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Research Article

Effects of Extended Reality-based Fall Prevention Training on Reflexes, Judgment, and Balance Control in Adults

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ABSTRACT

Background/Objectives: This study aims to investigate the impact of extended reality (XR) technology on adults' reflexes, judgment, and balance control, with the goal of proposing effective fall prevention methods.

Methods/Statistical analysis: This study was conducted on 42 male and female college students aged 20~25 years old who are enrolled in S University, A City, Korea, and were randomly distributed into XR-wearing exercise group (XRG) and verbal instruction exercise group (VIG) for 4 weeks after evaluating their health status and ability through preliminary interviews. The study evaluated the effects of each group through tests for judgment (K-MOKA), reflexes (TMT), and balance control (TUG, STS). Statistical analysis was performed using SPSS 22.0 to analyse differences between groups.

Findings: This study demonstrated that XR-based fall prevention training significantly improved adults' reflexes, judgment, and balance control abilities. This suggests that XR training is more effective than traditional methods and raises the possibility of establishing it as a new approach to fall prevention.

Improvements/Applications: Training programs utilizing XR technology can contribut e to fall prevention in the elderly and vulnerable populations. Future research should ex plore the diverse applications of XR and seek directions for developing it into a more c omprehensive treatment approach.

Keywords: Fall prevention, Extended Reality (XR), Reflexes, Judgment, Balance control , Elderly

1. Introduction

Falls are a major cause of injury among elderly individuals aged 65 and older [1]. As individuals age and their physical and cognitive abilities decline, muscle strength, coordination, and balance gradually decrease, increasing the risk of falls [2]. Falls are a major cause of injury, injury-related disability, and death among the elderly [3]. Falls can lead to injuries, loss of confidence, and a subsequent decrease in activity levels and community participation [4]. Accordingly, fall prevention has emerged as a crucial task for the health and well-being of the elderly population. Research aimed at predicting and preventing future fall rates, such as that conducted by Maria Jose Calero and others, is increasing [5].

Extended Reality (XR) is a comprehensive term that summarizes the entire spectrum of VR, AR, and MR, merging the real world and the virtual world in a way that creates a window between them [6,7]. Extended Reality (XR) not only combines aspects of actual reality (the physical world around us) with the power of virtual reality, but also integrates reality with possibilities. In other words, through Extended Reality, we can experience new objects or scenarios that do not actually exist. Mobile technologies, including smartphones, tablets, and HMDs like Microsoft's HoloLens and Magic Leap, can connect data and space through a process known as real-time reification [8,9]. As an example of XR, Lonergan and Hedley developed a series of applications that simulate virtual water flow across real surfaces, while Lochhead and Hedley provided simulations of virtual evacuees navigating through actual multi-layered architectural spaces. [10,11]. In both cases, the simulations were made possible through spatial data representations of the physical structures of the respective spaces.[12].

Extended Reality technologies have often been used for training and rehabilitation purposes. The popularity of these technologies has rapidly increased in recent years, garnering significant attention in scientific research [13]. Training with Extended Reality technologies simulates fall risk situations that can occur in everyday environments, and education in a simulated environment offers the possibility of immediate feedback [14]. Such immediate feedback enables learners to correct their mistakes on their own before the error propagates, promoting faster and more accurate learning [15]. Focusing on improving balance, reflexes, and motor control, this can help prevent falls and minimize injuries. According to Joke Schuermans' paper, extended reality has been found to provide added value in both sports injury prevention and rehabilitation outcomes. Especially, it provides an opportunity to prevent the underlying risks of common sports injuries, allowing athletes to train protective movement patterns more effectively [16]. It has been shown that extended reality-based fall prevention training can improve participants' balance control and motor skills.These results have potential value in reducing the risk of falls and improving the quality of life for the elderly and others with balance impairments.

Research on XR training-based rehabilitation therapy has been extensively conducted. A study found that MR-based exercises for a group of patients required to strengthen arm, hand, and finger functions improved arm function and finger dexterity, which was confirmed through the Wolf Motor Function Test, Box and Blocks Test, and Nine Hole Peg Test. Patients exhibited higher levels of attention and satisfaction compared to traditional exercises. Additionally, it demonstrated the potential to be integrated into clinical practice with high acceptability and relatively low costs. [17]. Another study indicated that XR-based rehabilitation system exercises facilitated the recovery process of the hemiplegic lower limb and provided new insights into the patients' brain functions. Notably, the flexion angle of the hemiplegic knee during walking improved when following the tempo of XR music. These results suggest that the XR system can have a positive effect on patients' rehabilitation [18]. According to Tiphanie E. Raffegeau's paper, using XR to simulate the effects on cognitive behavior can help improve cognitive function in the elderly and reduce the risk of falls. Elderly individuals can face various cognitive challenges in XR environments, which can enhance their attention, spatial awareness, and judgment. Additionally, XR-based training can present an effective strategy for improving cognitive function by assessing the cognitive abilities of the elderly and providing personalized intervention methods. This helps elderly individuals develop the ability to engage in daily activities more safely and independently [19].

Another study found that therapy using extended reality (XR) had a positive impact on the recovery of upper limb (UL) function and the improvement of activities of daily living (ADL) in stroke patients. However, therapy using these technologies did not show significant improvement in upper limb function tests. Therefore, while XR therapy shows superior results compared to traditional methods, its effectiveness appears to be minimal in terms of upper limb function measurement. These results can serve as a reference when evaluating the effectiveness of XR technology in the field of stroke rehabilitation and considering future research directions; however, there remains controversy regarding the effects of XR [20]. Research on the effects of mixed reality-based fall prevention training on adults' reflexes, judgment, and balance control is still limited. [21]. Additionally, according to M. Morel, there is a limitation that distance perception differs when using XR. It is underestimated in XR compared to real-life situations. For example, compared to real-life situations, the amplitude of the center of pressure and reaction time may differ in XR, potentially altering the patient's behavior. Therefore, there are often limitations that are overlooked or underestimated depending on the type of research. Accordingly, this study aims to investigate the effects of extended reality-based fall prevention training on adults' reflexes, judgment, and balance control.

