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ORIGINAL ARTICLE

Examining the effects of non-immersive virtual reality game-based training on knee hyperextension control and balance in chronic stroke patients: a single-blind randomized controlled study

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Abstract

Background Post-stroke hemiparesis can lead to decreased mobility, gait disturbances, impaired balance, postural instability, limitations in activities of daily living (ADL), and long-term disability.
Aims The aim of this study was to examine the effect of non-immersive virtual reality game-based training (nIVRGT) in addition to conventional rehabilitation in stroke patients on dynamic balance, knee hyperextension control, and ADL.
Methods Twenty-five chronic stroke patients aged between 51 and 70 were included in the study. Stroke patients were randomized to a control group ($n = 12$) and a study group ($n = 13$). Individuals in control group participated conventional physiotherapy and rehabilitation program for 60 min, 3 days a week for 6 weeks. individuals in the study group received 40 min of conventional physiotherapy and rehabilitation program plus 20 min nIVRGT. Functional Reach Test, Timed Up and Go Test, Computerized Gait Evaluation System and Barthel Index were used in the evaluation.
Result The study group improved significantly in dynamic balance, knee control, and ADL ($p < 0.05$). In the control group, significant improvements were observed in dynamic balance and knee control ($p < 0.05$), except ADL ($p > 0.05$). The study group improved in dynamic balance compared with the control group ($p < 0.05$). Knee control and ADL improved similarly in both groups ($p > 0.05$).
Conclusion Our results showed that conventional and additional nIVRGT rehabilitation improved dynamic balance and knee hyperextension control in chronic stroke. However, it was observed that the non-immersive virtual reality (nIVR) approach was more effective in improving dynamic balance in stroke patients than conventional rehabilitation alone.
Clinical trial code NCT05907473

Keywords Kinematics · Non-immersive virtual reality · Balance · Stroke · Knee hyperextension

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Introduction

Stroke is a global health problem. Post-stroke patients have problems maintaining postural control and cannot maintain balance due to abnormal body imbalance, asymmetrical posture, and difficulty in weight transfer. Stroke-related hemiparesis can lead to decreased mobility, gait asymmetry, impaired balance, postural instability, activities of daily living (ADL) difficulties, and long-term disability [1, 2].

Balance is the ability to maintain the line of gravity within the base of support with minimal postural sway. Control of human balance is a comprehensive process based on the integration of visual, vestibular, and somatosensory inputs into the central nervous system. It is reported that approximately 83% of stroke survivors experience static and dynamic balance disorders. Especially dynamic balance impairment causes short support time, gait and posture asymmetry, slow gait speed and may increase the risk of falling [3].

Significant differences in gait biomechanics are also seen in post-stroke patients [4]. Approximately 65% of stroke patients are reported [5] to have knee hyperextension, defined as an abnormal movement from the anatomically neutral position to extension during the stance phase, rather than mild knee flexion [6]. Poor eccentric control of the knee extensors, spasticity of the quadriceps and plantar flexors, weak hamstrings, and proprioceptive deficits are among the possible causes of knee hyperextension gait in stroke patients [7, 8]. If knee hyperextension is left untreated, it can lead to pain, decreased independence in ADL, deformities, and balance disorders [9]. In addition, this biomechanical disorder in the knee causes abnormal gait patterns, negatively affects the patients' balance, causes increased energy consumption and decreased gait speed and capacity [10]. Korkusuz et al. reported that cartilage thickness was less in the hemiplegic knee joint in stroke patients with knee hyperextension gait [11].

Applying current treatment methods for impairments in body structure and functions in hemiparetic individuals is consequential in improving activity and participation. In stroke rehabilitation, treatment programs that aim to transfer patients' clinical achievements to daily life and include motor and cognitive multitasking, taking into account individual-specific motor learning and plasticity principles are essential [12, 13]. Virtual reality game-based (VRG) systems combine computer-generated 3D images and animations with technology. In parallel with usual rehabilitation therapy programs, VRG systems can motivate patients to engage in more meaningful practices and also increase the intensity of purposeful movement [14].

Virtual reality game based systems divided into immersive and non-immersive systems. There are many studies in the literature that use nIVRGT to improve gait, balance, and ADL in post-stroke individuals [15, 16]. However, there are not enough studies examining the effect of nIVRGT on knee control.

