Research Article

Spor Bilimleri Dergisi / Hacettepe Journal of Sport Sciences
DOI: https://doi.org/10.17644/sbd.1861974 2026, 37(2), 118-134

The Effect of Virtual Reality-Supported Aerobic Exercises on Balance Performance and Attitudes Toward Technology in Older Adults: A Randomized Controlled Pilot Study

Sanal Gerçeklik Destekli Aerobik Egzersizlerin Yaşlılarda Denge Performansı ve Teknolojiye Karşı Tutum Üzerine Etkisi: Randomize Kontrollü Pilot Çalışma

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Geliş Tarihi (Received): 12.01.2026
Kabul Tarihi (Accepted): 25.02.2026

ABSTRACT

This pilot randomized controlled study aimed to investigate the effects of virtual reality (VR)-supported aerobic exercise on technology attitudes, balance performance, and cardiac autonomic function in older adults. Twenty-two community-dwelling older adults (mean age 73.4 ± 5.6 years) were randomly assigned to either a virtual reality group (VRG, n=12) or a control group (CG, n=10). Both groups completed a 6-week, twice-weekly supervised aerobic exercise programme lasting 30 minutes per session. The VRG performed an additional 10 minutes of VR balance games (Beat Saber, Tai Chi VR, FitXR) using a head-mounted display immediately following each aerobic session. Outcome measures included the Attitudes Towards Technology Scale (techno-enthusiasm and techno-anxiety subscales), Berg Balance Scale (BBS), resting heart rate, and peak heart rate during exercise. Assessments were conducted at baseline and post-intervention. Between-group comparisons were analysed using the Mann-Whitney U test. The VRG demonstrated significantly greater improvements in techno-enthusiasm (Δ=5.1±1.4 vs. 1.6±2.4, p=0.002) and reductions in techno-anxiety (Δ=-2.5±1.5 vs. 2.0±1.3, p=0.001) compared to controls. Resting heart rate significantly decreased in the VRG (Δ=-4.6±2.1 vs. -1.9±1.2, p=0.004), while peak heart rate during exercise significantly increased (Δ=8.5±3.3 vs. 0.1±6.7, p=0.003). Balance scores improved more in the VRG (Δ=5.1±2.1 vs. 2.9±2.9), but the between-group difference did not reach statistical significance (p=0.063). Participant feedback revealed high acceptability, with 91.7% reporting enjoyment and perceived benefits, and 100% expressing willingness to reuse VR. These findings suggest that VR-enhanced aerobic exercise positively influences technology-related attitudes and cardiac autonomic function in older adults, while demonstrating feasibility and acceptability. Further research with larger samples and longer intervention periods is needed to confirm potential balance improvements.

Keywords: *Virtual reality, Elderly, Balance, Aerobic exercise, Technology attitude*

ÖZ

Bu pilot randomize kontrollü çalışma, sanal gerçeklik (VR) destekli aerobik egzersizin yaşlı yetişkinlerde teknolojiye yönelik tutumlar, denge performansı ve kardiyak otonom fonksiyon üzerindeki etkilerini araştırmayı amaçlamıştır. Toplumda yaşayan 22 yaşlı yetişkin (ortalama yaş 73,4 ± 5,6 yıl), rastgele olarak sanal gerçeklik grubuna (VRG, n=12) veya kontrol grubuna (CG, n=10) atanmıştır. Her iki grup da 6 hafta boyunca haftada iki kez, seans başına 30 dakika süren denetimli aerobik egzersiz programını tamamlamıştır. VRG grubu, her aerobik seansın hemen ardından başa takılan bir ekran kullanarak 10 dakika daha VR denge oyunları (Beat Saber, Tai Chi VR, FitXR) oynamıştır. Sonuç ölçütleri arasında Teknolojiye Yönelik Tutum Ölçeği (teknoloji coşkusu ve teknoloji kaygısı alt ölçekleri), Berg Denge Ölçeği (BBS), dinlenme kalp hızı ve egzersiz sırasındaki en yüksek kalp hızı yer almıştır. Değerlendirmeler başlangıçta ve müdahale sonrası yapılmıştır. Gruplar arası karşılaştırmalar Mann-Whitney U testi kullanılarak analiz edildi. VRG, kontrollere kıyasla teknolojiye olan ilgide anlamlı derecede daha büyük iyileşmeler (Δ=5,1±1,4 vs. 1,6±2,4, p=0.002) ve teknoloji kaygısında azalmalar (Δ=-2,5±1,5 vs. 2,0±1.3, p=0,001) gösterdi. VRG'de dinlenme kalp hızı anlamlı derecede azaldı (Δ=-4,6±2,1 vs. -1,9±1,2, p=0,004), egzersiz sırasındaki en yüksek kalp hızı ise anlamlı derecede arttı (Δ=8,5±3,3 vs. 0,1±6,7, p=0,003). Denge puanları VRG grubunda daha fazla iyileşme gösterdi (Δ=5,1±2,1'e karşı 2,9±2,9), ancak gruplar arası fark istatistiksel olarak anlamlı değildi (p=0,063). Katılımcı geri bildirimleri yüksek kabul edilebilirlik gösterdi; %91,7'si keyif aldığını ve fayda gördüğünü, %100'ü ise VR'ı tekrar kullanmaya istekli olduğunu belirtti. Bu bulgular, VR destekli aerobik egzersizin yaşlı yetişkinlerde teknolojiyle ilgili tutumları ve kardiyak otonom fonksiyonu olumlu yönde etkilediğini, aynı zamanda uygulanabilirliğini ve kabul edilebilirliğini gösterdiğini düşündürmektedir. Potansiyel denge iyileşmelerini doğrulamak için daha büyük örneklem grupları ve daha uzun müdahale süreleri ile daha fazla araştırmaya ihtiyaç vardır.