Previous studies have focused on effective training methods for fall prevention, particularly investigating the potential of training utilizing mixed reality technology to enhance its effectiveness. It was a study conducted on elderly individuals, and there is a limitation due to the small sample size. To overcome these limitations, the study aims to be conducted on healthy adults instead of the elderly, with an expanded sample size. Additionally, while previous studies focused solely on balance control, this study will also investigate reflexes and judgment.

Therefore, the purpose of this study is to investigate the effects of fall prevention training utilizing extended reality (XR) technology on adults' reflexes, judgment, and balance control abilities, and to compare this with traditional fall prevention training. These abilities play a crucial role in performing daily activities, and the research findings are expected to enhance the understanding of effective treatments and training methods for fall prevention, contributing to the safety and health of the elderly and other vulnerable groups. It was hypothesized that the reflexes, judgment, and balance control abilities during XR training would be as effective as those in the verbal instruction group (VIG), and that XR training could enhance the effectiveness of training by providing users with immersion and various sensory stimuli.The effectiveness of XR training in enhancing adults' reflexes, judgment, and balance control will be comparable to that of the verbal instruction group (VIG) led by physical therapists. XR training is expected to provide users with an immersive experience and enhance the effectiveness of fall prevention training through diverse sensory stimuli.

2. Materials and Methods

2.1 *Participants*

This study was conducted with 42 healthy adults aged 20 to 25 enrolled at S University located in City A, South Korea. The sample size was calculated using the 'GPOWER, 3.1.9.7' program. Before participating in the study, all subjects were informed about the purpose and methods of the research. Participants in this study were individuals with no injuries and no prior medical history, who had provided consent in advance. The experimental subjects were selected based on the following criteria: 1) those who can stand for 30 seconds, 2) those who have the ability to walk with or without assistance, 3) those with normal or corrected normal hearing and vision, and 4) those with no medical history. The research participants were provided with a thorough explanation of the purpose and methods of the experimental study, and the researcher informed them that any physical or personal information obtained during the study would not be disclosed outside of the experiment. Subsequently, the participants voluntarily completed a written consent form before participating in the study. All participants had their height measured using the autonomic BMI measuring instrument (BSM 370, Korea, 2011) and their weight measured using the BODY COMPOSITION ANALYZER (INBODY 570, Biospace, Korea, 2013) before the experiment. The physical characteristics of the participants are shown in [Table 1].

Table1. General characteristics of subjects (n=21)

	XRG(N=21)	VIG(N=21)	p
Age (year)	21.714±1.736	21.524±1.327	.139
Height (cm)	167.667±10.185	167.857±9.248	.517
Weight (kg)	63.381±16.366	64.143±13.752	.600

Values indicated mean ± standard deviation, XRG: XR Group, VIG: Verbal Instructions Group

This study was set up as a single blind, meaning that the participants did not know which group they belonged to or what the other group was doing. They were randomly assigned to two groups using Excel functions before the experiment. This study was approved by the Institutional Review Board (IRB) of Dongbang Culture University (8223-202408-HR-012-01).

2.2. *Experiment procedures*

The research procedure is as follows. The research participants had their height and weight measured once before the experiment, and assessments of reflexes, judgment, and balance control were conducted twice: once before and once after the intervention.

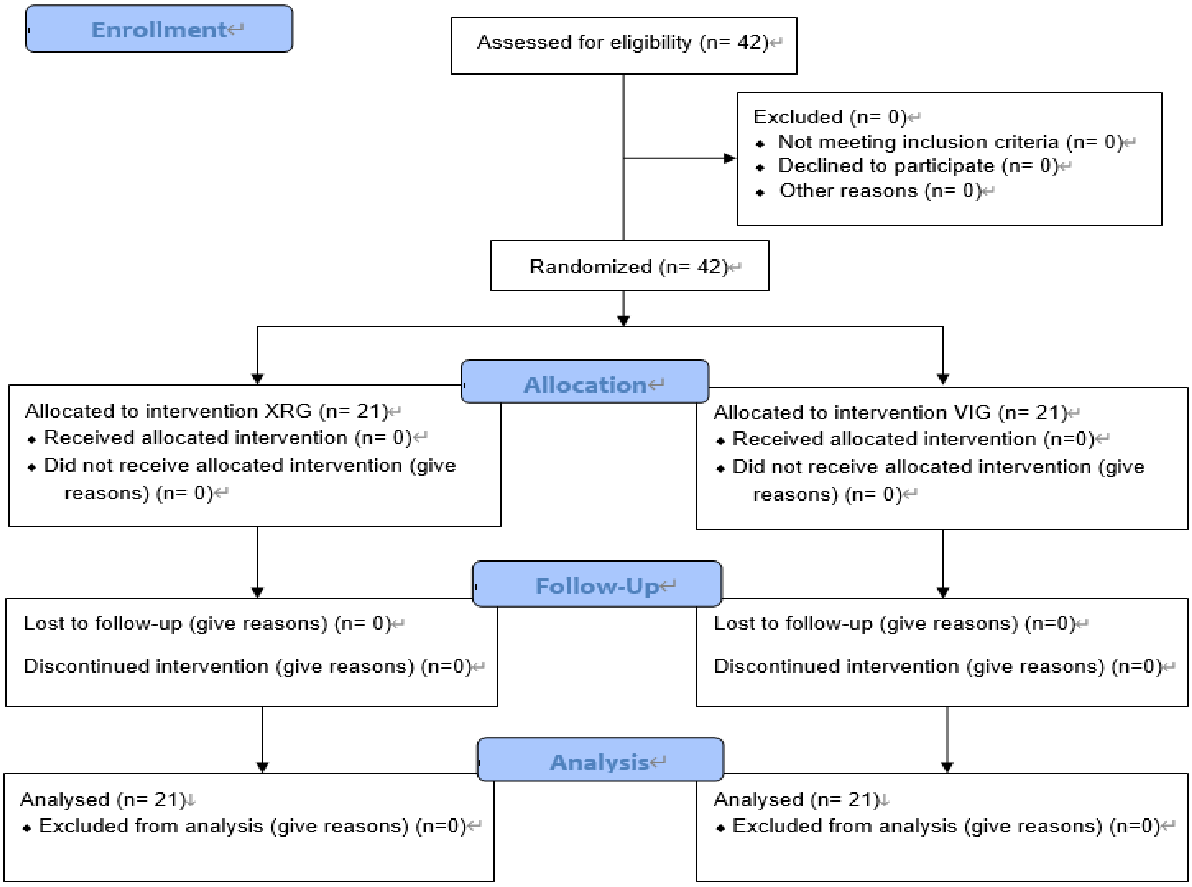


Figure 1. Experiment Procedures

2.3. *Measurement Tools and Methods*

All research participants had their height and weight measured once before the intervention, and assessments of reflexes, judgment, and balance control were conducted twice: once before and once after the intervention. All measurements and evaluations were conducted by the same researcher to minimize error, and the evaluation location and methods were standardized.