Considering this information, the aim of our study is to examine the effect of nIVRGT in addition to conventional rehabilitation in chronic stroke patients on dynamic balance, knee control, and ADL. The hypothesizes of the study are (1) nIVRGT in addition to conventional rehabilitation improved dynamic balance in chronic stroke patients, (2) nIVRGT in addition to conventional rehabilitation improved knee control in chronic stroke patients and (3) nIVRGT in addition to conventional rehabilitation improved ADL in chronic stroke patients.

Methods

Study design and participants

Twenty-five chronic stroke patients were included in this single-blind randomized controlled study, which was conducted to examine the effect of nIVRGT in addition to conventional rehabilitation on dynamic balance, knee control, and ADL in stroke patients. Ethics committee approval was received from Bandırma Onyedi Eylül University Health Sciences Ethics Committee with protocol code 2023-77. The Clinical trial registration number is NCT05907473. The study was carried out at the Private Physical Therapy and Rehabilitation Clinic between October 2023 and April 2024. Patients who were followed up with chronic stroke diagnosis were included in the study, considering the inclusion and exclusion criteria.

Inclusion criteria

- At least 6 months have passed since the cerebrovascular accident,
- Being between the ages of 18–70 years,
- Getting 24 points or more from the Standardized Mini Mental Test (SMMT),
- Presence of knee hyperextension in the mid-stance phase of gait,
- Quadriceps muscle spasticity degree was 1, 1+, and 2 according to Modified Ashworth Scale,
- Mild to moderate motor deficits,
- Having a stroke for the first time,
- Patients who can walk independently for at least 50 m.

Exclusion criteria

- Presence of neglect syndrome,
- Bilateral involvement,
- Botulinum toxin application has been made within the last three months.
- Having an additional neurological disease such as Parkinson's Disease or Multiple sclerosis.

Sample size

The sample size of the study was calculated with G*Power (G*Power Ver. 3.1, Franz Faul, Universität Kiel, Germany) software, considering the study of McCAin et al. [17] When the effect size was calculated with the knee hyperextension angle in this study, the effect size was found to be 1.748108. With this effect size value, it was determined that 7 patients in each group should be included in order for the study to have 80% power. However, considering the possible data loss, a total of 18 patients, 9 in each group, were planned to be included. When 9 patients were completed in each group, post-hoc analysis was performed again and it was determined that 13 patients should be included in each group in order for the study to have 80% power. Accordingly, although 13 patients were evaluated and treated in each group, 1 patient in the control group was removed from the analysis due to extreme values during the data analysis phase. Therefore, the study was completed with 25 patients, 12 in the control group and 13 in the study group, with a power of 79.4% in the balance parameter.

Procedures

Demographic information (age, gender, height, body weight, occupation, educational status, dominant side, affected side, duration of disease, treatments received, and use of assistive devices) of all individuals included in the study was recorded in the patient information form.

Considering the inclusion and exclusion criteria, the patients included in the study had similar clinical and demographic characteristics. Therefore, they were divided into two treatment groups by simple random method.

Dynamic balance assessment

Functional Reach Test (FRT) and Timed Up and Go Test (TUGT) were used for evaluating the dynamic balance.

FRT It is based on lifting the arm 90° upwards and reaching forward as much as possible while keeping the feet fixed on the ground. The risk of falling at 15 cm and below 15 cm increases significantly, and between 15 and 25 cm indicates a moderate risk of falling. Values less than 25.4 cm indicate an increased risk of falling [18].

TUGT TUGT is an objective, reliable and simple measure to assess balance and functional mobility. It can also be used to assess fall risk. The person is asked to get up from a chair, walk 3 m, turn around, walk back to the chair and sit down, and the score is calculated by measuring how many seconds it takes to complete the test. Use of a walking aid is allowed during testing [19].

Knee kinematic analysis

Computerized Gait Evaluation System (Zebris Rehawalk) was used for evaluating the knee control of the patients. Participants were asked to walk on the treadmill at a comfortable gait speed. During the gait, the gait was recorded with the video camera system integrated into the device (Fig. 1). With the help of the system, the knee joint angle during gait was calculated with markers placed along the femur and tibia shaft on the recorded video (Fig. 2) [20, 21].

ADL assessment

The Barthel Index (BI) developed by Mahoney and Barthel in 1965 was modified by Shah et al. This scale evaluates activities of daily living such as feeding, washing, self-care, dressing, defecation control, urinary control, going to the toilet, ability to move from bed to wheelchair, walking or being dependent on a wheelchair, and stair climbing on a scale of 5–15 points (depending on the question). It consists of a total of 10 items grading (0–15 points in 5-point increments). On this scale, the higher your score, the higher your level of independence [22].

