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ORIGINAL ARTICLE

The effects of augmented and virtual reality gait training on balance and gait in patients with Parkinson's disease

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Abstract

Objective Augmented reality (AR) and virtual reality (VR) facilitate motor learning by enabling the practice of task-specific activities in a rich environment. Therefore, AR and VR gait training may improve balance and gait in Parkinson's Disease (PD).

Methods Thirty patients with PD were randomly divided into study ($n = 15$) and control ($n = 15$) groups. The study group was given AR and VR gait training combined with conventional training. The control group was given conventional training only. The training was applied to both groups 3 days a week for 6 weeks. Motor symptoms with the Unified Parkinson Disease Rating Scale-Motor Examination (UPDRS-III), balance with posturography and Berg Balance Scale (BBS), perceived balance confidence with Activity-Specific Balance Confidence Scale (ABC), gait with spatio-temporal gait analysis, and functional mobility with Timed Up and Go Test (TUG) were assessed.

Results At the end of the study; UPDRS-III, posturography measurements, BBS, ABC, spatio-temporal gait parameters, and TUG improved in the study group ($p < 0.05$), while BBS, ABC, and only spatial gait parameters (except for step width) improved in the control group ($p < 0.05$). There was no change in posturography measurement, temporal gait parameters, and TUG in control group ($p > 0.05$). When the developed parameters in both groups were compared, the amount of improvement in BBS and ABC was found similar ($p > 0.05$), while the improvement in the other parameters was found higher in the study group ($p < 0.05$).

Conclusion It was concluded that AR and VR gait training provides the opportunity to practice walking with different tasks in increasingly difficult environments, thus improving balance and walking by facilitating motor learning.

Keywords Augmented reality · Virtual reality · Parkinson's disease · Balance · Gait

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Introductıon

Balance and gait disorders in PD show a disease-specific pattern. In patients with Parkinson's Disease (PD), it is seen that the limits of stability decreased, automatic postural strategies are delayed, walking slows down, the step length decreases, the duration of the stance phase and the number of steps increases, and the step length decreases when approaching obstacles, and freezing episodes occurred [1, 2].

Previous studies indicate that physiotherapy approaches improve balance and gait in PD [3, 4]. In these systematic reviews, it is emphasized that approaches aiming to improve balance and walking in PD should be based on motor learning and neural plasticity. This is possible with training in which task-specific activities are studied intensively in a diversified environment, and feedback is given on task performance to achieve effective functional movement. On the other hand, it is not possible to create a diversified environment, increase the difficulty of the task, give sufficient feedback, and practice intensively in the clinical environment. Augmented reality (AR) and Virtual reality (VR) can provide the needs necessary to provide these motor learning principles, which can be difficult to meet with traditional therapy [5]. VR applications, which enable patients to interact with an artificial virtual environment, also allow the physiotherapist to evaluate patients with objective methods and observe developments. Developing technology aims to increase the reality and immersion by adding sensory stimuli to the virtual environment in VR applications, which brings out AR systems. In AR, virtual objects placed in the virtual environment or added tactile, visual, and auditory stimuli increase the interaction of individuals with the virtual environment.

When the literature is examined, it is seen that VR practices generally focus on standing balance training, while the use of VR during gait training is a newer technology, and studies are limited in PD [6–9]. In these studies, it was shown that the spatio-temporal features of walking [6, 8] and functional mobility [7, 9] improved with VR training. In only one of these studies, in which different VR walking platforms were used, it was seen that VR and AR were used together in gait training [9].

As a result, it is seen that there is a need for studies examining the effects of augmented and virtual reality training in PD with objective measurement methods. Therefore, our study aimed to examine the effects of AR and VR gait training on balance and gait in early to mid-stage PD.

Methods

Participants

Between July and December of 2021, 30 patients with PD who applied to the Department of Physical Medicine and Rehabilitation, Republic of Türkiye Ministry of Health, Ankara Bilkent City Hospital and who were diagnosed by a neurologist participated in the study. The inclusion criteria were as follows: (1) Hoehn and Yahr (H&Y) ≤ 3; (2) being 40 years or older; and (3) that the individuals agreed to be included in the study after adequate information was given about the study. The exclusion criteria were as respectively: (1) standardized Mini-Mental State Examination score < 24; (2) the presence of cardiovascular, vestibular, musculoskeletal, or additional neurological disease; (3) having a sensorial impairment (i.e., auditory and visual loss). In addition, the study was approved by the Republic of Türkiye Ministry of Health, Ankara Bilkent City Hospital Clinical Research Center Ethics Committee (E2-21–632). The participants were randomized to the study ($n = 15$) and control ($n = 15$) groups (Fig. 1). The control group received conventional physiotherapy, and the study group received AR and VR training. Conventional training (except standing balance and walking exercises) was also applied to the study group. Both groups received routine medication for PD.

