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ORIGINAL ARTICLE

THE EFFECTS OF VIRTUAL REALITY-BASED EXERCISE ON PAIN AND FUNCTION IN OLDER ADULTS WITH KNEE OSTEOARTHRITIS: A RANDOMIZED CONTROLLED STUDY

Abstract

Introduction: This study aimed to investigate the effects of virtual reality therapy on pain, joint stiffness, physical function, balance, and fall risk in patients with knee osteoarthritis.

Materials and Method: A total of fifty-four patients with primary knee osteoarthritis were randomly assigned into three equal groups. The first group received conventional physiotherapy, the second group received conventional physiotherapy combined with virtual reality-based training, and the third group received virtual reality-based training alone. All participants underwent fifteen sessions over a three-week period. Pain was evaluated using the visual analog scale; functional status, stiffness, and physical function were assessed with the Western Ontario and McMaster Universities Osteoarthritis Index. Balance was assessed with the Berg Balance Scale, and fall risk was evaluated using the Tetrax posturography system.

Results: Statistically significant improvements were found in all groups in terms of pain, stiffness, physical function, and balance after treatment ($p < 0.001$). However, pain, physical function, and total osteoarthritis index scores were significantly better in the first and second groups compared to the third group ($p < 0.05$). In the stiffness subscale, the first group showed greater improvement than the second group ($p = 0.026$). No significant differences were detected among the groups in balance or fall risk scores ($p > 0.05$).

Conclusion: Although virtual reality therapy alone has positive effects on patients with knee osteoarthritis, it appears to be less effective than conventional physiotherapy or its combination with virtual reality. Virtual reality may serve as a supportive method within conventional rehabilitation programs.

Keywords: Osteoarthritis; Pain; Virtual Reality; Accidental Falls.

INTRODUCTION

Osteoarthritis (OA) is the most common chronic joint disease and one of the leading causes of disability worldwide (1). It is a degenerative joint disorder characterized by articular cartilage destruction, subchondral sclerosis, osteophyte formation at the joint margins, synovial inflammation, and thickening of the joint capsule (2).

Pathological differences in osteoarthritis are observed not only in the cartilage but also in all joint structures (3). These changes lead to pain, muscle weakness, decreased proprioception, and functional impairment (4). In addition to pain, patients may experience loss of function and muscle strength, muscle atrophy, exercise intolerance, and difficulty walking. As a result, the risk of falling increases, and quality of life decreases. The primary goals of treatment are to restore functional status, reduce pain, improve range of motion, and ultimately enhance quality of life (5).

Virtual reality therapy (VRT) is an effective computer-assisted application in which patients are exposed to stimuli in fully controllable environments. Virtual reality (VR) systems facilitate correct use of the body's balance mechanisms and promote proper exercise through visual and auditory biofeedback. They also enhance individual motivation by providing an engaging and interactive environment (6). Virtual Reality has been successful in a variety of applications, including acquired brain injury, neurological disorders, orthopedic problems, and anxiety (7).

The BTS Nirvana is a device that analyzes a patient's movements in a virtual environment with optoelectronic infrared sensors. The system is projected onto a main screen via a projector and includes a wide range of exercises targeting the trunk, lower and upper extremities, as well as cognitive functions (8).

Recent studies have investigated the integration of virtual reality in the rehabilitation of knee OA, particularly for improving balance and reducing pain. For instance, Wibelinger et al. reported that VR exercises improved WOMAC stiffness and balance in elderly OA patients, while conventional physiotherapy was more effective in reducing pain and physical limitations (9). Similarly, Lin et al. found that active video game therapy showed similar pain relief compared to traditional exercises. However, these studies often differ in terms of patient population, treatment protocols, and outcome measures, making their findings difficult to generalize (10). Moreover, there is limited data directly comparing VR alone, VR combined with conventional physiotherapy, and conventional physiotherapy alone. Therefore, further investigation is needed to clarify the specific contributions and effectiveness of VR-based interventions in knee OA rehabilitation.