Treatment protocol

After the individuals included in the study were randomized, individuals in the control group received conventional rehabilitation, while patients in the study group received nIVRGT in addition to conventional rehabilitation. Individuals in the control group received conventional rehabilitation for 60 min, with equal session duration in both groups, while individuals in the study group received 40 min of conventional rehabilitation plus 20 min of nIVRGT training.

Control groups Patients in this group were included in a conventional rehabilitation program for 6 weeks, 3 days a

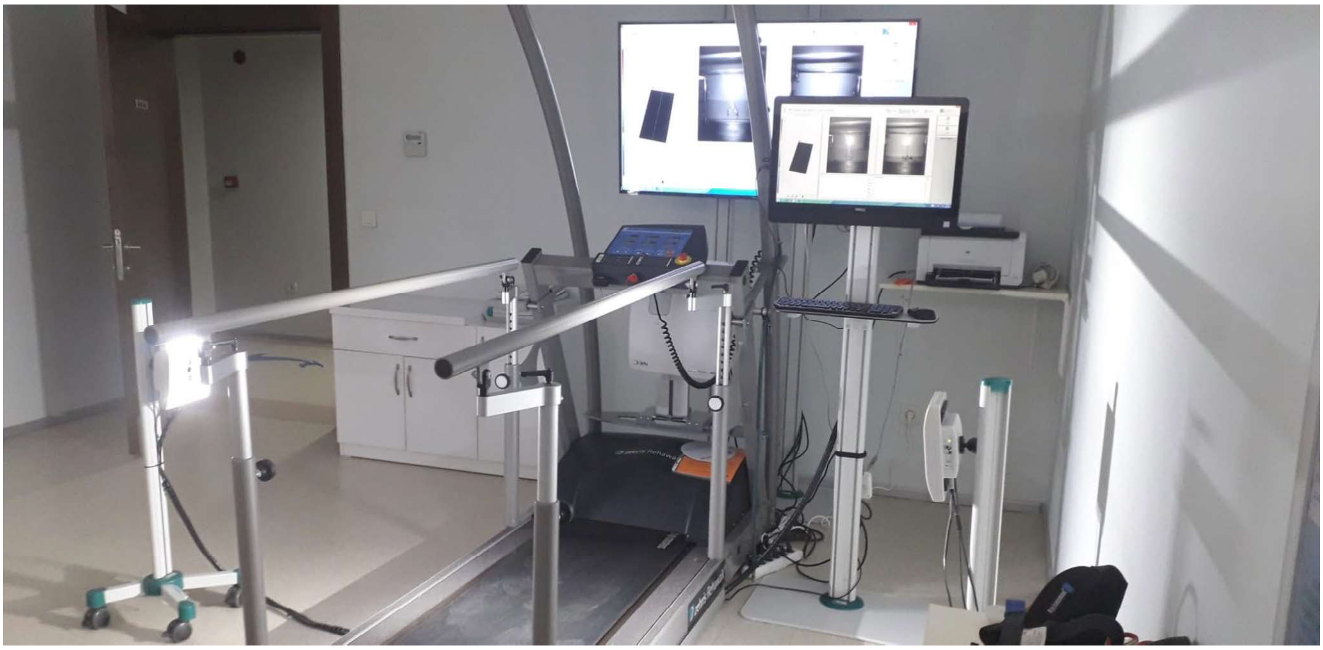

Fig. 1 Computerized Gait Evaluation System

week for 60 min. In the conventional rehabilitation program, patients were given mat activities, closed kinetic exercises for knee control, balance training inside or outside the parallel bar, gait and going up and down stairs training.

Study group Patients in this group received balance training by playing balance and weight transfer with Microsoft Kinect X Box for 20 min, along with a 40-minute conventional rehabilitation program, three days a week for 6 weeks.

Since the sense of pressure on the sole of the foot, strength and proprioception develop while playing the game, static and dynamic balance also develops. Visual biofeedback is provided with the games. Patients try to direct their body movements according to their own simulations on the screen. The ski games aims to develop functional balance with kneeling and weight transfer movements.

Before starting the study, the patients were informed about the game and played a trial game. The patients positioned themselves in front of the television screen, 250 cm away from the “Microsoft Xbox 360 KinectTM” sensor, so that the sensor could fully detect them. A perception test of the sensor in the game was performed for each patient.