Anahtar Kelimeler: *Sanal gerçeklik, Yaşlı, Denge, Aerobik egzersiz, Teknoloji tutumu*

INTRODUCTION

The global population is aging rapidly, with the number of individuals aged 60 years and over projected to exceed 2 billion by 2050 (World Health Organization [WHO], 2021). This demographic shift presents significant challenges, including an increased prevalence of chronic diseases, declining physical function, and cognitive impairment among older adults. Physical inactivity exacerbates these issues, contributing to sarcopenia, osteoporosis, and elevated fall risk a leading cause of injury, hospitalization, and healthcare costs in this population (Rubenstein, 2006). Approximately 30% of community-dwelling older adults fall each year, often resulting in fractures, loss of independence, and substantial economic burden (WHO, 2021). Concurrently, mild cognitive impairment (MCI) affects about 20% of adults over 65 and is a recognized precursor to dementia, further diminishing quality of life (Petersen et al., 2018).

Although exercise interventions such as aerobic or resistance training are effective in enhancing balance, gait, and the executive functioning of older adults (Sherrington et al., 2020), their adherence rates (usually lower than 50%), are still suboptimal mainly because of monotony, lack of motivation, and barriers to access (Bull et al., 2020). Virtual Reality (VR) can be viewed as one of the innovative solutions that combines physical exercise with the use of immersive environments, rendering reality-inspired tasks. VR exercises presented in the form of the exergames, supplied by a head-mounted display or motion-sensing device (e.g., Kinect, Wii Fit), are more engaging and ecological due to the feedback and gamification features, as well as the many sensory stimuli (Neri et al., 2017). Systematic reviews reveal that VR programs are better than traditional therapies in terms of promoting physical activity and may enhance the level of stable/dynamic balance and gait stability of healthy older adults (Gomez-Donate et al., 2024; Skjaret et al., 2023). Besides, the dual-task nature of VR, involving the integration of physical actions and cognitive activity, is aimed at addressing the dual degeneration of physical and mental well-being, neuroplasticity, and fear of falling (Percy et al., 2023).

The available literature emphasizes the versatile advantages of VR. As an example, VR immersion training has been linked to a higher quality of life in the form of better scores on the Berg Balance Scale and a maximum fall incidence of up to 42 percent lower in older adults (Calleja et al., 2024; Zahedian-Nasab et al., 2021). Cognitive benefits are also remarkable; meta-analyses indicate that VR should be used alongside physical activity to improve the global cognition and executive functions of older adults with MCI compared to paper-based therapies because of simulating instrumental activities of daily living (iADLs) (Karssemeijer et al., 2017; Li et al., 2022). These exciting, remotely based formats add to engagement and remove such obstacles as transportation (Yalfani et al., 2022). Nevertheless, inconsistency in the protocols (duration: 2045 minutes; frequency: 35 times a week) highlights the necessity of standardization (Skjaret et al., 2023). In general, VR is a paradigm shift that will combine physical rehabilitation and cognitive enrichment as a part of healthy aging.

Even with the fact that exercise has been proven to be useful in controlling the effects of ageing, there are considerable obstacles in the way of regular engagement by the elderly. Sedentary living, the fear of being injured, and social isolation create a cycle of deconditioning and dependency (Giovannini et al., 2022). The traditional ones are traditional are usually unable to maintain a long-term engagement as they are seen as monotonous and impersonalized, and the dropout rates are over 40% (Cho et al., 2014). It is especially essential in subgroups such as the vulnerable ones with MCI or falling history, where physical-cognitive impairment increases the risks (fall recurrence is 3351 times higher) and cognitive disparities hinder gait adaptation (Xu et al., 2021). In rural or low-income neighborhoods, access gaps also contribute to the burden on health systems due to the increase in the projections of dementia (434 million adults aged 80+ by 2050; WHO, 2021). The existing interventions usually do not consider the synergistic advantage of motor-cognitive integration, which results in inefficient outcomes of functional mobility and quality of life (Karssemeijer et al., 2017). This urgently requires overall, interactive, and scalable interventions which respond to these interrelated issues.

The hypothesis of this study assumes that VR-backed exercise programs will have a higher level of technology-related attitudes and balance performance improvement compared to traditional aerobic exercise alone among older adults. The main objective of this pilot study is to establish whether VR is possible to operate in the context of a small sample and calculate the effect sizes in the future.

The first one is to assess the short-term consequences of a 6-week intervention based on immersive VR exercise, with the inclusion of balance tasks, gait simulators, and cognitive dual-task, in adults over 65 years of age. Secondary objectives will involve the testing of viability, acceptability among users, and cost-effectiveness in comparison to the conventional exercise, and an objective of creating a replicable, home-based framework. This study will help fill in the gaps in the subgroup analyses (e.g., healthy vs. MCI) using a randomized controlled design to advance the protocol standardization and eventually make VR a primary prevention gerontology tool.

METHOD

Research Type: This study is a randomized controlled pilot study investigating the effects of VR-supported aerobic exercises in older adults.

Participants: 22 older adults (mean age: 73.4 ± 5.6 years) were voluntarily recruited. The sample size was determined based on feasibility considerations and sample sizes reported in similar pilot studies. The following were exclusion criteria: diagnosed dementia or major neurological disorder, uncontrolled cardiovascular disease, significant fall-related injury in the past 6 months, vestibular disorder, or severe visual/hearing impairment. The participants were invited from regular patrons of a Healthy and Active Aging Research and Application Center in the Çanakkale Onsekiz Mart University, who had no physical contraindication to exercise. The following were the exclusion conditions: diagnosed with dementia or a major neurological disorder, uncontrolled cardiovascular disease, a significant fall-related injury in the past 6 months, a vestibular condition or severe visual or hearing impairment. The sample size was achieved through literature and practical considerations of similar studies that have been done elsewhere. A priori power analysis (with G*Power 3.1.9.7 software) to reveal a significant difference between the means of a set of participants with alpha of 0.05, power (1- B) of 0.80, and the medium effect size (d = 0.60) showed that at least 18 participants were required in each group. The final sample of 12 and 10 participants in each group represents the small size of the sample and it may have reduced the statistical power and influence the level of significance. Nonetheless, because this is a pilot study to estimate the effect size and determine the methodological feasibility, this sample size was considered sufficient.