In our study, we used the BTS Nirvana virtual reality system and we planned this randomized-controlled prospective study to compare the effects of the VR system combined with conventional exercises on pain, disability, fall risk, and balance in patients with primary knee OA.

MATERIALS AND METHOD

Patients

This single-blinded randomized controlled and prospective trial was conducted at the Physical Therapy and Rehabilitation Clinic between February 2020 and February 2021. Fifty-four patients with primary knee OA were included in the study. The inclusion criterion was patients with Kellgren-Lawrence stage 2 or 3 knee OA , who agreed to participate in the study, and were 40-75 years of age. The exclusion criteria were as follows: cognitive dysfunction; inability to stand without support; visual and auditory disorders; knee surgery or injection in the last 6 months; systemic or localized infection; cancer, and systemic diseases that affect balance and participation in exercise (neurological disorders such as cerebrovascular diseases and multiple sclerosis).

The participants were randomly allocated to three groups via a computer-generated randomization sequence. The demographic data of all participants were obtained at baseline. Clinical measurements were taken before and after treatment. Eighteen patients received a conventional rehabilitation program. The second group (n=18) received a VRT program in addition to conventional therapy. The third group (n=18) received only one VRT program. All patients completed the study and participated in all the measurements. Written and verbal consent was obtained from all patients. In accordance with the Helsinki Declaration, the study complied with all ethical standards. The present study was approved by the Clinical Research Ethics Committee with the decision number 80558721-050.99-E.26788.

Intervention

The first group received a 40-minute conventional exercise therapy program consisting of strengthening, stretching, and range of motion (ROM) exercises targeting the lower extremities, particularly the quadriceps, hamstrings, gastrocnemius, and hip abductors. Strengthening exercises were performed using body weight and resistance bands in 3 sets of 10 repetitions, with a 30-second rest between sets. Stretching exercises focused on the hamstrings, calves, and hip flexors, and were held for 20–30 seconds each. Active and passive ROM exercises for the knee joint included flexion and extension movements to maintain or improve joint mobility.

The second group received the same 40-minute conventional program followed by an additional 20-minute VR-based exercise session using the BTS Nirvana system. The third group participated in VR-based training only, for 20–25 minutes per session. All patients underwent treatment five days a week for three weeks, completing a total of 15 sessions.

Virtual Reality Training

In our study, the virtual reality training BTS Nirvana system (BTS, Italy) was used. This system incorporates optoelectric infrared sensors to enable patients to interact with their movements in a virtual environment, projected onto a large screen. The system analyzes patient movements and generates various exercises targeting the trunk, lower extremities, upper extremities, and cognitive processes. Exercise lists and scores are displayed on the screen for monitoring (7). A total of 15 sessions of treatment, 5 sessions per week, were applied to the participants. Considering the variability in rest periods, each session lasted between 20–25 minutes. Five predetermined virtual applications were used (Panda tracking, leaf sweeping, guitar stringing, mole catching, and moonwalking). The application was carried out under the supervision of a clinician, with verbal or physical intervention when necessary. Beyond this intervention, the clinician was not involved in patient evaluations (Figure 1).

Measurements

A blinded physician unaware of the treatment allocation performed the clinical assessments at baseline and at the end of the therapy. The visual analog scale (VAS) was used for pain, the Western Ontario and McMaster Universities Arthritis Index (WOMAC) was used for functional capacity and disability, the Berg balance Scale (BBS) was used for balance, and the Tetrax system was used for fall risk. In addition, knee joint range of motion, including flexion and extension angles, was measured using a standard goniometer by the same physician, following standardized procedures.