Interventions

Conventional training

Conventional training was applied to the patients in the control group. It was planned with the following objectives in mind: increasing mobility by improving the impaired kinesthetic sensation; improving flexibility of soft tissues, body alignment, mobility in and out of bed; and improving balance and gait [10]. The training was applied 3 days a week for 6 weeks, with each exercise session lasting approximately one hour, accompanied by a physiotherapist. Training started with exercises in the supine position and continued with exercises in sitting and standing. After the walking exercises, the training was terminated with stretching and relaxation exercises. Each of the exercises was done in 2 sets of 10 repetitions. In gait training, each exercise was performed for 4 min.

Augmented and virtual reality gait training

Gait and balance training was given with AR and VR gait training using the C-Mill VR + (Motek Medical, Amsterdam, The Netherlands) device [11]. The training was

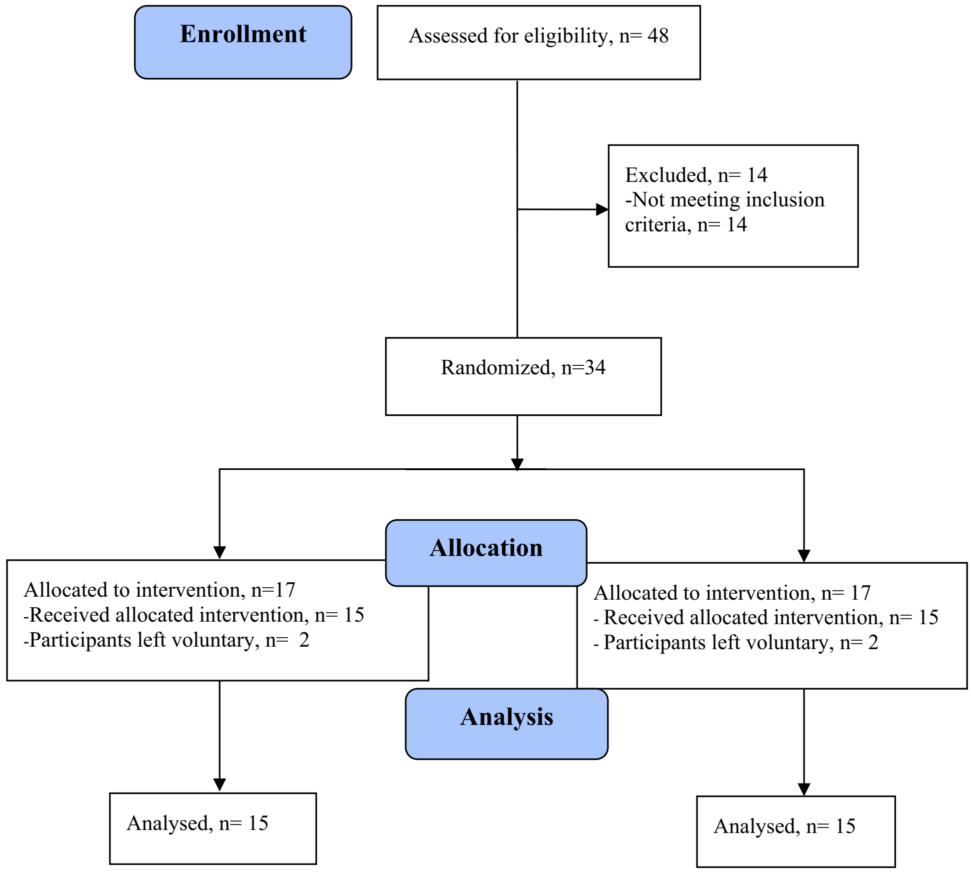


Fig. 1 Flow chart of the study

carried out 3 days a week for 6 weeks with each exercise session lasting approximately 1.5 h accompanied by a physiotherapist. Training started with conventional exercises (except for balance and walking exercises), continued with C-Mill VR + training, and ended with stretching and relaxation exercises. In all of the gait training, it