Two games were selected that included knee flexion/extension and weight-bearing activities. The first of the games is Skicross and the second is Bounty Super G. In “Skicross”, the patients were adapted to the game by skiing normally and were allowed to learn how to ski. In “Bounty Super G”, the motivation of the patients was increased with the prizes they collected.

The patients played the game on a firm surface, wearing comfortable, casual shoes, with their feet shoulder-width apart. The patients were not allowed to make lateral trunk flexion movements during the game. They were only allowed to kneeling and swinging from side to side by transferring weight to their hips and knees. The patients were told not to move their arms back and forth to keep their speed constant throughout the game. Because it was stated that their sliding speed would increase when they moved their arms back and forth. The patients used their arms only to change direction left and right. In this way, they were allowed to slide at an average speed of 40 mph (miles/hour) / (64.37 km/h). The patients tried to balance by transferring weight to their knees and hips throughout the game; the soles of their feet did not leave the ground. All patients started at the same difficulty level. The difficulty level of nIVRGT was modified by experienced therapists based on the abilities and therapeutic goals of each participant.

Statistical analysis

IBM SPSS 22.0 for Windows (SPSS, Inc, Chicago, IL, ABD) analysis program was used for statistical analysis. Categorical variables were analyzed with Fisher’s exact chi-square test. Comparisons of the groups before and after the study were made with the Mann-Whitney U Test. Changes in the groups before and after the study were evaluated with the Wilcoxon Signed Rank test. Statistical significance level was accepted as $p < 0.05$.

Fig. 2 Knee joint angle measurement

Results

Demographic and clinical characteristics

In our study, 25 chronic stroke patients aged between 51 and 70 were included. The patients were divided into two groups: control group (8 women, 4 men) and study group (8 women, 5 men). There was no drop-out in the study. Both groups in our study were found to be similar in terms of age, gender, disease duration, dominant extremity, affected extremity and SMMT scores ($p > 0.05$) (Table 1).

Dynamic balance, knee control, and ADL results in groups

There was a significant improvement in the FRT and TUGT values of the patients in the control group after conservative treatment ($p < 0.05$). Additionally, it was observed that the knee angle in the mid-stance phase decreased significantly in the control group ($p < 0.05$). No significant difference was seen in the control group in terms of ADL after treatment ($p > 0.05$) (Table 2).

When the FRT, TUGT, knee joint kinematic angles, and BI scores obtained from the first and second evaluation in the study group were examined, it was determined that the

Table 1 Demographic and clinical characteristics of the patients

		Control Group		Study Group		p^a
		$\overline{X}$± SD	$\tilde{X}$ (min–max)	$\overline{X}$± SD	$\tilde{X}$ (min–max)	
Age (year)		62.00 ± 6.63	62.5 (51–70)	61.00 ± 4.88	60 (54–70)	0.531
Disease Duration (month)		18.67 ± 5.67	16.50 (13–29)	19.23 ± 4.91	19 (12–28)	0.683
BMI		25.73 ± 2.37	25.87 (20.45–29.41)	25.17 ± 2.23	25.01 (20.81–29.32)	0.550
SMMT		27.08 ± 1.88	26.5 (25–30)	27.15 ± 1.67	27 (25–30)	0.890
		n	**%**	**n**	**%**	**p[b]**
Gender	Female	8	66.7	8	61.5	0.560
	Male	4	33.3	5	38.5	
Dominant Extremity	Right	9	75	11	84.6	0.459
	Left	3	25	2	15.4	
Affected Extremity	Right	5	41.7	4	30.8	0.440
	Left	7	58.3	9	69.2	

$\overline{X}$±SD: Mean±Standart Deviation, $\tilde{X}$(min-max): Median (minimum-maximum), cm: centimeter, sec: second, n: Number of patients, BMI: Body Mass Index, SMMT: Standardized Mini Mental Test, a: Mann-Whitney U Test, b: Fisher's Exact Test

Table 2 Dynamic balance, knee control, and ADL results of the control group before and after treatment

	Before Treatment		After Treatment		p^c
	$\overline{X}$± SD	$\tilde{X}$ (min–max)	$\overline{X}$± SD	$\tilde{X}$ (min–max)	
FRT (cm)	19.91 ± 2.31	19.75 (15.50–24.00)	21.70 ± 2.24	21.50 (18.00–26.00)	**0.002***
TUGT (sec)	19.63 ± 2.22	19.82 (16.00–23.20)	17.67 ± 2.46	17.50 (13.14–21.30)	**0.021***
KA (degree)	-5.22 ± 3.19	-4.67 ((-10.94) – (-1.15))	-2.07 ± 3.85	-2.67 ((-7.02) – (5.12))	**0.041***
BI	76.66 ± 4.43	75 (70–85)	77.91 ± 4.50	80 (70–85)	0.083