Visual Analog Scale

The pain levels of the patients at rest and with activity were evaluated with the VAS. No pain was reported as 0, the most severe pain felt in life was 10, and the patients were asked to indicate the

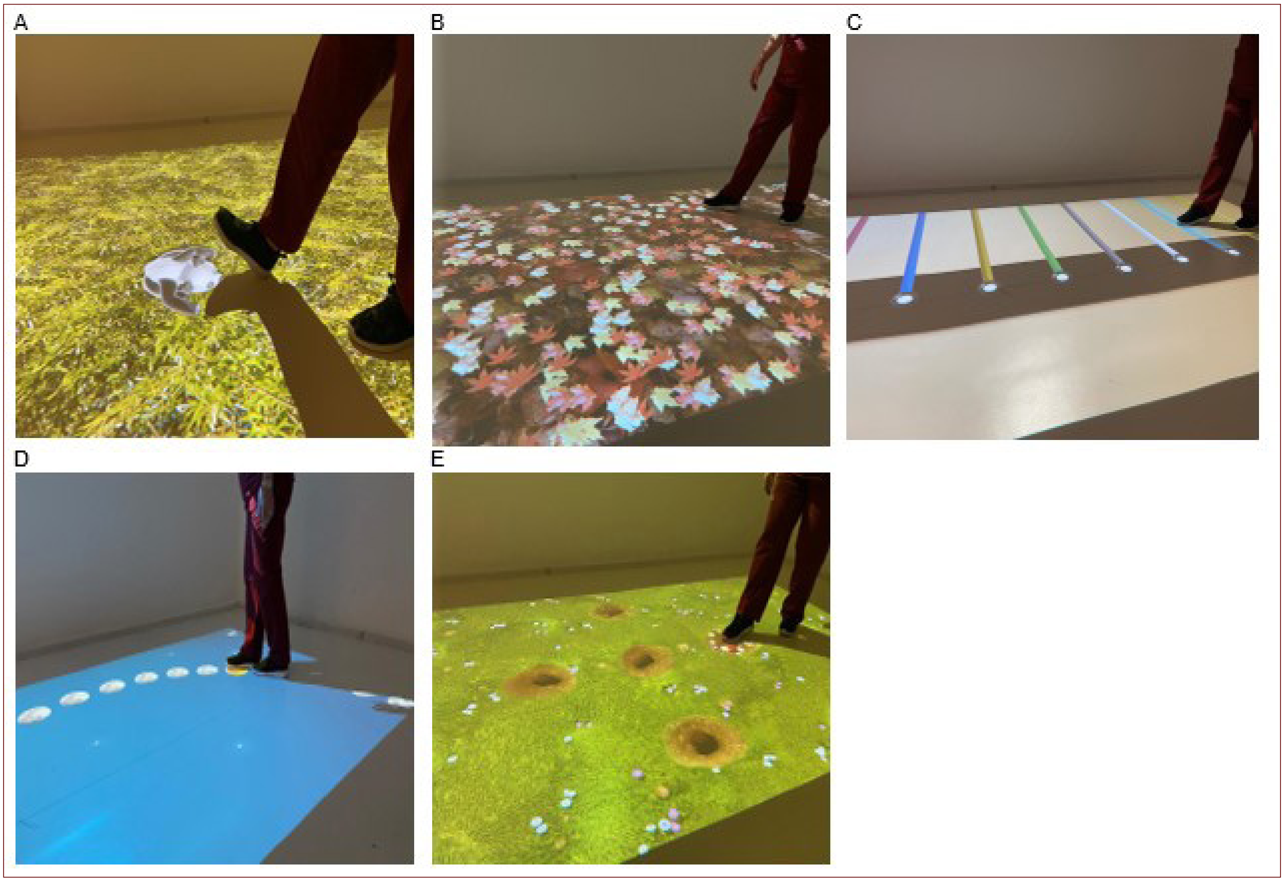

Figure 1. Virtual Reality Applications
A) Patients track a projected panda to enhance agility. B) Leaf-Sweeping: Balancing on one leg, patients sweep leaves to improve stability. C) Guitar String Walking: Virtual string steps produce sounds, aiding coordination. D) Moon-Stepping: Stepping on moons alters their color, enhancing balance. E) Mole Catching: Catching random moles improves reaction speed and control.

average pain intensity experienced in the previous week (11).