Procedure: Participants were randomly allocated to the Virtual Reality Group (VRG, n=12) or Control Group (CG, n=10) using a computer-generated random number sequence. Allocation was concealed using sequentially numbered opaque sealed envelopes prepared by an independent researcher. Outcome assessments were performed by a researcher blinded to group allocation (single-blind design). Both groups completed 6 weeks of supervised aerobic exercise twice weekly for 30 minutes. After a 5-minute rest, the VRG received an additional 10-minute VR session using a head-mounted display. Heart rate was measured using a validated Polar heart rate monitor/smartwatch.

Aerobic exercise protocol: The content of the 40-minute aerobic exercise sessions is adapted from literature and detailed in Table 1 (Villareal et al., 2017).

Table 1

Aerobic Exercise Session Plan

Duration	Activity / Content	Purpose / Goal
5 min	Warm-up – Light walking or marching in place	Increase heart rate, warm up muscles, reduce injury risk
10 min	Balance and coordination exercises	Improve static and dynamic balance: Single-leg stance (with support), side/forward stepping, walking around cone/ball
10 min	Moderate intensity aerobic activity	Improve cardio capacity: Brisk marching in place, light dance steps or simple aerobic moves, coordinated arm/leg movements
10 min	Muscle strengthening	Support functional strength: Resistance band/light dumbbell arm exercises, seated leg exercises (sit-to-stand, ball squeezes)
5 min	Cool-down and stretching	Relax muscles, return heart rate to baseline: Light walking, shoulder, arm, leg, and back stretches

Virtual Reality Game Activity: Participants played VR games focused on balance and postural control. Games were selected for their suitability for older adults and were played at the easiest difficulty level under continuous researcher supervision. Difficulty was adjusted individually if needed, and sessions were paused immediately upon any sign of discomfort. Games were rotated every two weeks to maintain engagement:

Beat Saber**:** A rhythmic motion game in which users slice oncoming blocks with lightsabers to music. Trains the upper extremity organization, weight moving (balance), response time, and attention.

Tai Chi VR**:** A traditional Tai Chi modification. Its slow and controlled movements are perfect in enhancing the balance of the older adults both in a static and dynamic manner providing a low-level intensity meditative experience.

FitXR (Boxing/Dance/HIIT**)**: It consists of dance, boxing, and fitness-based workouts. It also improves dynamic balance by stepping, rhythmic motion, and weight-shifting, and offers a low-to-moderate level of intensity to match the older adults.

Data Collection Instruments:

Technology attitudes**:** The scale was the "Attitudes Towards Technology Scale of Older Adults" created by Anderberg et al. (2019) and translated into Turkish by Ozgul et al. (2025). It is a 6-item, 5-point, Likert-scale (1: Strongly Disagree, 5: Strongly Agree) which consists of two subscales Techno-enthusiasm (items 1, 2, 3, 6) and Techno-anxiety (items 4, 5). The scores are higher hence more positive attitudes.

Balance performance**:** Balance and fall risk were measured with the help of the Berg Balance Scale (BBS). It is a 14-item performance-based test that measures the capacity to retain balance in different movements. All of them are rated between 0 and 4, and the possible maximum score is 56. The scores of 0-20 depict poor balance, 21-40 acceptable balance, and 41-56 good balance (Sahin et al., 2013).

Resting heart rate**:** Being a smartwatch measurement, the variable was taken after 2 hours of pre-exercise rest with a value in beats per minute (bpm) after a 1-minute reading in the sitting position (Palatini and Julius, 2009).

Instantaneous heart rate**:** In the present study, all participants were instructed to wear the smartwatch on their non-dominant wrist throughout each exercise session, and instantaneous heart rate values were recorded during the exercise protocols. The highest value recorded during the exercise was noted as bpm. (Yagi, et al., 2025).

VR experience observation**:** The study involved a 17-item researcher-derived questionnaire to be used to investigate the physical and perceived appropriateness of the VR activity

Ethics Approval and Informed Consent: The study was approved by the Çanakkale Onsekiz Mart University Social and Human Sciences Ethics Committee (number: 140/172, date: 16.05.2025). All participants were informed in detail about the study procedures, potential risks, and benefits, and written informed consent was obtained from all participants prior to participation. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Statistical Analysis: Statistical analyses were performed using SPSS version 22.0. The normality of continuous variables was assessed using the Shapiro–Wilk test. Due to the small sample size (VRG, n = 12; CG, n = 10) and the fact that several outcome variables (e.g., techno-anxiety change scores, balance scores) showed significant deviations from a normal distribution ($p < 0.05$), non-parametric methods were deemed appropriate. Between-group comparisons were conducted using the Mann–Whitney U test, and within-group comparisons (pre- vs. post-intervention) were performed using the Wilcoxon signed-rank test. The p-value of less than 0.05 was taken as statistically significant.

RESULTS

Table 2

Participants' Baseline Characteristics (Mean ± SD)

Characteristic	VRG (n=12) (Mean ±SD)	CG (n=10) (Mean ±SD)	Min	Max
Age (years)	73.5 ± 6.8	74.1 ± 3.8	61	81
Height (cm)	157.4 ± 8.6	159.3 ± 9.5	145	180
Weight (kg)	64.9 ± 5.7	69.1 ± 10.9	52	90
BMI (kg/m²)	26.3 ± 2.7	27.1 ± 3.2	21.48	31.96
Resting HR (bpm)	67.7 ± 4.5	65.8 ± 5.5	58	76
Instantaneous HR.	90.5 ± 6,9	88.1 ±5,1	78	102
Balance (BBS)	44.4 ± 2.9	44.9 ± 4.4	40	52

BMI: Body mass index, HR: Heart rate, BBS: Berg balance scale

Table 2 presents the demographic and physical characteristics of the 22 participants. The VRG and CG had similar mean ages (73.5 vs. 74.1 years). Body Mass Index (BMI) values placed both groups in the "overweight" category (VRG: 26.3 kg/m², CG: 27.1 kg/m²). Baseline Berg Balance Scale scores indicated an acceptable level of balance for both groups (>41 points). These data suggest balanced baseline characteristics between groups.