$\overline{X}$±SD: Mean±Standard Deviation, $\tilde{X}$(min-max): Median (minimum-maximum), cm: centimeter, sec: second, FRT: Functional Reach Test, TUGT: Time Up and Go Test, BI: Barthel Index, KA: Knee Angle, c: Wilcoxon Signed Rank Test, *: $p < 0.05$

Table 3 Dynamic balance, knee control, and ADL results of the study group before and after treatment

	Before Treatment		After Treatment		p^c
	$\overline{X}$± SD	$\tilde{X}$ (min–max)	$\overline{X}$± SD	$\tilde{X}$ (min–max)	
FRT (cm)	20.73 ± 3.67	20.00 (15.00–27.00)	24.65 ± 3.28	25.00 (20.00–31.00)	**0.001***
TUGT (sec)	19.87 ± 3.77	18.84 (12.50–26.45)	15.06 ± 2.90	15.22 (8.20–18.65)	**0.001***
KA (degree)	-7.01 ± 3.44	-6.92 ((-12.13) – (-1.75))	-5.17 ± 3.48	-5.45 ((-10.35) – (2.01))	**0.002***
BI	79.61 ± 8.52	80 (70–90)	84.23 ± 9.54	85 (70–95)	**0.003***

$\overline{X}$±SD: Mean±Standard Deviation, $\tilde{X}$(min-max): Median (minimum-maximum), cm: centimeter, sec: second, FRT: Functional Reach Test, TUGT: Time Up and Go Test, BI: Barthel Index, KA: Knee Angle, c: Wilcoxon Signed Rank Test, *: $p < 0.05$

parameters improved, and these results were statistically significant ($p < 0.05$) (Table 3).

Dynamic balance, knee control, and ADL results between the groups

The groups were determined to be similar in terms of clinical parameters at the beginning of the study ($p > 0.05$). After the treatment, FRT and TUGT scores were significantly different in study group than the control group ($p < 0.05$) (Table 4). There was no difference in BI and knee angle between the groups ($p > 0.05$) (Table 4).

Discussion

Twenty-five chronic stroke patients were included in this study, which was conducted to examine the effect of nIVRGT in addition to conventional rehabilitation in stroke patients on dynamic balance and knee control. Our study results showed that conventional rehabilitation and conventional rehabilitation with nIVRGT were effective in dynamic balance, knee control, and ADL. However, nIVRGT was more effective in improving the dynamic balance of the patients.

Our study showed that knee control improved both in the control group that received traditional rehabilitation and in the study group that received nIVRGT in addition to traditional rehabilitation. There are a limited number of studies in the literature showing the effect of VR on knee kinematics. Eighteen stroke patients were included in the randomized controlled study conducted by Mirelman et al.

Table 4 Comparison of study and control group

		Control Group		Study Group		p[a]
		$\overline{X}\pm$ SD	$\tilde{X}$ (min–max)	$\overline{X}\pm$ SD	$\tilde{X}$ (min–max)	
Before Treatment	FRT (cm)	19.91 ± 2.31	19.75 (15.50–24.00)	20.73 ± 3.67	20.00 (15.00–27.00)	0.702
	TUGT(sec)	19.63 ± 2.22	19.82 (16.00–23.20)	19.87 ± 3.77	18.84 (12.50–26.45)	0.913
	KA (degree)	-5.22 ± 3.19	-4.67 ((-10.94) – (-1.15))	-7.01 ± 3.44	-6.92 ((-12.13) – (-1.75))	0.211
	BI	76.66 ± 4.43	75 (70–85)	79.61 ± 8.52	80 (70–90)	0.485
After Treatment	FRT (cm)	21.70 ± 2.24	21.50 (18.00–26.00)	24.65 ± 3.28	25.00 (20.00–31.00)	**0.033***
	TUGT (sec)	17.67 ± 2.46	17.50 (13.14–21.30)	15.06 ± 2.90	15.22 (8.20–18.65)	**0.044***
	KA (degree)	-2.07 ± 3.85	-2.67 ((-7.02) – (5.12))	-5.17 ± 3.48	-5.45 ((-10.35) – (2.01))	0.064
	BI	77.91 ± 4.50	80 (70–85)	84.23 ± 9.54	85 (70–95)	0.146

