								Control group (n=30)									
	Baseline		After treatment		Δ				Baseline		After treatment		Δ					
	Median	Q1-Q3	Median	Q1-Q3	Median	Q1-Q3	Z	p^*	Median	Q1-Q3	Median	Q1-Q3	Median	Q1-Q3	Z	p^*	Z	$p^\#$
FMA-LE	16.5	13.0-27.0	27.0	14.0-28.0	1.0	0.0-8.0	**-3.732**	**0.001**	19.5	11.7-28.0	22.0	11.7-28.0	0.0	0.0-0.0	**-2.032**	**0.042**	**-3.560**	**0.001**
RMI	13.0	8.0-14.0	14.0	10.7-14.0	1.0	1.0-2.0	**-4.316**	**0.001**	10.5	6.0-14.0	12.0	6.7-14.0	1.0	0.0-1.0	**-3.581**	**0.001**	-1.669	0.095
10MWT (sec)	42.0	30.0-49.0	52.5	33.7-56.0	-6.0	-11.0 to -5.0	**-4.795**	**0.001**	39.5	29.2-49.0	42.5	30.5-53.2	-7.0	-9.0 to -5.0	**-4.792**	**0.001**	-0.425	0.671
BBS	35.5	22.5-47.0	29.0	16.0-39.0	6.0	4.0-11.0	**-4.789**	**0.001**	31.0	23.0-67.5	25.5	19.0-60.0	3.0	1.0-4.0	**-4.301**	**0.001**	**-3.769**	**0.001**

FMA-LE: Fugl-Meyer analysis-lower extremity; RMI: Rivermead Mobility Index; 10MWT: 10-m walk test; BBS: Berg Balance Scale; Z: Statistical value; * Wilcoxon signed-rank test; # Mann-Whitney U test.

results in the literature is the wide variety of VR exercises and the methodological differences between studies.

There are also varying results in the literature regarding the effects of VR training on balance in stroke patients. In a study of stroke patients conducted by Barcala et al.,[26] both groups received the same conventional treatment, and the study group received an additional VR component. They determined that balance improved significantly and to a similar degree in both groups.[26] In another study in which the groups received different treatment durations, there was a significant improvement in the BBS results of both groups, but the VR group was superior to the control group.[27] However, the fact that the groups differed in terms of treatment duration should be considered when interpreting the results of these studies.

Studies examining the effectiveness of VR training on balance in groups with the same treatment have also yielded different results in terms of BBS scores. However, in most studies, both groups achieved significant improvement in BBS scores at the end of treatment.[22,23,28,29] A meta-analysis including only studies with equal treatment in both groups revealed that VR was superior to conventional treatment in improving BBS scores.[7] Both groups in the present study received treatment of equal duration, and consistent with the literature, the results demonstrate that balance improved significantly in both groups and that VR training with conventional treatment was superior to conventional treatment alone for improving balance. We believe this is related to balance training in VR rehabilitation, which involves multitasking similar to daily life, leading to more progress. The results may be affected by the fact that the exercise duration for balance training in the conventional treatment program was more limited than for the VR treatment.

This study has certain limitations. First, this study was planned to evaluate the short-term effect of VR. Therefore, the long-term effects have not been evaluated in the current study. Second, there was a difference in baseline cognitive function between the groups. This may have had an impact on the study outcomes. Third, the inclusion of only patients with no cognitive dysfunction and a history of the first stroke precludes the generalization of these results to all stroke patients. In addition, the study included patients from both the adult and geriatric populations. Finally, the study did not have a group receiving only the

VR intervention. We expect the inclusion of a group receiving only VR training in future studies to be more meaningful in demonstrating the effectiveness of VR in these patients.

In conclusion, VR training with conventional physiotherapy is an effective method in improving motor function, mobility, walking speed, and balance, which are among the primary problems in patients with chronic hemiplegia. Virtual reality requires active patient participation, offers many game options to suit individual interests and preferences, and is more economical than other rehabilitation technologies. Therefore, we believe that adding a VR component to rehabilitation programs will have a favorable impact on treatment outcomes.

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Ethics Committee Approval: The study protocol was approved by the Health Sciences University Interventional Research Ethics Committee (2019/02-2). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: The study design: F.Y., M.A.L.; Data collection: F.Y., M.İ.K.; Analysis and interpretation of the data: F.Y., İ.O., V.K.; Literatüre review, writing the article and references: F.Y., M.A.L., İ.O.; Supervision of the article: V.K., M.A.L., İ.O.

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