Table 3

Homogenity Test Between Study Groups at Baseline (Mann-Whitney U Test)

Variable	Group	Mean Rank	Sum of Runks	U	P
Age	VRG	11.75	141.00	57.00	0.842
	CG	11.20	112.00		
Height	VRG	11.04	132.50	54.500	0.716
	CG	12.05	120.50		
Weight	VRG	9.92	119.00	41.000	0.208
	CG	13.40	134.00		
BMI	VRG	10.58	127.00	49.000	0.468
	CG	12.60	126.00		
Resting HR	VRG	12.54	150.50	47.500	0.408
	CG	10.25	102.50		
Instantaneous HR.	VRG	12.42	149.00	49.000	0.463
	CG	10.40	104.00		
Balance	VRG	11.63	139.50	58.500	0.920
	CG	11.35	113.50		

BMI: Body mass index, HR: Heart rate, BBS: Berg balance scale, VRG: Virtual reality group, CG: Control group

Table 3. shows mean rank, sum of ranks, u, and p-values for age, height, weight, BMI, resting HR, and balance. All p-values were > 0.05, indicatingno significant differences at baseline and suggesting that randomization was successful.

Table 4

Between-Group Comparison of Pre-test and Post-test Measurements (Mann-Whitney U Test)

Variable	Group VRG Pre/ post (Mean ±SD)	Group CG Pre/ post (Mean ±SD)	Change (Mean ±SD) VRG/CG	U	P
Techno-enthusiasm	9.2±0.9 / 14.4±0.9	8.2±2.2 / 9.8±1.3	5.1±1.4 / 1.6±2.4	13.000	0.002
Techno-anxiety	5.7±0.7 / 3.1±0.9	5.5±1.1 / 7.5±1.5	-2.5±1.5 / 2±1.3	1.500	0.001
Balance (BBS)	44.4±2.9 / 49.5±2.4	44.9±4.4/ 47.8±3.5	5.1±2.1 / 2.9±2.9	32.000	0.063
Resting HR	67.7±4.5 / 63.1±4.6	65.8±5.5/ 63.9±4.4	-4.6±2.1 / -1.9±1.2	17.000	0.004
Instantaneous HR.	90.5±6.9 / 99.1±6.2	88.1±5.1/ 88.2±5.6	8.5±3.3 / 0.1±6.7	14.500	0.003

HR: Heart rate, BBS: Berg balance scale, VRG: Virtual reality group, CG: Control group SD: Standard deviation

Table 4 shows the between-group comparisons. In the experimental group (VRG), techno-enthusiasm significantly increased (5.1±1.4), while techno-anxiety markedly decreased (-2.5±1.5); in contrast, the control group exhibited more modest changes in both variables (p<0.05). Resting heart rate significantly decreased in the VRG (-4.6±2.1), whereas instantaneous heart rate showed a significant increase (8.5±3.3); no significant changes were observed in the control group for these parameters (p<0.05). Although balance scores (BBS) improved to a greater extent in the VRG compared to the control group, the between-group difference did not reach statistical significance (p=0.063). These findings indicate that the intervention administered in the VRG positively influenced technology-related attitudes and led to significant alterations in autonomic functions.