$\overline{X}\pm$SD: Mean±Standard Deviation, $\tilde{X}$(min-max): Median (minimum-maximum), cm: centimeter, sec: second, FRT: Functional Reach Test, TUGT: Time Up and Go Test, BI: Barthel Index, KA: Knee Angle, [a]: Mann-Whitney U Test, *: $p < 0.05$

[4] to examine the effect of VR rehabilitation on gait biomechanics. Patients were divided into two groups. One group was given ankle exercises in the VR system, while the other group was given exercises without a VR system, that is, without any auditory or visual feedback, 3 days a week for 4 weeks. Although Mirelman et al. [4] focused on the immediate effects of training to provide a mechanical explanation for the changes in gait speed after VR, the results showed that there were kinetic and kinematic changes in the ankle and knee. In this study, significant changes in knee range of motion during stance were found only in patients in the VR group after training. As a result of the study, it was reported that the knee joint angle in the VR group showed ROMs closer to normative values. Inadequate activity of the ankle plantar flexors during the stance phase of gait in stroke patients may result in poor control of the tibia. The most commonly adopted compensation pattern is for the knee to hyperextend or collapse into flexion to provide stability during mid-stance. However, improvement in tibial control may result in less residual flexion and better extension. Distal control achieved through training can lead to improved proximal control. In this study, it was reported that the use of VR improved motor control in the ankle, and possibly, kinematic and functional improvements were observed in the knee and ankle joints. In our study, VR training was combined with conventional rehabilitation, and kinematic analysis was performed only on knee joint. Also VR games focused not only on the ankle but also on knee and hip joints in our study. The results of our study showed that knee control was improved in both groups. Therefore VR was not superior to conventional rehabilitation. Our results were different than Mirelman et al. [4]. The improvement in knee control in both groups might be due to the inclusion of knee-oriented exercises and tasks in both conventional exercises and VR.

Bian et al. [23] compared the effects of VR-based intervention and conventional rehabilitation on motor function, balance, and gait parameters of 44 stroke patients. - The patients were divided into two groups. One group received VR-based intervention and the other group received conservative treatment. All participants underwent a 5-hour rehabilitation program, 5 days a week for 3 weeks. Study results showed that the maximum knee joint angle in the sagittal plane enhanced significantly at 6-month follow-up from baseline with VR-based training. There were also improvements in lower extremity motor function, balance, and gait performance. However, non-immersive VR-based intervention was no more effective than conservative treatment. The authors concluded that non-immersive VR-based interventions may thus be a valuable addition to conventional rehabilitation to enhance treatment efficacy. Bian et al.(38)'s study supported our results. The games used in both studies were similar. The similarity of the games used in both studies may have provided these results.

In a randomized controlled study conducted by Lee et al. [24] examining the effect of VR application on balance, ADL, and quality of life in stroke patients. Berg Balance Scale, FRT, TUGT, and BI were used as outcome measures. Both groups showed significant improvements in the Berg Balance Scale and TUGT. However, no significant differences were observed in FRT and BI within or between groups. In a meta-analysis conducted by Li et al. [16], 16 studies evaluating the effectiveness of VR interventions in improving balance in acute, sub-acute, and chronic stroke patients were included. This meta-analysis showed that stroke patients who received VR interventions had significant improvements on the Berg Balance Scale and TUGT compared to those who did not receive rehabilitation but did not show significant improvements on the FRT. The TUGT results of these studies were in accordance with our study. Contrary to Lee et al. [24] and Li et al. [16], VR rehabilitation was superior to conventional rehabilitation in the FRT in our study. FRT is a specific dynamic balance test that uses forefoot sensation. Task variability in games and the forefoot sensation of the patients might affect the study results. The ski games used in our study may have contributed to the development of sole pressure sense, strength and proprioception through active squatting and swinging, and thus, unlike other studies, an improvement may have been observed in the FRT, where balance is evaluated.

The impairments affect the ADL of stroke patients. There was a slight increase in the ADL with VR training in addition to conventional rehabilitation in our study. However, VR training was not superior to conventional rehabilitation on ADL. A systematic review by Hao et al. [25] revealed that the effects of VR-based intervention on ADL were similar to control interventions. The authors concluded that VR is a feasible approach and demonstrates comparable effectiveness in functional outcomes with conventional rehabilitation in patients with stroke at the early stage. In the early stage, the recovery rate is high in stroke patients. Therefore therapeutic interventions support neuroplasticity. In the chronic stage, habitual movement patterns are developed during functional activities. The changes in the ADL might be limited in chronic patients.