was basically aimed to increase the step length and improve the swing phase and the walking adaptability to the changes in the environment (surface, speed, auditory stimulus). Training procedure was planned as follows: informing individuals about the device and exercises, using safety vests to minimize the risk of falling during training, providing visual and auditory feedback to individuals by the device and physiotherapist during training, increasing the individual specific difficulty level of each exercise in the training content through different variables, and adjusting the initial difficulty level of the training between 12 and 15 points which indicates medium difficulty according to the Borg scale [12]. The 10 exercises (Fig. 2.) in AR and VR gait training were as, respectively: 1. Stepping stones, 2. Random stepping stones, 3. Obstacle avoidance, 4. Speed adaptation, 5. Slalom, 6. Monster game, 7. Balls track, 8. Auditory cueing, 9. Nature island, 10. The Italian Alps. Exercises were performed for 4 min resting the individuals for about 1 min between exercises.

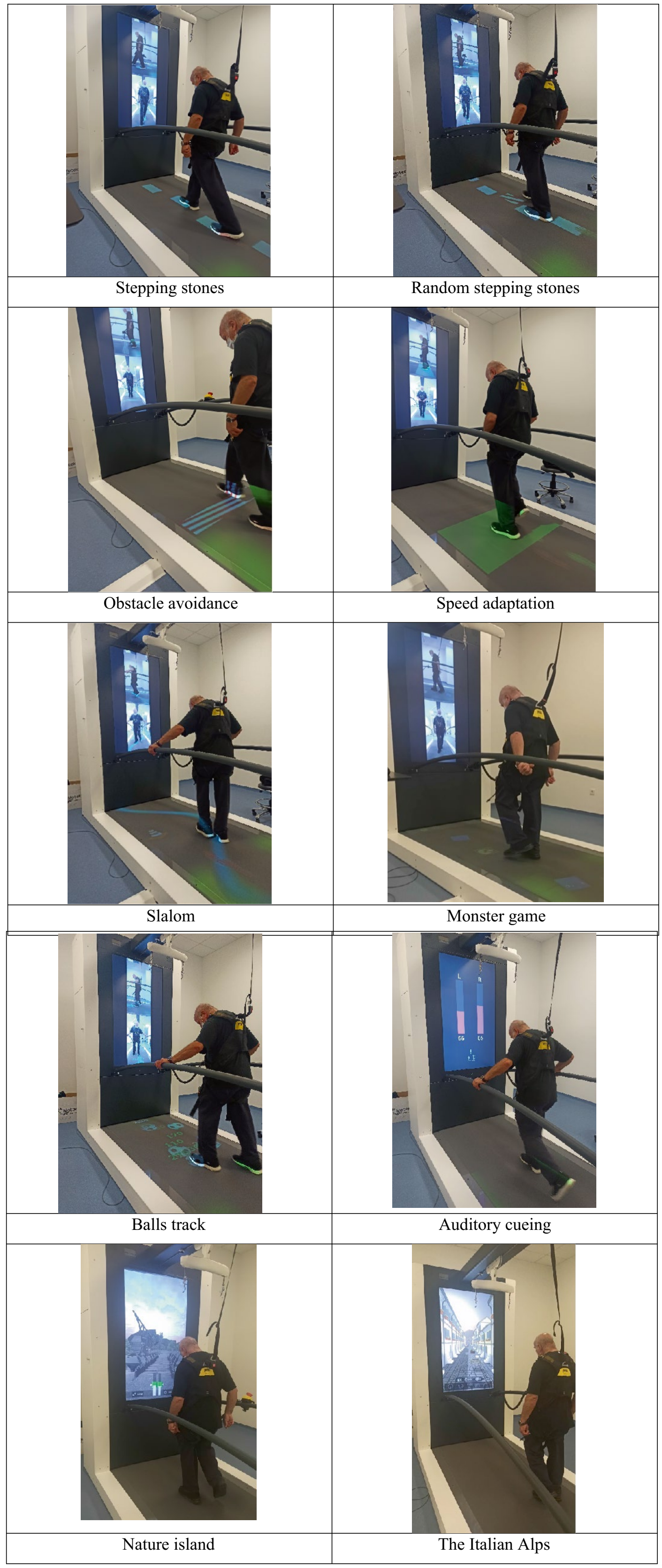
Data acquisition and assessment

Patients were evaluated twice, before and after 6 weeks. The evaluations started 30–45 min after the patients took their dopaminergic drugs. All assessments were made by a physiotherapist blinded to the study groups. The demographics and disease characteristics were recorded.