Figure 1

Experiences and Opinions of VRG

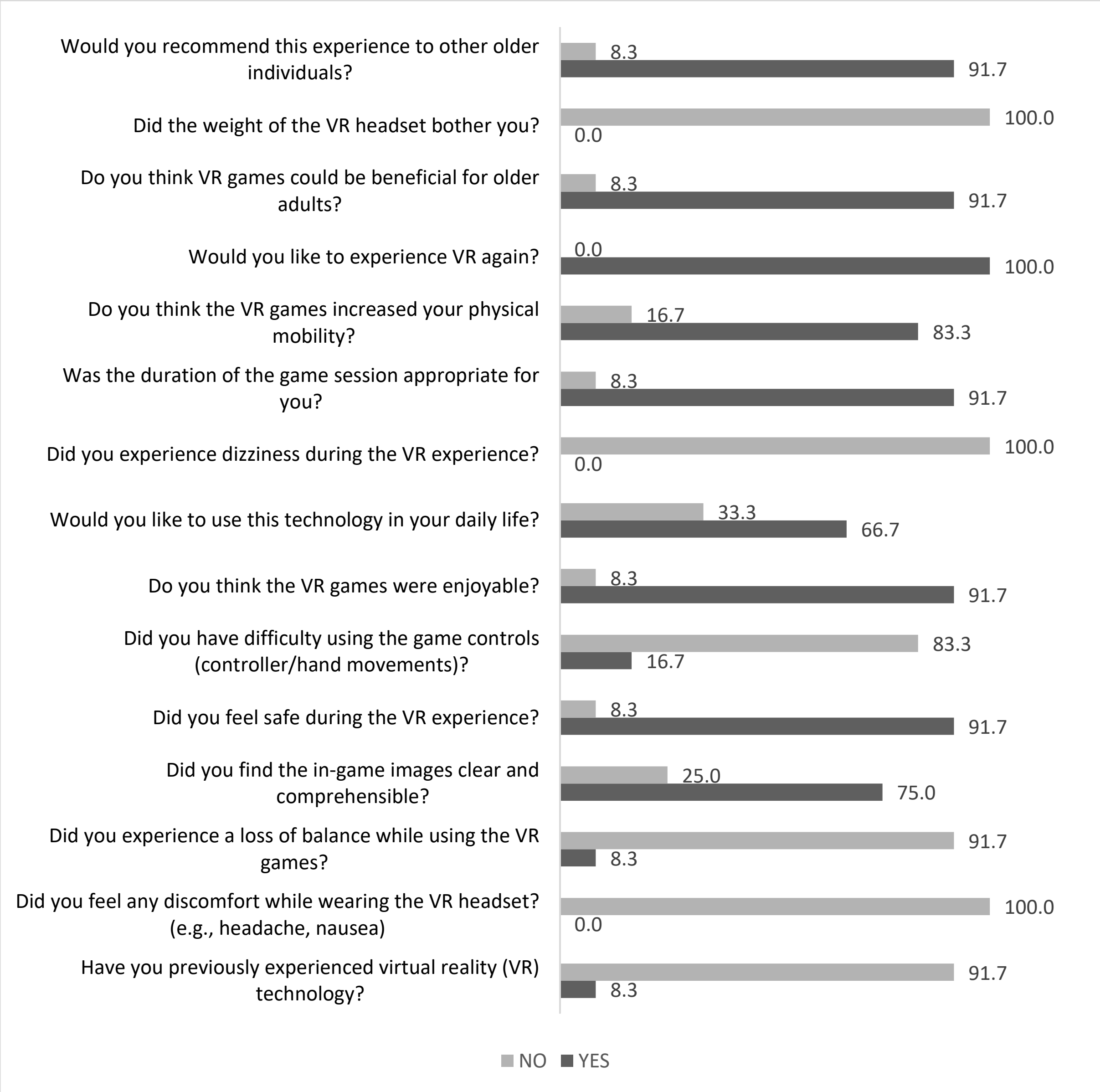

Figure 1 shows the percentage distribution of the experiences and opinions of VRG participants (n=12) after the 6-week virtual reality exercise program. The findings reveal that participants exhibited an extremely positive attitude toward VR technology. All participants (100%) stated that the weight of the VR headset did not bother them, they wanted to experience VR again, they did not experience dizziness during the VR experience, and they did not feel discomfort while wearing the VR headset.

In terms of physical and cognitive effects, 91.7% of participants thought that VR games could be beneficial for the elderly, found the VR games entertaining, found the game duration appropriate, felt safe during the VR experience, did not experience loss of balance while using the VR games, and had experienced virtual reality technology before. Similarly, 91.7% of participants stated they would recommend this experience to other older individuals.

In terms of perceived physical gains of VR, 83.3% of the respondents believed that VR games enhanced their physical mobility, and 16.7% of them had an opposite opinion on the same issue. On the same note, those who said that they had difficulties using the game controls (controller/hand movements) were 16.7 and those who said that they could use the controls comfortably were 83.3. The proportion of those who considered the in-game pictures to be clear and comprehensible was 75.0, and 25.0% had negative comments regarding the issue.

The least positive response rate was observed in the willingness to apply VR technology in everyday life (66.7% yes, 33.3% no). The above discovery implies that, whereas the older generation is open to VR when it comes to exercise and rehabilitation, they are skeptical when it comes to using VR to become part of their daily technology consumption. On the whole, the graphic indicates that older people were safe, enjoyed themselves, were comfortable, and felt VR exercises were useful and offered a high degree of user satisfaction. These acceptability rates endorse the possibility of the use of VR technology as a sustainable intervention instrument in geriatric rehabilitation. The 100 percent willingness of the participants to reuse and the 91.7 percent rate of referring others to the experience is tangible evidence of VR ability to boost motivation and engagement among the elderly population.

DISCUSSION

This pilot study showed that a 6-week VR-supported aerobic exercise program significantly improved technology attitudes in older adults. Techno-enthusiasm increased, and techno-anxiety decreased markedly in the VRG compared to controls. The results showed the VR intervention improved technology acceptance, decreased technology anxiety, and trend-improved balance performance. These findings, in comparison with the existing evidence from literature, suggest that VR is a promising treatment system for physical and cognitive health in the elderly population. In our study, there was a statistically significant increase in techno-enthusiasm scores (p=0.001), while the decrease in techno-anxiety was also significant (p=0.001) for the VR group. These results indicate that exercises in a virtual environment provide an avenue for technology acceptance and digital literacy in older adults. Szczepocka et al. (2024), in 188 elderly subjects, found high acceptability of the VR interventions (61%) and a change toward a positive attitude towards technology.

Likewise, Ip et al. (2024) found that fully immersive VR technology showed a high level of acceptability and usability with a high completion rate of 83.78% when studying 31 older adults in Hong Kong. This study strongly supported the technology attitude findings of our study. The role of VR has been widely reported in the literature to enhance motivation levels and make individuals more eager to participate, in contrast to conventional exercise programs (Cho et al., 2014). A study done by Makmee and Wongupparaj (2023) in older adults with mild cognitive impairment found an immersive VR cognitive-based program with a duration of 8 weeks to be effective with high levels of patient participation and satisfaction. The idea of gamification, providing real-time feedback, and an interactive environment has a profound impact on enhancing intrinsic motivation levels for exercise and making it more interesting for older persons (Gómez-Donate et al., 2024). Games such as Beat Saber, Tai Chi VR, and FitXR, which we have utilized in our study, with varying levels of difficulty, would have definitely kept the interest levels of the participants alive. Although there was no significant difference found between the groups on the post-test scores of the Berg Balance Scale (BBS), with p = 0.367, the VR group showed an indicative positive trend with a larger mean rank value (12.63) than the other group

(10.15), indicating that the balance performance was improved after the 6-week intervention. This might be attributed to the following reasons: the sample size was small (n = 22), the duration of the study was short (6 weeks), and the balance performance at the beginning was already at an acceptable level for both groups (>44 points). However, there is concrete support present in the recent literature on the effectiveness of VR for balance and fall prevention with credible evidence. In their systematic review to determine the effects of immersive VR training on balance, gait, and mobility among the elderly, Lee et al. (2024) found the VR interventions to demonstrate significant improvements with regard to scores on the Berg Balance Scale. Wei et al. (2025), in their meta-analysis on dual-task performance, found significant improvements with VR training in the spatiotemporal parameters of gait speed, stride length, and cadence among the elderly.

In a systematic review, Calleja et al. (2024) found that the incidence of falling was decreased by as much as 42% by training using virtual reality. Furthermore, Zahedian- Nasab et al. (2021) conducted a randomized control trial with a sample of 60 residents of nursing homes and demonstrated that six weeks of using Xbox Kinect to exercise in VR significantly increased the scores for the Berg Balance Scale (BBS) ($p<.001$) and reduced the time to complete the Timed Up and Go (TUG) test. In addition, Ip et al. (2024) completed a pilot study with older adults diagnosed with mild cognitive impairment (MCI) living in the community and reported an increase in the BBS scores after eight weeks of fully immersive VR training compared to traditional exercise. Both our study's data and the data referenced in this paragraph indicate a positive trend supporting the possibility of significant results with increased sample sizes and longer intervention duration.