Based on the CDC's fall risk assessment recommendations (STEADI), a reliable clinical test set focused on mobility and strength was conducted to evaluate the validity of head movement tracking exercises. The assessment of reflexes was measured using the Trail Making Test (TMT). The Trail Making Tests (TMT) require a combination of visual perceptual ability, visual search, motor speed, complex visual scanning, and agility. Participants must perform the test at their fastest possible speed, and the test will be terminated if three uncorrected errors occur during the assessment. The participants underwent the Trail Making Test (TMT) to measure the average response time and average accuracy values [Figure 2-A].

The assessment of judgment was measured using the Korean version of the Montreal Cognitive Assessment (K-MOKA). The Korean version of the Montreal Cognitive Assessment is a tool designed to be sensitive to mild cognitive impairment, consisting of execution tasks and attention tasks. It consists of seven subcategories: visuospatial/executive function (5 points), vocabulary (3 points), attention (6 points), sentence construction (3 points), abstraction (2 points), recall (5 points), and orientation (6 points). The maximum score is 30 points, and a score of 23 or higher is considered normal. Additionally, there is a memory item, but no score is assigned to it. Considering this, the Korean version of the Montreal Cognitive Assessment (K-MOKA) was administered to the participants, and the total scores for each item were measured and recorded [Figure 2-B].

The assessment of balance control was measured using the Timed Up & Go (TUG) test. A chair with a backrest was placed, and a piece of tape was laid on the floor 3 meters away from the front edge of the chair to mark the position. The patient started seated in the chair with their back against the backrest and arms resting on the armrests. The test was conducted by measuring the time it took for the patient to stand up from the chair, walk 3 meters at a normal pace (rather than a fast speed), turn around, and return to the chair. The patient performed the test once, and if there were any clear errors, the TUG was repeated once more. Lower limb strength and balance ability were assessed using the Sit To Stand (STS test) - 30. The Sit To Stand (STS test) was conducted using a chair without armrests (height 45 cm, width 41 cm), and to minimize the risk of falling, the chair was supported against a wall. The participants were instructed to sit against the chair with their arms crossed over their chest, and the test was conducted for 30 seconds, during which the participants repeatedly stood up and sat down. During the test, the participants were instructed to perform the task "as quickly as possible." The examiner measured the number of times the participants completed the sit-to-stand task within the 30 seconds [Figure2-C, Figure2-D].

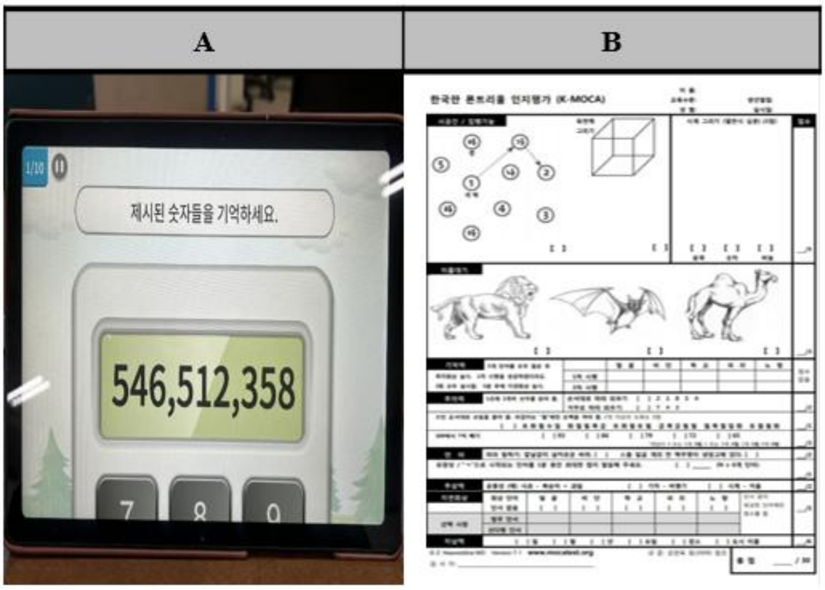


Figure2-A, Figure2-B

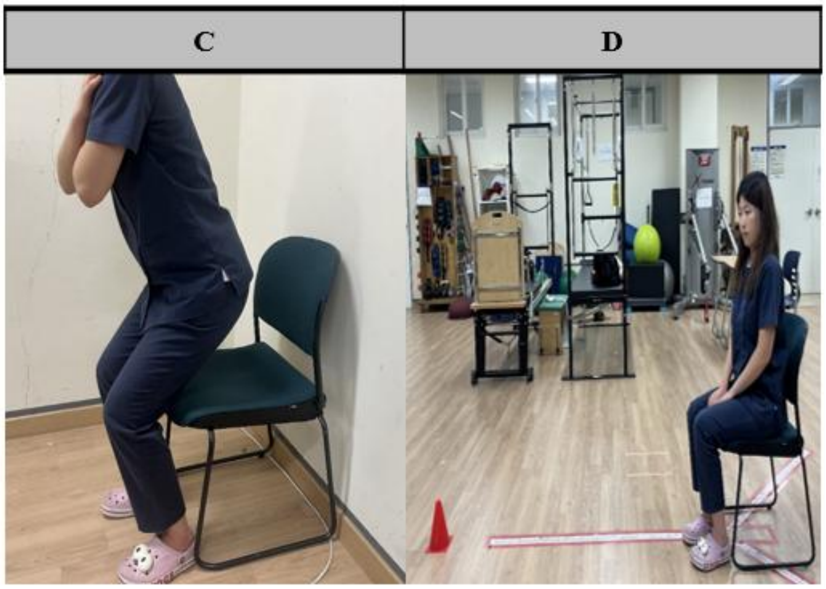


Figure2-C, Figure2-D

2.4. *Intervention method*

Both groups, XRG (= XR) and VIG (= verbal instructions), performed all exercises in 2 sets, with 15 repetitions per set. The fall prevention training consisted of exercises using a wedge and a ball to strengthen the lower limb and trunk muscles. All exercises were performed bilaterally. The XR device used in the XRG group was the Microsoft HoloLens 2. The Microsoft HoloLens 2 is a mixed reality device that allows interaction with 3D digital objects in real space. Eye-tracking that accurately tracks eye movements and 3D spatial recognition technology can create an enhanced work environment. With a 2K resolution, it provides a high level of immersion and allows for the free configuration of the GUI through various hand gestures such as pinch and drag. After having the participants wear the device, they viewed a video of the same exercise program applied to both groups while simultaneously performing the exercises. The VIG group implemented the same exercise program as Group 1 under the direct verbal instructions

of the therapist.