Western Ontario and McMaster Universities Arthritis Index

The WOMAC is the most widely used scale to determine functional capacity and disability in patients with knee osteoarthritis. It is evaluated in 3 categories: pain, stiffness, and physical function. It consists of 24 questions, 5 for pain, 2 for stiffness, and 17 for physical function. In the Likert version, each question is scored between 0 and 4, with scores of 0: none; 1: light; 2: moderately severe; 3: severe; 4: very severe; low scores indicate low-level symptoms. The maximum scores that can be obtained are 20, 8, and 68 points for pain, stiffness, and physical function, respectively (12). The validity and reliability of the WOMAC osteoarthritis index in Turkey were assessed by Tüzün et al (13).

Falling Risk

A static posturography device (Tetrax, Sunlight Medikal Ltd) was used to assess the risk of falling. The system consists of 4 platforms sensitive to pressure changes coming from both fingertips and both heels, and a computer where the information coming from it is combined and processed digitally. These digital data are calculated with a special algorithm and documented as visual and numerical data. Patients are evaluated in 8 different positions. Each position time consists of 32 seconds. With the data obtained as a result of the measurements, the falling index is calculated via the Tetrax software program. The higher the fall index is, the greater the risk of falling. 0-36 indicates minimal fall risk, 37-58 indicates moderate fall risk, and 59-100 indicates high fall risk (14).

Berg balance scale

The Berg balance scale is a reliable test that measures the ability of individuals to maintain their balance while performing functional activities. The highest score that can be obtained is 56. The score is evaluated as 'poor balance' between 0 and 20 and as 'good balance' between 40 and 56 (15). Sahin et al. demonstrated the validity and reliability of the Turkish version of the BDI (16).

Statistical Analyses

The required sample size was determined via power analysis based on previous studies. Power analysis was performed with G-Power 3.0.10. Since the study will be examined with 3 independent groups and 2 repeated measurements, calculations were made by considering the analysis of the variance method in repeated measurements. Considering the medium effect size (f=0.25), the significance level of 0.05, and the power of 90%, a total of 54 patients were included in the study. The number of people was evenly distributed among the groups. Eighteen patients were planned as 18 patients for each group.

In this study, the Shapiro–Wilk test was used to evaluate the conformity of continuous variables to a normal distribution. Paired t-tests and one-way ANOVA were used for normally distributed variables. All demographic and quantitative data are presented as the means (SDs). A paired t test was used to evaluate changes before and after treatment, and one-way ANOVA was used to evaluate differences between multiple variables. In the case of a significant difference according to the ANOVA test, the differences among the groups were evaluated with the Tukey test. The relationships between categorical variables were evaluated with the chi-square test, and the values are presented as frequencies and percentages. The IBM SPSS Statistics 20.0 (SPSS Inc., Chicago, Illinois) program was used for data analysis. The statistical significance level was set at $P<0.05$.

RESULTS

The study was conducted with 54 patients, 43 women (79.6%) and 11 men (20.4%). When the occupational status of the patients was examined, 3 (5.6%) were working, 11 (20.4%) were retired and 40 (74%) were housewives. There was no statistically significant difference between the treatment groups in terms of sex, occupation, or educational status (Table 1).

The mean age, weight, height, and body mass index (BMI) were 60.83 ± 6.06 years, 81.64±10.38 kilograms, 1.605±0.062 meters, and 31.69±3.6 kg/m2, respectively. A total of 34 (63%) patients with stage 2 disease and 20 (37%) patients with stage 3 disease were included in the study. At baseline, there were no statistically significant differences between the three groups in any of the evaluated parameters, including pain, stiffness, physical function, balance, or fall risk scores ($p > 0.05$). This indicates that all groups were comparable before treatment.