Dual task performance enhancement through combining physical activity with cognitive requirements is another unique quality of VR. In their systematic review, Percy and colleagues (2023) concluded that VR reduces kinesiophobia, falls, and balance control issues in older adults based on the evidence of the literature, and they speculate that some of this benefit can be attributed to the dual task functionality of VR. In a recent meta-analysis, Wei and colleagues (2025) provided strong evidence to support that VR effectively enhances dual task ability in older adults, especially when completing two tasks at the same time, such as walking and doing a cognitive activity at the same time. Therefore, VR provides a realistic reflection of actual tasks that older adults may encounter throughout their day, such as talking to someone while walking or maintaining balance while shopping. In a systematic review and network meta-analysis, Yang et al. (2025) found immersive VR interventions for older adults with MCI to be effective at enhancing memory, attention, speed of information processing, and executive functions. In particular, VR cognitive-motor dual-task training was more effective than VR cognitive training by itself in enhancing attention and processing speed. Li et al. (2022) also provided evidence that VR-based interventions improved overall cognition, memory, attention, and executive functions for older adults with MCI. Thus, VR provides a platform for not only motor rehabilitation but also cognitive enrichment and enhanced neuroplasticity.

The Beat Saber game used in our study requires rhythm-based movement, while Tai Chi VR offers slow, controlled movements and balance, and FitXR offers dance and boxing combinations, supporting motor-cognitive integration. Makmee and Wongupparaj (2023), in their study supported by electroencephalography (EEG) evidence, reported that an immersive VR cognitive-based intervention significantly improved verbal and visuospatial short-term memory, executive functions, and well-being status in both healthy and MCI older adults. The observation of similar neural patterns between VR and physical environments (EEG power spectrum analysis) supports that VR offers ecological validity close to real-world scenarios in terms of brain activation. In our study, instantaneous heart rate significantly increased during VR exercises in the experimental group (8.5±3.3), indicating that an additional 10 minutes of VR gameplay imposed a measurable cardiovascular load. In contrast, resting heart rate significantly decreased in the VRG (-4.6±2.1) compared to the control group, suggesting a positive adaptation in cardiac autonomic function. In the literature, it is widely accepted that aerobic exercise reduces resting heart rate and improves heart rate variability (HRV) in the elderly. De Andrade et al. (2023), in their study examining heart rate variability during and after aerobic exercise in older hypertensive individuals, reported that 30 minutes of aerobic activity positively affected cardiac autonomic modulation. Huang et al. (2005), in their meta-analysis, showed that controlled aerobic training reduced resting heart rate by an average of 6 bpm (8.4% reduction) in sedentary older adults, and this reduction was more pronounced in training lasting longer than 30 weeks. The 6-week duration in our study may not have been sufficient to observe a significant change in resting heart rate. However, it is thought that VR exercises increase cardiovascular load, and this situation offers an opportunity to personalize exercise intensity. Integration of heart rate monitoring systems is important for safe and effective exercise prescription in the elderly (Palatini and Julius, 2009).

The present study also examined the effects of VR-supported aerobic exercise on cardiac autonomic function, as reflected by resting and instantaneous heart rate responses. Our findings revealed that the VR group demonstrated a significant reduction in resting heart rate (Δ = -4.6 ± 2.1 bpm) compared to the control group (Δ = -1.9 ± 1.2 bpm), with a statistically significant between-group difference (U = 17.000, p = 0.004). Concurrently, instantaneous heart rate during exercise increased substantially in the VR group (Δ = 8.5 ± 3.3 bpm), whereas no meaningful change was observed in the control group (Δ = 0.1 ± 6.7 bpm), yielding a significant between-group difference (U = 14.500, p = 0.003). These findings suggest that the addition of just 10 minutes of immersive VR gameplay immediately following aerobic exercise imposed a measurable and progressive cardiovascular load, sufficient to induce early autonomic adaptations over a 6-week period. The reduction in resting heart rate observed in the VR group is consistent with well-established physiological adaptations to regular aerobic training, primarily mediated by enhanced parasympathetic tone and reduced sympathetic activity (Palatini and Julius, 2009). Although the 6-week intervention duration in our study was relatively short compared to the 12–30 weeks typically required for substantial resting bradycardia in sedentary older adults (Huang et al., 2005), the magnitude of reduction (4.6 bpm) is clinically noteworthy and exceeds the minimal clinically important difference reported for cardiovascular outcomes in aging populations. This may indicate that the interactive and engaging nature of VR-based exergaming potentiates the physiological training effect, possibly through higher volitional effort, increased movement amplitude, or sustained attention during gameplay.

The significant increase in instantaneous heart rate during VR-enhanced sessions further supports this interpretation. While the control group performed aerobic exercise alone at a consistent intensity across the 6-weeks, the VR group exhibited a progressive rise in peak exercise heart rate. This suggests that participants in the VR group did not habituate to the exergaming stimulus; rather, they maintained or even increased their cardiovascular engagement over time. This finding aligns with previous reports that gamification elements—such as real-time feedback, rhythm-based movement, and immersive audiovisual environments—enhance intrinsic motivation and encourage older adults to sustain or intensify their physical effort (Cho et al., 2014; Gómez-Donate et al., 2024). The Beat Saber and FitXR games used in our protocol, in particular, require coordinated upper extremity movements and weight shifting in response to rapidly presented stimuli, which may elicit phasic heart rate elevations beyond those achieved during conventional aerobic exercise. Comparable findings have been reported in the emerging literature on VR-based cardiac rehabilitation. In a recent randomized controlled trial, Yagi et al. (2025) demonstrated that wearable-integrated VR training significantly improved exercise capacity and heart rate recovery in older adults with cardiovascular disease. Similarly, De Andrade et al. (2023) reported that a single bout of aerobic exercise acutely modulated heart rate variability in older hypertensive adults, with greater effects observed when exercise was combined with cognitively engaging tasks. Our findings extend this evidence by demonstrating that repeated exposure to VR-enhanced exercise over 6 weeks produces both acute (instantaneous HR) and chronic (resting HR) cardiac adaptations in healthy community-dwelling older adults.

Importantly, the cardiovascular responses observed in our study occurred in the absence of adverse events or reported discomfort, and all participants completed the 10-minute VR sessions without dizziness or falls. This suggests that low-to-moderate intensity VR exergaming is not only safe and acceptable for older adults but also physiologically effective. The integration of real-time heart rate monitoring during VR exercise, as piloted in this study, may offer a practical strategy for individualizing exercise prescription and ensuring that older adults train within safe and effective intensity zones.