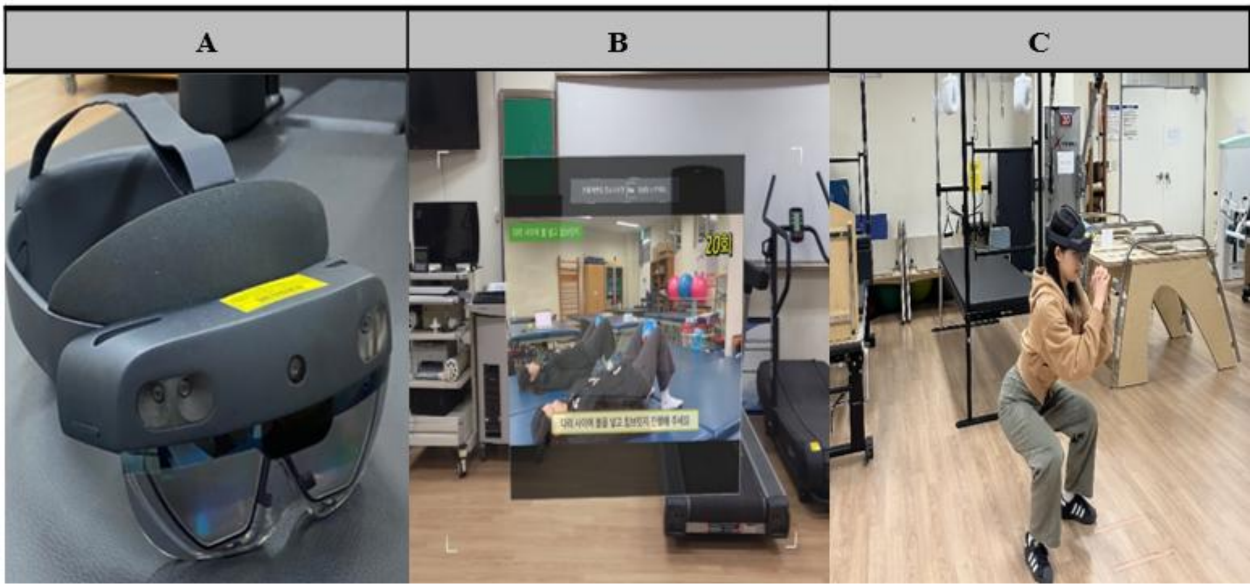
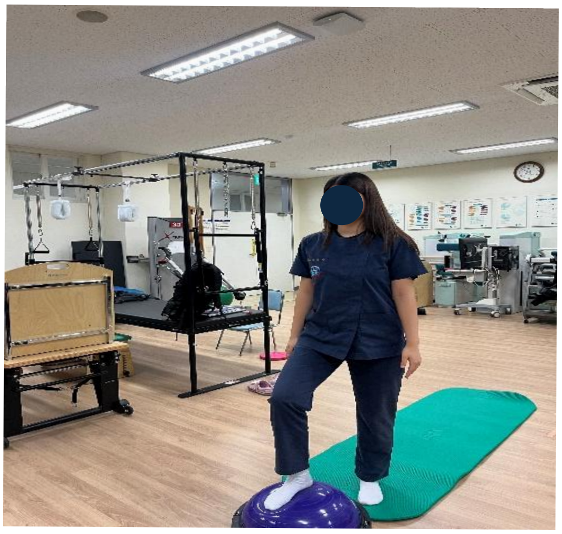


Figure3 XR exercise

name	explanation
Knee to Chest (warm up)	1. Start in a standing position. Bend your knees and keep your feet flat on the floor. 2. Slowly pull one knee towards your chest. You can wrap your hands around the knee or pull it gently if needed. 3. Hold the knee towards your chest for about 10 seconds. 4. After pulling one knee, pull the opposite knee in the same manner.

	
Standing Forward Bend **(warm up)**	1. Stand straight with your feet shoulder-width apart to begin. 2. Take a deep breath in, and as you exhale, bend at the waist to lean your upper body forward. It's fine to slightly bend your knees. Your hands can touch the floor or hold your ankles or toes. 3. Hold the upper body in the forward bent position for about 10 seconds. 4. Inhale again and slowly raise your upper body, returning to a standing position. 
Balance Ball Clap	1. Place the balance ball on the floor and stand with your feet shoulder-width apart to get ready. 2. Place your foot in the center of the balance ball to maintain your balance. 3. While on the balance ball, clap your hands. It's important to

	maintain your balance during this. 4. After clapping, step down from the balance ball. Lift your feet off t he center of the ball and land steadily on the floor 5. Repeat this process 15 times for 2sets.  .
Single Leg Balance on Balance	1. Place the balance ball on the floor and stand with your feet shoulder-width apart to get ready. 2. Place one foot in the center of the balance ball while lifting the other foot off the ground so that it doesn't touch the floor. 3. Stand on one foot, engage your core muscles, and maintain your balance while keeping your body centered. 4. Maintain your balance for 15 seconds. 5. After completing the standing motion on one foot, repeat the same method with the opposite foot. 