A systematic review conducted by Zhang et al. [26] reported that ADL improved in the VR group compared to the control group. Data from this review [26] indicate that VR is more effective than conventional rehabilitation in improving balance and ADL. The beginning values of ADL level were moderate in our study. Considering these circumstances, there might not have been any change in our study. Moreover, the improvement of the dynamic balance ability could not be transferred to ADL abilities in our patients.

A systematic review of randomized controlled trials examining the effects of virtual reality rehabilitation after total knee arthroplasty was conducted by Gazendam et al. Although conducted in a different disease group, the included studies showed that, similar to our study, balance ability and knee control improved in the VR rehabilitation groups compared to the control groups.

The objective kinematic evaluation of the knee is the strength of the study. The most important limitation of our study is that it does not include a follow-up evaluation to evaluate the duration of treatment maintenance.

Conclusion

Many studies examined the effects of VR-based intervention in the literature. However, there is no consensus between the studies. Our study results showed that both conventional and additional nIVRGT improved dynamic balance and knee control. nIVRGT was effective in improving the dynamic balance of stroke patients. We suggest that VR-based interventions combined with conventional rehabilitation enhance treatment efficacy in chronic stroke. Technology is an essential part of our life. Technology-based interventions support motor learning and enhance the impairments of stroke patients.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10072-024-07830-z.

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Declarations

Ethical standard All procedures involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. This study had been approved by the local Ethic Committee, and informed consent had been received from all participants resp. their patients.

Competing interest The authors have nothing to declare.

References

1. Zhang B, Wong KP, Kang R, Fu S, Qin J, Xiao Q (2023) efficacy of robot-assisted and virtual reality interventions on balance, Gait, and daily function in patients with stroke: a systematic review and network meta-analysis. Arch Phys Med Rehabil 104:1711–1719. https://doi.org/10.1016/j.apmr.2023.04.005
2. Winstein CJ, Stein J, Arena R, Bates B, Cherney LR, Cramer SC, Deruyter F, Eng JJ, Fisher B, Harvey RL, Lang CE, MacKay-Lyons M, Ottenbacher KJ, Pugh S, Reeves MJ, Richards LG, Stiers W, Zorowitz RD, American Heart Association Stroke Council CoC, Stroke Nursing CoCC, Council on Quality of C, Outcomes R (2016) Guidelines for adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke 47:e98–e169. https://doi.org/10.1161/STR.0000000000000098
3. Li J, Zhong D, Ye J, He M, Liu X, Zheng H, Jin R, Zhang SL (2019) Rehabilitation for balance impairment in patients after stroke: a protocol of a systematic review and network meta-analysis. BMJ Open 9:e026844. https://doi.org/10.1136/bmjopen-2018-026844
4. Mirelman A, Patritti BL, Bonato P, Deutsch JE (2010) Effects of virtual reality training on gait biomechanics of individuals post-stroke. Gait Posture 31:433–437. https://doi.org/10.1016/j.gaitpost.2010.01.016
5. Knutsson E, Richards C (1979) Different types of disturbed motor control in Gait of hemiparetic patients. Brain: a journal of neurology 102:405–430. https://doi.org/10.1093/brain/102.2.405
6. Cooper A, Alghamdi GA, Alghamdi MA, Altowaijri A, Richardson S (2012) The relationship of lower limb muscle strength and knee joint hyperextension during the stance phase of gait in hemiparetic stroke patients. Physiother Res Int 17:150–156. https://doi.org/10.1002/pri.528
7. Balaban B, Tok F (2014) Gait disturbances in patients with stroke. PM&R 6:635–642. https://doi.org/10.1016/j.pmrj.2013.12.017
8. Bleyenheuft C, Bleyenheuft Y, Hanson P, Deltombe T (2010) Treatment of genu recurvatum in hemiparetic adult patients: a systematic literature review. Ann Phys Rehabil Med 53:189–199. https://doi.org/10.1016/j.rehab.2010.01.001
9. Chen Z, Xian Z, Chen H, Zhong Y, Wang F (2023) Immediate effects of a buffered knee orthosis on gait in stroke patients with

knee hyperextension. J Back Musculoskelet Rehabil 36:445–454. https://doi.org/10.3233/bmr-220069