Taken together, these cardiovascular findings provide objective physiological evidence that VR-enhanced aerobic exercise confers additional autonomic benefits beyond those achieved by aerobic exercise alone. The significant reduction in resting heart rate and the progressive increase in instantaneous heart rate during VR gameplay indicate that even brief, low-frequency VR exposure can elicit meaningful cardiovascular adaptations in older adults. Future trials with longer intervention durations and direct measures of heart rate variability are warranted to elucidate the underlying autonomic mechanisms and to determine optimal dosing parameters for VR-based cardiovascular training in geriatric populations.

VR's ability to create functional transfer through simulated activities of daily living (ADL), such as cooking, cleaning and shopping, is one of the most important benefits of using VR for therapy. Liu and colleagues demonstrated that when comparing traditional paper-based methods with a combination of VR and exercise in older adults with MCI using a combination of these approaches produces greater functional transfer than paper alone. Gómez-Donate and colleagues conducted a systematic review of the use of VR therapy for improving balance and gait in older adults and found that there is a high degree of ecological validity to the VR therapy interventions. FitXR had components to practice dance and boxing, both of which provided challenges in maintaining dynamic balance and performing appropriate weight shifts. Liu et al. (2022) conducted a systematic review and found that immersive VR had a greater effect on postural control, dynamic stability, and functional mobility than traditional PT for older adults, and VR's ability to create realistic and engaging therapeutic environments provides the opportunity to simultaneously stimulate sensory and motor systems, which encourages neuroplastic adaptations.

The study we conducted (Figure 1) indicates that the VR Experience outcomes provide a very encouraging picture when compared to what has been presented in the current literature on this topic. In our study, 100% of participants said they experienced no discomfort wearing the VR headset (0% reported dizziness) and expressed interest in using it again. These findings reflect those of other researchers who have investigated older adults using the VR headset in the research conducted by Ip et al. (2024) in Hong Kong, where the level of acceptance for fully immersive VR technology was very high with a completion rate of 83.78% for 31 older adults. Similarly, Szczepocka et al. (2024) found the CoSoPhy FX study to have high levels of acceptance, as over 61% of older participants (n=188) reported being very satisfied with the VR experience. Our finding that 91.7% of participants recommended the VR experience to other seniors and that all participants were interested in using the VR headset again further supports the conclusion that short-term low-intensity use of VR experiences will elicit a very positive response from users. Additionally, Chen et al. (2025) conducted a usability study with 35 older adults (ages 70-85) and had participants try out two different types of VR controllers (symmetric and asymmetric). It was determined that both types of VR controllers received ratings of over 7.5 and were very well accepted by the participants in the study.

The 83.3% of participants who indicated they could use the game controls comfortably supports the findings of other studies. Even though the 16.7% who did not report having problems with game controls indicate that there are differences based on age and motor coordination skill and that each individual has a different learning curve, there are still some important implications. For example, Li et al. (2024) examined the effects of using VR versus traditional means on 113 nursing home residents and found that the VR group displayed significantly increased proactivity and interpersonal relationships than their traditional counterparts. They also suggested that being supported by caregivers or trusted individuals helped increase the likelihood of older adults adopting the VR experience. Similarly, in our study, the fact that all sessions were conducted under the supervision of a researcher may have provided some form of agency that would allow users to have an easier time adapting to the experience. The fact that fewer participants were willing to use VR in their daily lives (66.7% compared to other response items) corresponds with literature on VR technology and its acceptance by older adults. Roberts et al. (2019) reported that although older adults demonstrated a positive attitude toward VR regarding the perceived usefulness and ease of use, they had greater concerns regarding the integration of this technology into their daily lives. Huygelier et al. (2019) also reported that although older adult participants had higher levels of acceptance of immersive VR in the contexts of rehabilitation and exercise, these same participants had a lower acceptance rate of integrating immersive VR into their daily lives. Therefore, it can be inferred that older adults view VR as having potential for use in specific health-related contexts, but they do not yet see it as an everyday technology.

The safety and side effects of VR interventions are a critical issue, especially in the elderly population. In our study, 100% of participants reported not experiencing dizziness during the VR experience, a finding more positive than most studies in the literature. Drazich et al. (2023), in their systematic review examining fully immersive VR and cybersickness in older adults, reported that most included studies reported only minor levels of cybersickness among older participants. However, methodological differences and Simulator Sickness Questionnaire (SSQ) scoring variations among studies make comparisons difficult. Li and Muschalla (2024), in their study examining VR group intervention in nursing home residents, reported that most of the 27 participants reported negligible side effects but that session duration affected cybersickness prevalence. Limiting VR session duration to 10 minutes in our study may have been effective in minimizing side effects. Rmadi et al. (2023), in their studies assessing the tolerance of immersive head-mounted VR in nursing home residents, showed that short session durations and slow camera movements reduced cybersickness. The relationship between age and cybersickness is controversial. A meta-analysis showed that older participants were less susceptible to cybersickness than younger adults because vestibular system sensitivity decreases with age (Séba et al., 2023). Some researchers are sceptical that age does not produce a meaningful or substantial connection to cybersickness. In their initial work, Dilanchian et al. (2021) reported that there was no statistically significant difference between presence, workload, and cybersickness according to participant age groupings. Conversely, in our study, we found no participants aged 70 years and older who reported feeling dizzy after participating in a VR experience and this correlates with the findings of Dilanchian et al. (2021). In addition to age, the type of content featured in VR experiences influences cybersickness. Szczepocka et al. (2024) cited the rapid camera motion, low image resolution, and low refresh rates as all contributing to cybersickness. However, the VR gaming applications we used in this research (i.e., Beat Saber, Tai Chi VR, and FitXR) were specifically designed for older adults, avoiding any abrupt or rapid head movement. It is probable that selecting these types of games contributed to our zero reported dizziness occurrences. Finally, Ahmad et al. (2024) reported that VR-based simulation tools can safely contribute to the assessment of fall risk in older adults. In line with these safety considerations, participants underwent a supervised warm-up prior to engaging in VR exercises, safety mats were placed beneath them during the sessions, and adequate supervision was maintained throughout the VR interventions.