Squart	1. Stand with your feet shoulder-width apart, with your toes slightly pointed outward. You can keep your arms by your sides or cross them in front of your chest. 2. Exhale as you push your hips back and bend your knees. At this time, your upper body should naturally lean forward, and be careful not to let your knees go past your toes. 3.Sit as low as possible. Generally, it's best to lower your thighs to be parallel to the floor or even lower. 4. Inhale as you push your hips up while keeping your heels on the ground to rise up. 5. Repeat this process for 20 times in 2 sets.  .
Hip Bridge with Ball Squeeze	1. Lie on your back with your knees bent and your feet shoulder-width apart. Place a small ball (e.g., a balance ball or massage ball) between your feet. 2.Gently squeeze the ball between your knees to hold it in place. It's important to engage your hips and core during this process. 3. Exhale as you lift your hips. Keep your hips and thighs in a straight line, ensuring your shoulders remain on the ground. 4. Hold your hips at the highest position for 1-2 seconds, squeezing the ball to further activate your glute muscles. 5. Inhale as you slowly lower your hips back down to the floor, maintaining the pressure on the ball. 6. Repeat this process for 20 times in 2sets..

	
plank	1. Start in a prone position on the floor. Support your body with your elbows on the ground. 2. Position your elbows directly under your shoulders, and keep your arms shoulder-width apart. 3. Support your body with your toes on the ground, keeping your body in a straight line. Your feet can be together or slightly apart. 4. Contract your abdominal and glute muscles to maintain stability. Be careful not to let your lower back sag or arch upward during this time. 5. Keep your gaze directed at the floor and hold this position for 30 seconds. 6. When the time is up, slowly lower your knees to the ground and return to a prone position. 7.Proceed with 2 sets.  .

Breathing Exercise **(cool down)**	1. Start by sitting or lying down in a comfortable position. Relax your shoulders and allow your body to unwind. 2. Place one hand on your chest and the other hand on your abdomen. This way, you can feel the movement of your body while breathing. 3. Slowly take a deep breath in. You should feel your abdomen expand while keeping your chest as still as possible. 4. After inhaling, pause for a moment and hold your breath for 1-2 seconds. 5. Slowly exhale through your mouth, feeling your abdomen contract. Try to exhale as completely as possible. 6. Repeat this process 10 times. 

Figure 4 Exercise program

2.5. ***Statistical Analysis***

In this study, descriptive statistics were used to calculate general characteristics, and the mean and standard deviation of each variable were calculated. In this study, all statistical analyses were conducted using IBM SPSS 26.0 statistical software. After the normalization test, an independent sample t test was performed to find out the difference in the amount of change between the two groups, and a corresponding sample t test was performed to compare the before and after experiments within groups A and B.

3. Results

This study measured and compared the effects of fall prevention training with verbal instruction and fall prevention training with XR wearing. The normalization test showed that all variables followed a normal distribution. Paired t-test was performed on the results of STS, TUG, K-MOCA, TMT1, and TMT2 evaluations for pre- and post-experiment comparisons within each group. The results showed significant differences in both STS, TUG, and K-MOCA assessments for XRG and VIG ($p<.05$), but no significant difference for TMT1 and TMT2 ($p>.05$). In addition, an independent t-test was performed to determine the pre- and post-experimental differences between the two groups in STS, TUG, K-MOCA, TMT1, and TMT2, and found that there was no significant difference in STS, TUG, and K-MOCA assessments for XRG and VIG ($p>.05$), but there was a significant difference in TMT1 and TMT2 ($p<.05$).

Table 2. Comparison of Pre and Post results between the two groups

	group	XRG	VIG	t	p
STS	pre	25.33±7.19	27.14±7.98	-.772	.96
	Post	31.00±6.55	33.10±8.49	-.895	.14
	t	-4.661	-2.949		
	p	.00	.01		
TUG	pre	5.87±0.97	5.55±0.93	1.088	.49
	Post	4.92±0.71	4.79±0.61	.644	.60
	t	5.188	3.655		
	p	.00	.00		
K-MOCA	pre	27.38±2.06	27.24±1.67	.247	.14
	Post	28.76±1.37	28.67±1.35	.226	.68
	t	-2.968	-3.291		
	p	.01	.00		
TMT1	pre	79.05±18.41	69.52±16.27	1.776	.76
	Post	82.86±17.07	83.81±18.57	-.173	.79
	t	-.810	-2.970		
	p	.43	.01		
TMT2	pre	4.37±1.07	4.48±1.26	-.303	.43
	Post	4.09±1.01	3.78±0.88	1.074	.34
	t	1.121	3.540		
	p	.28	.00		

*p<.05, **p<.01, ***p<.001 (STS: Sit To Stand, TUG: Time Up and Go test)

Within-group comparisons showed significant differences between XRG and VIG (p<.05). In STS, there was no significant difference between the two groups, with the experimental group increasing from 25.33±7.19 pre to 31.00±6.55 post, and the control group increasing from 27.14±7.98 pre to 33.10±8.49 post. This suggests that the fall prevention program used in this study may help improve balance ability. An increase in STS test results indicates improved muscle strength and dynamic balance.

In the TUG, there was no significant difference between the two groups, with a decrease from 5.87±0.97 pre-hoc to 4.92±0.71 post-hoc in the experimental group, and 5.55±0.93 pre-±0.61 post-hoc in the control group. On the TUG test, a decrease in time indicates an increase in dynamic balance capacity and an improvement in functional mobility. This can be considered a foundational ability for fall prevention, which supports the effectiveness of this program.

In TMT1 and TMT2, there was no significant difference between the two groups, with the experimental group increasing from 79.05±18.41 pre-hoc to 82.86±17.07 post-hoc and the control group increasing from 69.52±16.27 pre-hoc to 83.81±18.57 post-hoc. In TMT2, the experimental group decreased from 4.37±1.07 to 4.09±1.01 post, and the control group decreased from 4.48±1.26 to 3.78±0.88.

In K-MOCA, there was no significant difference between the two groups, with the experimental group increasing from 27.38±2.06 beforehand to 28.76±1.37 post, and the control group increasing from 27.24±1.67 to 28.67±1.35 before. These results support the assumption that the program improved cognitive performance.