The clinical motor symptoms of the patients were evaluated with the motor assessment subscale of the *Unified Parkinson's Disease Rating Scale (UPDRS-III)*. The severity of motor symptoms was evaluated with 13 items in UPDRS-III. Items are scored between 0 and 4; 0 = no impairment, 4 = severe impairment. Higher scores indicate more serious impairment [13].

Static and dynamic standing balance was evaluated with the Huber 360° Evolution System (LPG Systems, Valence, France), which objectively evaluates postural sway and limits of stability [14]. The stability test was performed by recording the amount of sway of the Center of Pressure (CoP) under standing on double-leg and single-leg conditions. The test was performed under eyes open and eyes-closed conditions. The lower values mean that the amount of sway is low and the postural stability is better. In the limits of stability test, while on standing and with fixed feet position, patients were asked to shift their weight in a total of

Fig. 2 AR and VR gait training



eight directions according to the trigonometric coordinate system. The high values mean that the amount of CoP sway is high, and the stability limits of the patient are good.

Functional balance was evaluated with *Berg Balance Scale (BBS)* [15].

The level of confidence that an individual feels during the activities of daily living related to balance was evaluated with *Activities-Specific Balance Confidence Scale (ABC)* [16].

Spatio-temporal gait analysis was performed with the C-Mill VR + (Motek Medical, Amsterdam, The Netherlands) device. In the test, patients were asked to walk on the platform of the C-Mill VR + device for 3 min at the highest confident speed they felt safe [11]. Right-left step and stride length, step width, stance-swing phases, and total double support phase duration were recorded.

Functional mobility was assessed with the *Timed Up and Go test (TUG)* [17].

Statistical analysis

Statistical analyzes were performed using SPSS v.23.0 (SPSS Inc, Chicago, IL, USA). Non-parametric tests were used because the number of cases was not in accordance with the normal distribution. Descriptive statistics were made by giving the median and interquartile range (25–75 interquartile range: IQR). Descriptive statistics of categorical variables were expressed as frequency and percentage (%). A comparison of data within the group was made using the Wilcoxon test. The amount of improvement after the training in the research and control groups was compared with the Mann–Whitney *U* Test. The level of statistical significance was set at $p < 0.05$. The sample size calculation was based on the significant improvement of the BBS after similar intervention study in PD [9]. To achieve %80 power with a two-sided level of 5%, the sample size required per group was 14 using G*Power software (version 3.1.9.7; Heinrich Heine Universitat, Dusseldorf, Germany).

Results

Table 1 shows the demographic and disease characteristics of the groups. According to the results of the study, UPDRS-III total score decreased in both groups after the training ($p < 0.05$, Table 2). There was no difference between the amount of decrease ($p > 0.05$, Table 3).

In the study group, there was an improvement in all parameters of open-closed eyes double-leg stability tests, single-leg stability test, limits of stability test, BBS, and ABC with AR and VR training ($p < 0.05$, Table 2). In the control group, there was only an improvement in BBS and ABC ($p < 0.05$, Table 2). There was no difference between the groups in terms of the number of developments in BBS and ABC ($p > 0.05$, Table 3).

Our findings showed that in the study group, after the training right-left step length, stride length, and right-left swing phase duration increased, while step width, right-left stance phase duration, and total double support phase duration decreased ($p < 0.05$, Table 2). However, in the control group, it was observed that the right-left step length and stride length increased ($p < 0.05$, Table 2), and no difference was found in other gait parameters ($p > 0.05$, Table 2). The right-left step length and stride length which are the parameters that developed in both groups, improved more in the study group than in the control group ($p < 0.05$, Table 3).

Table 1 Demographic and clinical characteristics of the disease (Could you write the median and iqr in all tables on a bottom row?)