Within-group comparisons revealed that all three groups showed statistically significant improvements in pain, stiffness, physical function, and balance scores after the three-week treatment period ($p < 0.001$ for VAS and WOMAC subscales; $p < 0.05$ for BBS). No statistically significant changes

Table 1. Demographic and clinical characteristics of the groups

	Group 1 (N=18)	Group 2 (N=18)	Group 3 (N=18)
Gender (Female/Male)	14/4	14/4	15/3
Age (years)	61.1 (6.15)	60.77 (6.46)	60.6 (5.95)
Job			
Worker	0	1 (%5.6)	2 (%11.1)
Housewife	13 (%72.2)	13 (%72.2)	14 (%77.8)
Retired	5 (%27.8)	4 (%22.2)	2 (%11.1)
Body mass index (kg/m2)	32.8 (4.1)	31.8 (3.18)	30.45 (3.22)
K-L radiological stage 2/3	11/7	8/10	15/3
Affected extremity (right/left)	10/8	9/9	8/10
Flexion angle	126.66 (5.1)	126.66 (5.1)	126.66 (5.1)
Extension angle	0	0	0
Education			
Literate	1 (%5.6)	2 (%11.1)	2 (%11.1)
Primary school	9 (%50)	13 (%72.2)	10 (%55.6)
Middle School	1 (%5.6)	0	0
High school	6 (%33.4)	2 (%11.1)	4 (%22.2)
License	1 (%5.6)	1 (%5.6)	2 (%11.1)

Date are mean (SD), Group 1: Conventional treatment group Group 2: VR in addition to conventional treatment Group 3: VR applied group

were observed in fall risk scores within any group ($p > 0.05$).

Between-group comparisons demonstrated that Group 1 (conventional therapy) and Group 2 (combined therapy) achieved significantly greater reductions in VAS scores and improvements in WOMAC total, pain, and physical function subscales compared to Group 3 (virtual reality therapy alone) ($p < 0.05$). In the WOMAC stiffness subscale, Group 1 showed significantly more improvement than Group 2 ($p = 0.026$). No statistically significant differences were found among the three groups in terms of post-treatment balance or fall risk scores ($p > 0.05$).

The detailed values for pre- and post-treatment changes are presented in Table 2 and Table 3.

Table 2. Comparison of the VAS, WOMAC, BBS and fall risk scores within groups

	Group 1 (N=18)	Group 2 (N=18)	Group 3 (N=18)
VAS movement			
Before treatment	6.1 (0.96)	6.4 (1.24)	6.27 (0.95)
After treatment	2.38 (1.57)*	2.6 (1.57)*	4.38 (1.33)*
VAS rest			
Before treatment	6.05 (1.21)	6.05 (1.21)	5.88 (1.18)
After treatment	2.1 (1.81)*	1.5 (1.5)*	3.66 (1.18)*
WOMAC pain			
Before treatment	10.3 (1.81)	10.3 (1.8)	10.66 (1.57)
After treatment	4.6 (2.4) ‡	3.7 (2.1) ‡	6.8 (1.75) ‡
WOMAC stiffness			
Before treatment	4.7 (1.07)	3.9 (1.1)	3.77 (1.35)
After treatment	3.4 (1.14) ‡	2.3 (1.2) ‡	2.77 (1.2) ‡
WOMAC function			
Before treatment	49.07 (6.4)	47.3 (7.3)	50.1 (8.2)
After treatment	28.3 (7.8) ‡	23.4 (13.4) ‡	41.7 (9.4) ‡
WOMAC total			
Before treatment	65.04 (6.9)	61.9 (7.9)	65.2 (9.2)
After treatment	35.57 (7.79) ‡	29.7 (15.4) ‡	51.78 (11) ‡
Fall risk			
Before treatment	42.3 (27.39)	46.4 (19.4)	55.56 (19.69)
After treatment	38.77 (24.6)	42.3 (21.3)	49.67 (4.78)
BBS			
Before treatment	50.6 (3.29)	49.5 (2.7)	50.5 (1.79)
After treatment	53.3 (2.47)*	52.7 (2.1)‡	52.16 (2.6)†

Data are mean (SD), VAS; visual analog scale WOMAC; Western Ontario and McMaster Universities Arthritis Index BBS; Berg Balance Scale
* $p<0.001$, ‡ $p<0.01$, †$p=0$