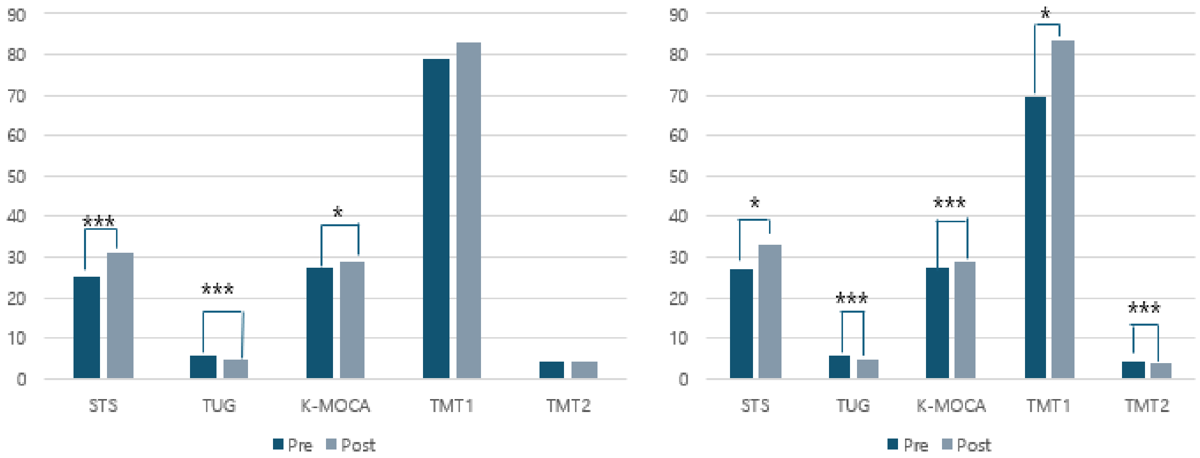


Figure 6: Reach the difference between pre and post between Groups

4. Discussion

The XR intervention in this study was sufficient to improve the subjects' reflexes, judgements, balances, and various senses. When examining each group, the ability to judgment using the Korean version of the Montreal K-MOCA, the standing and walking test, Time Up & Go (TUG test), and the sit to stand (STS test) were used to measure the ability to judgment using the Korean version of the Montreal K-MOCA, and the before and after comparison of the XRG group and the VIG group, and there was a statistically significant difference when compared before and after the experiment. However, there was no statistically significant difference in reflex tests using the Trail Making Test.

Falls occur during a variety of daily activities that are limited by the Limits of Stability (LOS). The limit of stability refers to the maximum distance a person can intentionally shift their center of gravity and lean in a given direction without losing their balance or holding it. According to a study by Rydwik, E, strength training alone is not enough to improve balance, which is related to the fact that muscle weakness, gait, and balance deficits increase the risk of falls. Therefore, a combination of strength training and balance training may be the most effective in reducing the incidence of falls. Muscle strength contributes to successful performance in daily activities such as climbing stairs, regaining balance after a fall or slip, and getting up from a chair.

In addition, in the elderly, the integration of multiple sensory information is necessary to maintain balance, and the lack of muscle strength and balance negatively affects this integration process. Studies have shown that strength training contributes to increased muscle mass and improved balance in older adults, suggesting that such training may play an important role in the prevention of falls. In particular, it has been shown that when strength training strengthens the lower limbs, it improves body balance and functional mobility in older adults, which reduces the risk of falling. Therefore, the development of programs that incorporate strength and balance training can be an important strategy in the prevention of falls.

In this study, STS and TUG tests confirmed that lower limb muscle strength and balance improved after training in a fall prevention exercise program. There are many factors that affect the balance of the body, but lower limb strength is one of the most important factor. Lower limb muscle strength decreases by 1~2% every year with age, and compared to middle-aged adults, older adults have lower lower limb muscle strength and impaired balance. A study by Ryushi T found that improving lower limb strength improved body balance and reduced the risk of falling. In addition, other studies have demonstrated the effectiveness of simultaneous training in improving strength and balance. In light of this, it is shown that the fall prevention exercise program using XR in this study contributed to improving balance indicators by training lower limb strength and balance at the same time. It is closely related to the exercise of the flexors, extensors, abductors, and adductors of the hip joint, and the improvement of the muscle strength of the hip, knee, and ankle joints plays an important role in independent walking and balance recovery. Therefore, the

XR-based strength and balance integration training used in this study will substantially help improve balance.

The K-MOCA was used to assess the cognitive performance of the subjects, and both performance scores were found to increase after training. These results support the hypothesis that an XR-assisted fall prevention exercise program improved cognitive performance. Previous research has shown that XR training through virtual reality improves memory and attention function in older adults. This is consistent with previous research on the pathology of Alzheimer's disease, which found that exercise helps delay cognitive decline and improve cognitive performance in older adults. Similarly, physical activity in older adults has been reported to improve cognitive function and lower the risk of dementia. Taken together, these results show that the results of the fall prevention program using XR for 4 weeks helped to improve the participants' muscle strength as well as motor cognition.

It is worth noting that there was no significant difference between the two groups in the results of TMT. This indicates that XR training had no direct effect on reflex speed or reaction time. Training in an XR environment had a positive effect on judgment and balance, but suggests that there may be a more complex factor at play in the case of reflexes. In particular, in TMT, greater improvements were observed in the VIG group than in the XRG group in assessing visual attention and reflexes on task switching. Successful TMT requires a variety of cognitive skills, including letter and number recognition, mental flexibility, visual scanning, and motor skills, and the impact of these factors on training effects needs to be analyzed in more depth in future studies.

While wearing XR may increase engagement, the XR paradigm has the potential to cause cybersickness, which may affect these outcomes. Cybersickness occurs as a response to exposure to XR, and a study by Nalivaiko et al. found a moderate correlation between reaction times ($r=0.5$; $P=.006$). Therefore, if participants experience cybersickness, there are concerns that the potential benefits and ecological validity of XR may be compromised. While XR technology offers several key advantages over traditional work, these systems can cause side effects such as cybersickness. In Rebecca Kirkham's study, only 21% of participants included an assessment of cybersickness, and this study shows a similar situation. This suggests that even if XR training is effective, we need to find ways to minimise side effects and maintain experiment comfort. In addition, there is a tendency to increase eye strain when wearing XR. The main physiological indicator of eye strain is a decrease in the blinking rate, which Yan et al. (2008) found can be quantitatively measured. A study by Richard W. Marklin, Jr. also found that wearing XR devices can increase the risk of eye strain, and that the blinking rate was reduced by 8 to 11 beats per minute in two tasks during the experiment. This reduction suggests that if the experimenter uses the device for a long time without adequate rest, it may cause eye strain. In particular, there are studies on the possible side effects of wearing XR for 30 minutes. Keshavarz et al. (2015) reported that 30 minutes of XR use may cause cybersickness and eye strain in participants, and they used a variety of assessment tools to measure each side effect. This study highlights the effects of prolonged use in a VR environment on physiological responses. In conclusion, this study shows the effectiveness and potential of XR training, but there needs to be sufficient consideration of side effects such as cybersickness and eye strain. Future research needs to explore ways to address these issues and discuss ways to improve XR training. This will further increase the likelihood that XR-based programs can contribute to fall prevention and rehabilitation in the elderly and other vulnerable groups.