	Study Group $n = 15$ median (IQR)	Control Group $n = 15$ median (IQR)	*p*
Gender			
Female	2 (13.3)	2 (13.3)	1.000
Male	13 (86.7)	13 (86.7)	
Age, (year)	61 (57–66)	60 (51–67)	0.884
BMI, (kg/m^2)	27.70 (26.80–29.10)	27.50 (25.70–30.40)	0.836
Disease duration, (year)	6 (1–10)	6 (1–9)	0.771
H&Y stage, (0–5)	3 (2–3)	3 (2–3)	0.870
H&Y	***n* (%)**	***n* (%)**	
1	1 (6.7)	2 (13.3)	0.763
2	6 (40)	4 (26.7)	
3	8 (53.3)	9 (60)	

BMI Body Mass Index, *H&Y* Hoehn and Yahr, *$p < 0.05$

Table 2 A comparison of before and after training

		Study Group			Control Group		
		Before trainig median (IQR)	After trainig median (IQR)	*p*	Before trainig median (IQR)	After trainig median (IQR)	*p*
UPDRS-III, (0–108)		15.0 (10.0–23.0)	11.0 (9.0–17.0)	**0.002***	20.0 (15.0–33.0)	17.0 (8.0–24.0)	**0.001***
Double-leg Stability Test							
Eyes Open	Area (mm^2)	159.45 (93.80–186.65)	112.08 (76.96–145.91)	**0.005***	139.86 (99.56–287.69)	143.52 (88.17–524.77)	0.268
	Length (mm)	471.24 (365.74–550.06)	285.03 (199.00–344.23)	**0.001***	354.69 (243.25–548.86)	372.98 (253.84–564.87)	0.650
	Speed (mm/s)	9.42 (7.31–11.00)	6.02 (4.02–6.72)	**0.001***	7.09 (4.87–10.98)	6.99 (5.03–11.30)	0.776
Eyes Closed	Area (mm^2)	316.21 (165.50–410.47)	204.14 (92.19–271.00)	**0.036***	253.01 (119.15–2481.66)	265.11 (156.13–899.23)	0.140
	Length (mm)	580.92 (431.21–777.12)	377.63 (226.43–606.42)	**0.003***	552.01 (413.16–806.96)	431.21 (323.94–809.13)	0.281
	Speed (mm/s)	11.62 (8.62–15.54)	7.69 (5.44–12.13)	**0.004***	11.04 (8.26–16.14)	7.69 (6.70–10.67)	0.125
Single-Leg Stability Test							
Area, (mm^2)	Right	889.95 (590.65–1964.63)	684.43 (277.00–882.59)	**0.031***	1681.59 (668.11–2561.94)	1313.02 (601.77–1964.63)	0.233
	Left	720.75 (563.23–1065.66)	566.12 (373.70–713.49)	**0.004***	1030.59 (656.76–2159.53)	1233.24 (611.81–3245.69)	0.307
Length, (mm)	Right	1072.69 (709.46–1321.95)	554.05 (376.79–862.39)	**0.008***	868.86 (759.40–1231.15)	855.53 (622.04–1227.41)	0.570
	Left	807.27 (543.46–1341.02)	518.53 (389.17–982.92)	**0.009***	892.43 (646.21–1129.77)	672.13 (543.46–904.77)	0.078
Limits of Stability Test, (mm^2)		21,663.63 (14,418.97–40,447.57)	36,678.34 (22,455.59–50,963.31)	**0.001***	18,351.90 (10,650.80–34,461.20)	25,455.13 (13,023.49–38,498.43)	0.233
Berg Balance Scale, (0–56)		53.0 (48.0–55.0)	54.0 (50.0–56.0)	**0.009***	50.0 (39.0–54.0)	52.0 (44.0–55.0)	**0.002***
ABC, (0–100)		85.30 (67.50–97.30)	94.37 (82.50–98.00)	**0.003***	58.0 (44.60–94.37)	62.0 (52.0–96.25)	**0.001***
Step Length, (m)	Right	0.33 (0.28–0.44)	0.50 (0.41–0.69)	**0.001***	0.27 (0.24–0.41)	0.36 (0.31–0.48)	**0.001***
	Left	0.33 (0.27–0.44)	0.53 (0.38–0.70)	**0.001***	0.28 (0.14–0.42)	0.38 (0.23–0.49)	**0.001***
Stride Length (m)		0.66 (0.61–0.87)	1.02 (0.80–1.37)	**0.001***	0.56 (0.34–0.84)	0.79 (0.52–0.97)	**0.001***
Step Width (m)		0.15 (0.14–0.19)	0.13 (0.11–0.15)	**0.010***	0.15 (0.13–0.18)	0.15 (0.12–0.17)	0.155
Stance Duration, (s)	Right	0.33 (0.28–0.44)	0.50 (0.41–0.69)	**0.001***	0.78 (0.69–0.90)	0.80 (0.65–0.91)	0.460
	Left	0.33 (0.27–0.44)	0.53 (0.38–0.70)	**0.001***	0.83 (0.70–0.93)	0.79 (0.71–0.91)	0.281
Swing Duration, (s)	Right	0.38 (0.32–0.42)	0.41 (0.36–0.47)	**0.001***	0.37 (0.28–0.43)	0.35 (0.27–0.41)	0.069
	Left	0.37 (0.35–0.43)	0.42 (0.37–0.48)	**0.003***	0.33 (0.23–0.41)	0.37 (0.23–0.43)	0.078
Total Double Support Duration, (s)		0.46 (0.37–0.51)	0.33 (0.26–0.39)	**0.011***	0.47 (0.38–0.59)	0.44 (0.34–0.52)	0.057
TUG (s)		10.0 (8.0–11.0)	8.0 (5.0–10.0)	**0.002***	11.0 (10.0–14.0)	11.0 (9.0–14.0)	0.118