Table 3. Comparison of the VAS and WOMAC scores among the groups

	Before Treatment			P*	After Treatment			P*	** Multiple comparision
	Group 1	Group 2	Group 3		Group 1	Group 2	Group 3		
VAS motion	6.1 (0.96)	6.4 (1.24)	6.27 (0.95)	0.546	2.38 (1.57)	2.6 (1.57)	4.38 (1.33)	0.01 0.02	1-2 1-3
VAS rest	6.05 (1.21)	6.05 (1.21)	5.88 (1.18)	0.891	2.1 (1.81)	1.5 (1.5)	3.66 (1.18)	0.01 0.02	1-2 1-3
WOMAC pain	10.3 (1.81)	10.3 (1.8)	10.66 (1.57)	0.807	4.6 (2.4)	3 .7 (2.1)	6.8 (1.75)	<0.001	1-3 2-3
WOMAC stiffness	4.7 (1.07)	3.9 (1.1)	3.77 (1.35)	0.047	3.4 (1.14)	2.3 (1.2)	2.77 (1.2)	0.026	1-2
WOMAC function	49.07 (6.4)	47.3 (7.3)	50.1 (8.2)	0.508	28.3 (7.8)	23.4 (13.4)	41.7 (9.4)	0.03	1-3 2-3
WOMAC total	65.04 (6.9)	61.9 (7.9)	65.2 (9.2)	0.401	35.57 (7.79)	29.7 (15.4)	51.78 (11)	<0.001	1-3 2-3

Data are mean (SD). *p<0.05 one-way ANOVA test **Tukey test

DISCUSSION

We aimed to evaluate the effectiveness of conventional treatment, VRT combined with conventional treatment, and VRT alone in improving pain, fall risk, and balance parameters in patients with primary knee OA). In all three treatment groups, the VAS (rest and movement), WOMAC (pain, stiffness, physical function, and total), and Berg balance scale scores values improved after treatment. The results of our study showed that all three treatments were effective in patients with knee OA. The improvements in WOMAC and VAS scores associated with both VRT combined with conventional exercise and conventional exercise alone were greater than those associated with VRT alone. According to the systematic analysis data covering the years 1990-2017, symptomatic knee OA is more common in women, especially in the 55-59 age range (1). The demographic characteristics of the patients in our study were consistent with this data across all treatment groups. The mean age of the participants was 60.83 ± 6.06 years, and the majority of the population was women (79.6%).

Pain, loss of function, loss of muscle strength, muscle atrophy, loss of condition, exercise intolerance, and deterioration in ambulation can be observed in patients with knee OA, seriously affecting people's daily living activities (6). Knee OA affects the body's balance mechanism, leading to postural balance issues and an increased risk of falling. Although reduced muscle strength in the knee flexors and extensors contributes to this, the effectiveness of muscle strengthening in reducing fall risk remains uncertain—possibly due to impaired sensory integration (17).

The guidelines, recommend range of motion, aerobic, strengthening, and proprioceptive exercises as effective treatments for OA (18). Additionally, virtual reality applications are increasingly being incorporated into rehabilitation programs, although their potential benefits for knee OA remain unclear due to the limited number of studies involving various VR systems (10,19).

Wibelinger et al. compared conventional exercises with VRT (with Nintendo Wii Fit) and reported a more significant improvement in WOMAC stiffness and BBS scores in the VR group. There was a more significant decrease in WOMAC pain and physical function scores in the conventional exercise group (9).