In the literature, there is significant variability in protocol parameters of VR interventions (session duration, frequency, intervention duration, immersion level). Ren et al. (2023), in their meta-analysis, reported that protocols with a session duration of 20-45 minutes, frequency ≥3 times per week, and intervention duration of 5-8 weeks were most effective. Yang et al. (2025), in their studies investigating the optimal dosage of VR interventions in older adults with MCI, reported that immersive, semi-immersive, and non-immersive levels all improved attention and information processing speed, but the immersive level showed larger effects on executive functions. In our study, a protocol consisting of 30 minutes of aerobic exercise and 10 minutes of VR (virtual stimulation) was applied twice a week for 6 weeks. Because this protocol was one of the first pilot applications for an elderly group, the durations were shorter than those recommended in the literature. Despite this, positive changes were observed in the parameters. The cost-effectiveness and accessibility of VR technology compared to traditional rehabilitation are important issues. Yalfani et al. (2022) reported that an 8-week VR training program improved pain, fall risk, and quality of life in elderly women with chronic low back pain and eliminated barriers such as transportation with its home-applicable format. Zhao et al. (2025) reported that immersive VR was more effective than serious games in mild cognitive impairment, but costs and technology requirements were higher. The VR headset and games used in our study are relatively low-cost and accessible technologies. In the future, smartphone-based VR applications and cloud-based platforms could further increase cost-effectiveness. However, a lack of digital literacy and technology fear among older individuals may limit access. The decrease in technology anxiety and increase in enthusiasm in our study show that these barriers can be overcome with appropriate support and training.

This study has several limitations that should be considered. First, although the sample size was determined beforehand via power analysis (G*Power 3.1) and is consistent with preliminary randomized controlled trials in this population, the modest sample size may limit generalizability and hinder subgroup analysis. Future studies should utilize multicenter designs with larger cohorts to improve external validity. Second, while the 6-week intervention duration is consistent with many published virtual reality protocols that demonstrate significant balance improvements, emerging evidence suggests that longer interventions may yield superior results. Third, the 10-minute VR session duration, practically chosen to minimize cybersickness and fatigue in novice older adult users, falls considerably short of the 30-45 minute session durations commonly used in effective protocols. Ren et al. (2023) highlighted that session duration and frequency are critical determinants of training adaptation, and this finding was corroborated by subsequent trials showing significant improvements in balance and gait after 30-60 minute sessions conducted 2-3 times a week for 8 weeks. Despite these limitations, we emphasize that this study is preliminary; the significant reductions in resting heart rate and the increases in instantaneous heart rate observed provide conceptual evidence that even short-term VR exposure creates a measurable cardiovascular load. Future trials should systematically manipulate dosage parameters to determine optimal training thresholds for cardiovascular and functional outcomes in geriatric populations.

This study showed that a 6-week virtual reality-supported aerobic exercise program significantly improved technology attitudes in older adults. While enthusiasm toward technology increased markedly in the VR group participants, technology anxiety decreased. Although no statistically significant between-group difference was observed in balance performance as measured by the Berg Balance Scale ($U = 32.000$, $p = 0.063$), the VR group demonstrated a greater magnitude of improvement ($\Delta = 5.1 \pm 2.1$) compared to the control group ($\Delta = 2.9 \pm 2.9$). This positive trend, approaching conventional significance thresholds, suggests that a longer intervention duration and larger sample size may yield statistically significant between-group differences. These findings indicate a potential clinical benefit of VR-based training for balance function in older adults, warranting further investigation with adequately powered trials**.** The brief time span of our protocol has resulted in some of the most significant changes regarding the elderly's positive attitude toward technology and their acceptance of it. Elderly individuals can accept digital technologies if provided with adequate training and support. Digital technologies are a valuable resource for geriatric rehabilitation. As a new and innovative paradigm, virtual reality technology has many applications, including supporting healthy aging, maintaining independent living, and enhancing quality of life for senior citizens. An innovative approach to combine physical rehabilitation and cognitive enhancement through virtual reality will provide both preventive and therapeutic benefits in helping to combat age-related declines. Future studies that will provide an in-depth investigation into the areas of protocol standardization, subgroup analysis, neurophysiological mechanisms of action, and cost-effectiveness will help solidify the place of virtual reality in geriatric care while expediting the entry of virtual reality into the clinical application.

In summary, the current findings indicate that virtual reality-based exercise promotes technology acceptance in older adults, as evidenced by a significant increase in techno-enthusiasm (5.1 ± 1.4, $p = 0.002$) and a marked reduction in techno-anxiety (-2.5 ± 1.5, $p = 0.001$) in the VR group compared to controls. Although the between-group difference in balance performance did not reach statistical significance ($U = 32.000$, $p = 0.063$), the VR group exhibited a clinically meaningful improvement in Berg Balance Scale scores ($\Delta = 5.1 \pm 2.1$), exceeding the minimal detectable change threshold reported for community-dwelling older adults. Furthermore, significant reductions in resting heart rate (-4.6 ± 2.1, $p = 0.004$) and increases in instantaneous heart rate during VR exposure (8.5 ± 3.3, $p = 0.003$) provide objective physiological evidence of cardiovascular engagement. In comparison with the existing literature, these findings corroborate previous reports that VR-based interventions can simultaneously enhance affective attitudes toward technology and induce measurable physiological adaptations. Collectively, the present study suggests that virtual reality constitutes a viable and potentially effective intervention for promoting healthy aging in elderly individuals.

Conflict of Interest: The authors have no conflicts of interest to declare**.**

Financial Disclosure: The authors declared that this study has received no financial support**.**

Author Contribution:

1. **Özhan BAVLI:** Concept/Idea, Design, Data Collection and Processing, Analysis and Interpretation, Literature Review, Manuscript Writing
2. **Gülşah ŞAHİN:** Concept/Idea, Design, Data Collection and Processing, Analysis and Interpretation, Literature, Review, Manuscript Writing

Information About Ethical Board Permission

Committee Name: Çanakkale Onsekiz Mart University Social and Human Sciences Ethics Committee

Date: 16.05.2025

Issue No: 140/172

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