UPDRS-III Unified Parkinson's Disease Rating Scale-Motor assessment subscale, *ABC* Activities-Specific Balance Confidence Scale, *TUG* Timed Up and Go Test, $*p<0.05$

Discussion

In this study, which we aimed to analyze the effects of AR and VR gait training combined with conventional training on balance and gait in PD, it was observed that the severity of motor symptoms decreased, and balance, balance confidence perception and gait improved after 6 weeks of training.

As stated in the results, a similar amount of decrease in the severity of motor symptoms was observed in both groups. In our study, conventional training consisting of exercises aimed at improving bradykinesia, hypokinesia, rigidity, posture, postural control, and walking was applied to both groups. Therefore, the improvement in these symptoms is considered as a natural result of training. Considering that AR and VR are not accessible practices in every clinic, it is a positive result to achieve improvement with conventional training. Previous studies have also shown that both VR gait and conventional gait training are effective in

Table 3 Comparison of the improvement amounts of parameters which developed in both groups

	Study Group Δ median (IQR)	Control Group Δ median (IQR)	*p*
UPDRS-III, (0–108)	−4.00 [(−5.00) to (−1.00)]	−5.00 [(−7.00) to (−3.00)]	0.489
Berg Balance Scale (0–56)	2.0 [(1.0) to (3.0)]	2.0 [(1.0) to (3.0)]	0.433
ABC (0–100)	4.0 [(0.70) to (11.30)]	4.0 [(3.12) to (6.87)]	0.967
Step Length (m)			
Right	0.16 [(0.12) to (0.24)]	0.06 [(0.03) to (0.13)]	**0.001***
Left	0.17 [(0.11) to (0.24)]	0.06 [(0.03) to (0.13)]	**0.005***
Stride Length (m)	0.35 [(0.27) to (0.42)]	0.17 [(0.07) to (0.24)]	**0.001***

UPDRS-III Unified Parkinson's Disease Rating Scale-Motor assessment subscale, *ABC* Activities-Specific Balance Confidence Scale, *$p < 0.05$

reducing the severity of motor symptoms in patients with early to mid-stage PD [8, 18].

Although balance disorder becomes evident with disease progression, posturographic evaluations in individuals with early-stage PD show abnormalities in postural sway [19]. In our study, postural sway decreased, and the stability limits increased under standing on both single-double leg and eyes-closed conditions in the study group after the AR and VR gait training. There has also been improvement in clinical testing functional balance and the perception of confidence in balance-related activities in the study group. This similar improvement, which was obtained in different dimensions of balance, was only achieved in BBS and ABC in the control group.

Although the AR and VR gait training we have implemented is specific training for walking, the training has created a richer and increasingly difficult environment for patients to transfer weight in different directions with a dual-task and practice staying on a single leg than conventional training, so that static and functional balance has also improved. On the other hand, the improvement in functional tests only in the control group is an important indicator of how the content of the training affects the outcome measures.—Another reason for the improvement in all parameters of balance in the study group is that AR and VR training was given on a moving surface, with intense visual and auditory stimuli that both corrected the movement and motivated the patient.