The reduction in pain with VRT is explained by the gate control theory proposed by Melzack and Wall. According to this theory; individuals may perceive stimuli differently depending on factors such as attention to pain, feelings associated with pain, and past painful experiences. With VRT, attention is diverted and the perception of pain is reduced (20). Lin et al., in a randomized controlled single-blind trial with stage 2 or 3 knee OA patients, compared the effectiveness of active video games with that of conventional therapy. Both groups showed a significant reduction in WOMAC pain, with no difference in treatment effectiveness between them. No superiority was observed in WOMAC stiffness or physical function between the treatment groups (10). Despite some differences in methods and materials, our results are similar to those of these studies. In our study, significant improvements in the VAS and WOMAC scores were observed in all the groups posttreatment. Compared with the VR group, the conventional treatment group and the VR and conventional treatment groups showed greater improvement. Although no statistically significant difference was observed between the combined and conventional therapy groups, both showed superior outcomes compared to VR alone. However, more significant improvements in conventional and VR methods may make this application preferable as an alternative adjunctive treatment option. In addition, a significant reduction in pain in patients who only receive VR may save time and labor in the rehabilitation program. This significant reduction in pain likely occurred because patients focus their attention on games in the created virtual environment, their participation in treatment, and their motivation-enhancing effect.

In a pilot study evaluating the efficacy of Nintendo Wii Fit video games involving a small number of elderly patients, significant improvement in the BBS scale was found after treatment (21). In another randomized controlled trial with Nintendo Wii Fit in elderly women with knee OA, significant improvements in BBS were observed in the VR group (9). In their study, Wi et al. compared VRT with conventional treatment in elderly women with knee OA to evaluate its effect on balance. Posttreatment balance improvement, assessed via using postural sway, was greater in the VRT group than in conventional treatment group (19). A meta-analysis concluded that active video games are more effective than conventional exercises or no treatment in improving the BBS scale in older individuals (22). Our study demonstrated improvement in the BBS across all three treatment groups, indicating enhancement in both dynamic and static balance. While this contrasts with our original hypothesis regarding the superiority of VRT, it supports its efficacy in balance enhancement, whether used alone or with traditional exercise.

In VRT, participants engage with targets on the screen, encouraging the active use of lower extremities to achieve higher scores. Compared with traditional therapeutic exercises, this dynamic interaction often yields superior outcomes in terms of dynamic balance, physical function, and overall physical health (23). Moreover, such games stimulate dopamine release, which is associated with improved learning, behavior reinforcement, attention, and sensorimotor integration. All these effects contribute in part to the potential positive effect of the treatment (24). Despite these positive effects, the results of a meta-analysis suggest that conventional exercise is more effective than active video games in the healthy elderly population (25). In our study, games enhanced patient participation and helped ensure consistency in treatment sessions.

There is no clear consensus on the frequency and duration of VRT sessions. In a study of elderly female knee OA patients, 18 sessions were conducted 3 days a week, with 40 patients completing at least 15 sessions (19). Lin et al. treated 80 patients 3 days a week for 4 weeks, totaling 12 sessions (10). In our study, we enrolled 54 patients and administered 15 sessions to each group, in alignment with similar protocols in the literature.

The limitations of our study are that the patients participating in the study were not blinded to treatment, they were evaluated at a single time point after treatment, there was no long-term follow-up, the difference in treatment duration, and the small size of the study sample. While stratified randomization was not used, baseline group characteristics were statistically comparable, minimizing the risk of confounding. The exclusion of individuals with comorbidities or cognitive and neurological impairments, while necessary to improve internal validity, limits the generalizability of the findings to the broader knee osteoarthritis population. Moreover, treatment under surveillance may not accurately reflect real-world adaptability to home settings with advancing technology. In addition, the absence of a sham virtual reality control group limits the ability to differentiate specific therapeutic effects from expectation-driven responses.

CONCLUSION

The potential therapeutic effects of VRT in OA patients remain unclear. Our study aimed to assess whether VRT yielded greater improvements in pain, disability, and balance parameters than did conventional therapy. While VR did not show superiority over conventional treatment, it improved pain parameters, suggesting its potential as an adjunctive therapy. Larger, longer-term studies are needed to explore this potential further. Our study sets a precedent for future research in this area, highlighting the need for larger sample sizes and longer follow-up periods. VRT can be a time- and labor-saving method by increasing patient participation and providing an engaging treatment environment.

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