This study showed that the effects of training, focusing on improvements in balance, muscle strength, and cognitive function, persisted for 4 weeks after rest after training, suggesting that the effects of the fall prevention exercise program using XR were integrated into daily life. As the subjects improved their balance and strength, they were more likely to continue exercising more than before. These results are consistent with previous studies on the effects of video game training in older adults, indicating that exercise effects persist after training. In recent years, there has been a growing interest in sarcopenia, a condition in which muscle performance and function decline with age, which is a major factor in cognitive impairment and increased risk of falls. Therefore, the results of this study suggest that training of a fall prevention exercise program with XR may have a positive effect on muscle strength, balance, and cognitive ability in patients with sarcopenia, and highlights the need for further research in these patients.

In addition, this study investigated XR-based balance training and strength improvement training programs. One prior study confirmed the efficacy of a balance training programme using Nintendo Wii Fit Plus and reported that most participants felt more enjoyable and motivated by the programme than with the regular intervention programme. In this study, the participants showed high participation through the fall prevention exercise programme using XR, and none of them showed boredom. This means that the participants were satisfied and motivated throughout the training sessions for strength and balance with XR.

Previous studies of XR rehabilitation devices have reported positive effects on cognitive function, balance, and muscle strength. In one study, XR dual-task training effectively improved concentration, memory, and balance by improving cognition and balance, but there was a relative lack of research on muscle strength. So far, few studies have been conducted to simultaneously improve balance, strength, and cognitive function through a single intervention program. Traditional exercise programmes and equipment usually focus on only one or two of these functions. However, the XR-based strength and balance integration training program used in this study was able to improve these three factors simultaneously. In addition, by conducting a multifaceted assessment of each factor using various scales, it was possible to quantitatively measure the improvement of cognitive ability, muscle strength, balance, and the persistence of exercise effects, which can be seen as an important feature of this study compared to the previous study.

The findings of this study are noteworthy in that the XR-based fall prevention training program demonstrates effects comparable to those of physical therapists. Through XR training, the participants exhibited significant improvements in muscle strength, balance, and cognitive function, mirroring the positive outcomes typically expected from physical therapist interventions. These results suggest that XR technology has the potential to complement or even replace traditional physical therapy methods. Notably, training in an XR environment provides participants with a sense of immersion and enhances motivation, which can contribute to sustained engagement—a critical factor in physical therapy. Numerous studies have also demonstrated that XR training effectively enhances balance control and judgment by simultaneously providing physical stability and cognitive stimulation. The immersive experience of XR training enhances user concentration, thereby maximizing the effectiveness of the training.

The various assessment methods employed in this study, such as the K-MOCA, STS, and TUG tests, indicate that XR training can establish itself as an effective intervention comparable to physical therapy. Particularly, the TUG test serves as a crucial indicator in fall risk assessment, and the positive changes observed in this metric through XR training underscore its effectiveness. XR training, particularly for the elderly, holds significant potential as an approach to simultaneously enhance physical and cognitive functions, complementing the role of physical therapists. Consequently, this study supports the assertion that XR-based training programs can produce effects similar to those of physical therapists or even replace them. The advancement and broader application of XR technology are expected to make significant contributions to fall prevention and rehabilitation in the future. The advancement of these technologies is expected to contribute significantly to the health and quality of life of the elderly population

This study has several limitations. Firstly, the lack of significant differences in the TMT results for reflex assessment makes it challenging to clearly determine the impact of XR training on specific aspects of reflexes. Future research should conduct a more detailed analysis of the specific components that constitute reflexes. secondly, the study did not sufficiently address strategies to minimize potential side effects of XR training, particularly cyber sickness and eye fatigue. These side effects can undermine the practicality and effectiveness of XR technology and are crucial for maintaining the comfort of participants. Therefore, future research should explore methods to minimize the side effects of XR training and create a comfortable environment that allows participants to engage in prolonged training sessions.

5. Conclusion

This study aims to evaluate the impact of an Extended Reality (XR)-based fall prevention training program on adults' reflexes, judgment, and balance control abilities. The results are as follows. Firstly, both groups showed significant improvements in balance control and cognitive abilities. Secondly, there were no significant differences between the two groups in reflex assessment, suggesting that XR training may have limitations in immediately improving reflexes. Consequently, the XR training program has the potential to complement or even replace the role of physical therapists. This study demonstrates the potential of XR technology and provides foundational data for introducing a new paradigm in fall prevention training. Given that the XR training program demonstrates effects comparable to those of physical therapists, future research and practical applications should further explore its potential.

References

[1] Jin, J. 2018.Prevention of falls in older adults.***JAMA** , 319*, 1734.

[2] Kendrick, D.; Kumar, A.; Carpenter, H.; Zijlstra, G.R.; Skelton, D.A.; Cook, J.R.; Stevens, Z.; Belcher, C.M.; Haworth, D.; Gawler, S.J. 2014.Exercise for reducing fear of falling in older people living in the community.***Cochrane database of systematic reviews*** .

[3] Vieira, E.R.; Palmer, R.C.; Chaves, P.H. 2016.Prevention of falls in older people living in the community.***BMJ** , 353*.

[4] Calero, M.ª.; López-Cala, G.; Ortega, A.R.; Cruz-Lendínez, A.J. 2016.Prevention of falls in the elderly: a review of new concepts based on the evidence.***European Journal of Investigation in Health, Psychology and Education** , 6*, 71–82.

[5] Çöltekin, A.; Griffin, A.L.; Slingsby, A.; Robinson, A.C.; Christophe, S.; Rautenbach, V.; Chen, M.; Pettit, C.; Klippel, A. 2020.Geospatial information visualization and extended reality displays.***Manual of digital earth*** , 229–277.