10. Cooper A, Alghamdi GA, Alghamdi MA, Altowaijri A, Richardson S (2012) The relationship of lower limb muscle strength and knee joint hyperextension during the stance phase of gait in hemiparetic stroke patients. Physiotherapy Res Int 17:150–156
11. Korkusuz S, Kibar S, Özgören N, Arıtan S, Seçkinoğulları B, Fil Balkan A (2023) Effect of knee hyperextension on femoral cartilage thickness in stroke patients. Am J Phys Med Rehabil. https://doi.org/10.1097/phm.0000000000002323
12. Iruthayarajah J, McIntyre A, Cotoi A, Macaluso S, Teasell R (2017) The use of virtual reality for balance among individuals with chronic stroke: a systematic review and meta-analysis. Top Stroke Rehabil 24:68–79. https://doi.org/10.1080/10749357.2016.1192361
13. Johnson SJ, Guediri SM, Kilkenny C, Clough PJ (2011) Development and validation of a virtual reality simulator: human factors input to interventional radiology training. Hum Factors 53:612–625. https://doi.org/10.1177/0018720811425042
14. Hao J, Xie H, Harp K, Chen Z, Siu KC (2022) Effects of virtual reality intervention on neural plasticity in stroke rehabilitation: a systematic review. Arch Phys Med Rehabil 103:523–541. https://doi.org/10.1016/j.apmr.2021.06.024
15. Aminov A, Rogers JM, Middleton S, Caeyenberghs K, Wilson PH (2018) What do randomized controlled trials say about virtual rehabilitation in stroke? A systematic literature review and meta-analysis of upper-limb and cognitive outcomes. J Neuroeng Rehabil 15:29. https://doi.org/10.1186/s12984-018-0370-2
16. Li Z, Han XG, Sheng J, Ma SJ (2016) Virtual reality for improving balance in patients after stroke: a systematic review and meta-analysis. Clin Rehabil 30:432–440. https://doi.org/10.1177/0269215515593611
17. McCain KJ, Pollo FE, Baum BS, Coleman SC, Baker S, Smith PS (2008) Locomotor treadmill training with partial body-weight support before overground gait in adults with acute stroke: a pilot study. Arch Phys Med Rehabil 89:684–691. https://doi.org/10.1016/j.apmr.2007.09.050
18. Duncan PW, Weiner DK, Chandler J, Studenski S (1990) Functional reach: a new clinical measure of balance. J Gerontol 45:M192–197. https://doi.org/10.1093/geronj/45.6.m192
19. Podsiadlo D, Richardson S (1991) The timed up & go: a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39:142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x
20. Schlick C, Ernst A, Bötzel K, Plate A, Pelykh O, Ilmberger J (2016) Visual cues combined with treadmill training to improve gait performance in Parkinson's disease: a pilot randomized controlled trial. Clin Rehabil 30:463–471. https://doi.org/10.1177/0269215515588836
21. Kibar S, Yavuz F, Balaban B (2016) An accelerated multi-modality rehabilitation protocol combined with botulinum toxin-A injection in adult idiopathic toe walking: case report. J Clin Diagn Res 10:Yd01–03. https://doi.org/10.7860/jcdr/2016/19595.7946
22. Mahoney FI, Barthel DW (1965) Functional evaluation: the Barthel index: a simple index of independence useful in scoring improvement in the rehabilitation of the chronically ill. Maryland state medical journal
23. Bian M, Shen Y, Huang Y, Wu L, Wang Y, He S, Huang D, Mao Y (2022) A non-immersive virtual reality-based intervention to enhance lower-extremity motor function and gait in patients with subacute cerebral infarction: a pilot randomized controlled trial with 1-year follow-up. Front Neurol 13:985700. https://doi.org/10.3389/fneur.2022.985700
24. Lee HC, Huang CL, Ho SH, Sung WH (2017) The effect of a virtual reality game intervention on balance for patients with stroke: a randomized controlled trial. Games Health J 6:303–311. https://doi.org/10.1089/g4h.2016.0109
25. Hao J, Yao Z, Harp K, Gwon DY, Chen Z, Siu K-C (2023) Effects of virtual reality in the early-stage stroke rehabilitation: a systematic review and meta-analysis of randomized controlled trials. Physiother Theory Pract 39:2569–2588. https://doi.org/10.1080/09593985.2022.2094302
26. Zhang B, Li D, Liu Y, Wang J, Xiao Q (2021) Virtual reality for limb motor function, balance, gait, cognition and daily function of stroke patients: a systematic review and meta-analysis. J Adv Nurs 77:3255–3273. https://doi.org/10.1111/jan.14800

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