When the literature is reviewed, it is seen that the number of studies evaluating the effects of AR and/or VR gait training on balance in PD using posturography is insufficient [9]. For this reason, our study stands out as a study that evaluates the effect of AR and VR gait training on postural stability in Parkinson's patients using posturography. Wang et al. used the C-Mill VR + system that we used in our study, and they only examined the developments in the postural stability tests but did not evaluate the stability limit. According to the results of their study, they showed that the postural sway rate did not change in PD without postural instability and gait disturbance, and the rate of postural sway increased in those with postural instability and gait disturbance with training. This result brings us to the opposite conclusion of our study because the AR and VR walking training applied by Wang et al. consisted of 5 exercises together with a warm-up and the training lasted only 7 sessions, and it was not combined with conventional exercises. Despite this different result, the functional balance evaluated by BBS in both groups is similar to the results of our study.

Gait disturbances are common in the mid to late stages of PD and lead to falls and losses of independence. In PD, cadence and double support phase duration increase, while step length, swing phase duration, and walking speed decrease [20]. One of the important disorders in walking in PD is the decrease in walking speed and deterioration of walking performance with the motor or cognitive dual-task added to walking. This situation is associated with impaired executive function [21].

In our study, when examined the gait after the training, it was seen that the patients in both groups walked with longer strides, but this improvement was higher in AR and VR gait training applied group. In addition, with AR and VR gait training, it was observed that the patients were able to walk with a narrower support surface, and the temporal parameters of gait improved, while it was determined that there was no improvement in these parameters of gait in the control group. Additionally, while functional mobility improved in the study group, it did not improve in the control group.

In our study, we had the chance to use more visual and auditory stimuli with the AR and VR training compared to the control group. In previous studies, it has been reported that the intense audio-visual cues and feedback mechanism of VR systems can facilitate motor learning when combined with exercise training [8, 22]. We can say that this situation provided an advantage in our study group compared to the control group, especially in improving the temporal characteristics of gait. Likewise, using the cues resulted in greater improvement in step and stride length in gait than conventional training.

The number of studies that analyze the effects of VR training on the spatio-temporal characteristics of walking with similar gait analysis methods to our study is very few [6, 8]. In other studies, it is seen that only its effects on functional mobility were examined [7, 9]. Mirelman et al. showed an increase in walking speed and stride length in PD patients who were given VR gait training on the treadmill. In another study, Calabro et al. showed that the spatio-temporal properties of walking with VR gait training applied on a treadmill provided more improvement than conventional training. In the studies of Feng et al. [7] and Wang et al. [9], who used the same AR and VR application as our study, study spatio-temporal gait analysis was not performed, and it was shown that functional mobility as assessed by TUG improved. As a result, in these studies, the researchers stated that the spatio-temporal features of walking and functional mobility are due to the VR environment's ability to provide rich audio-visual stimuli, practice tasks that require cognitive demand, provide training at the level of difficulty for the patient, and motivate the patient. It is thought that the improvement in walking is related to these advantages of AR and VR gait training.

We think that the improvement we achieved in walking and functional mobility with AR and VR gait training is also related to the decrease in the severity of parkinsonian motor symptoms and the improvement in static and functional balance.

The most important limitation of our study is that although we provided dual-task walking training, we did not evaluate the improvement in dual-task performance, and the other limitation is that we did not examine the long-term effects of the training due to the COVID-19 pandemic.

Another limitation of our study is the low number of cases. We recommend that future studies be conducted by including more cases.

If we want to report our experiences and observations about AR and VR training, compared to conventional training, exercise sessions have become more enjoyable for patients thanks to features such as intense visual and auditory cues, goal-oriented games, and scoring systems included in the content of AR and VR training.

All of the patients participated in the training without interruption and stated that they wanted to continue the sessions afterward. We can say that this training has also changed the perspective of our patients who define exercise as boring. This seems to be an important advantage of AR and VR technologies to ensure that patients with chronic diseases such as PD continue to exercise. In conclusion, our findings demonstrate that AR and VR gait training combined with conventional training is an effective tool in the rehabilitation of balance and gait in patients with PD.

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Declarations

Conflict of interest None.

Ethical approval Republic of Türkiye Ministry of Health, Ankara Bilkent City Hospital Clinical Research Center Ethics Committee No. 2, with the decision number E2-21–632. The study was registered in the ClinicalTrial.gov PRC system (ClinicalTrial.gov ID: NCT05439967, Date of registration: 27/06/2022, "retrospectively registered".)

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