[6] Hoenig, W.; Milanes, C.; Scaria, L.; Phan, T.; Bolas, M.; Ayanian, N. (2015).Mixed reality for robotics, 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), IEEE: , pp. 5382–5387.

[7] Pose-Díez-de-la-Lastra, A.; Moreta-Martinez, R.; García-Sevilla, M.; García-Mato, D.; Calvo-Haro, J.A.; Mediavilla-Santos, L.; Pérez-Mañanes, R.; Von Haxthausen, F.; Pascau, J. 2022.HoloLens 1 vs. HoloLens 2: improvements in the new model for orthopedic oncological interventions.***Sensors** , 22*, 4915.

[8] Móga, K.; Boesl, D.B.; Haidegger, T. (2021).Augmented/mixed reality technologies supporting digital surgery, 2021 IEEE 19th International Symposium on Intelligent Systems and Informatics (SISY), IEEE: , pp. 183–189.

[9] Lonergan, C.; Hedley, N. 2014.Flexible mixed reality and situated simulation as emerging forms of geovisualization.***Cartographica: The International Journal for Geographic Information and Geovisualization** , 49*, 175–187.

[10] Lochhead, I.; Hedley, N. 2018.Communicating multilevel evacuation context using situated augmented reality.***ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences** , 4*, 33–40.

[11] Çöltekin, A.; Lochhead, I.; Madden, M.; Christophe, S.; Devaux, A.; Pettit, C.; Lock, O.; Shukla, S.; Herman, L.; Stachoň, Z. 2020.Extended reality in spatial sciences: A review of research challenges and future directions.***ISPRS International Journal of Geo-Information** , 9*, 439.

[12] Papegaaij, S.; Morang, F.; Steenbrink, F. 2017.Virtual and augmented reality based balance and gait training.***White Pap*** , 1–8.

[13] Haque, S.; Srinivasan, S. 2006.A meta-analysis of the training effectiveness of virtual reality surgical simulators.***IEEE Transactions on Information Technology in Biomedicine** , 10*, 51–58.

[14] Kaplan, A.D.; Cruit, J.; Endsley, M.; Beers, S.M.; Sawyer, B.D.; Hancock, P.A. 2021.The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis.***Hum Factors** , 63*, 706–726.

[15] Schuermans, J.; Van Hootegem, A.; Van den Bossche, M.; Van Gendt, M.; Witvrouw, E.; Wezenbeek, E. 2022.Extended reality in musculoskeletal rehabilitation and injury prevention-A systematic review.***Physical therapy in sport** , 55*, 229–240.

[16] Colomer, C.; Llorens, R.; Noé, E.; Alcañiz, M. 2016.Effect of a mixed reality-based intervention on arm, hand, and finger function on chronic stroke.***Journal of neuroengineering and rehabilitation** , 13*, 1–11.

[17] Chang, W.; Ko, L.; Yu, K.; Ho, Y.; Chen, C.; Jong, Y.; Huang, Y. 2019.EEG analysis of mixed-reality music rehabilitation system for post-stroke lower limb therapy.***Journal of the Society for Information Display** , 27*, 372–380.

[18] Raffegeau, T.E.; Young, W.R.; Fino, P.C.; Williams, A.M. 2023.A perspective on using virtual reality to incorporate the affective context of everyday falls into fall prevention.***JMIR aging** , 6*, e36325.

[19] Leong, S.C.; Tang, Y.M.; Toh, F.M.; Fong, K.N. 2022.Examining the effectiveness of virtual, augmented, and mixed reality (VAMR) therapy for upper limb recovery and activities of daily living in stroke patients: a systematic review and meta-analysis.***Journal of neuroengineering and rehabilitation** , 19*, 93.

[20] Morel, M.; Bideau, B.; Lardy, J.; Kulpa, R. 2015.Advantages and limitations of virtual reality for balance assessment and rehabilitation.***Neurophysiologie Clinique/Clinical Neurophysiology** , 45*, 315–326.

[21] Sun, R.; Aldunate, R.G.; Sosnoff, J.J. 2019.The validity of a mixed reality-based automated functional mobility assessment.***Sensors** , 19*, 2183.

[22] Sun, R.; Aldunate, R.G.; Sosnoff, J.J. 2019.The validity of a mixed reality-based automated functional mobility assessment.***Sensors** , 19*, 2183.

[23] Lord, S.R.; Fitzpatrick, R.C. 2001.Choice stepping reaction time: a composite measure of falls risk in older people.***The Journals of Gerontology Series A: Biological Sciences and Medical Sciences** , 56*, M627–M632.
[24] Nasreddine, Z.S.; Lee, J.Y. 2006.Korean version of the Montreal cognitive assessment..
[25] Podsiadlo, D.; Richardson, S. 1991.The Timed "Up & Go": A Test of Basic Functional Mobility for Frail Elderly Persons.***Journal of the American Geriatrics Society** , 39*, 142–148. doi : 10.1111/j.1532-5415.1991.tb01616.x. Available online: https://doi.org/10.1111/j.1532-5415.1991.tb01616.x.
[26] Jones, C.J.; Rikli, R.E.; Beam, W.C. 1999.A 30-s chair-stand test as a measure of lower body strength in community-residing older adults.***Res Q Exerc Sport** , 70*, 113–119.
[27] Boukadida, A.; Piotte, F.; Dehail, P.; Nadeau, S. 2015.Determinants of sit-to-stand tasks in individuals with hemiparesis post stroke: a review.***Annals of physical and rehabilitation medicine** , 58*, 167–172.
[28] Tveter, A.T.; Dagfinrud, H.; Moseng, T.; Holm, I. 2014.Health-related physical fitness measures: reference values and reference equations for use in clinical practice.***Arch Phys Med Rehabil** , 95*, 1366–1373.
[29] Rubenstein, L.Z. 2006.Falls in older people: epidemiology, risk factors and strategies for prevention.***Age Ageing** , 35*, ii37–ii41.
[30] Sturnieks, D.L.; St George, R.; Lord, S.R. 2008.Balance disorders in the elderly.***Neurophysiologie Clinique/Clinical Neurophysiology** , 38*, 467–478.
[31] Weirich, G.; Bemben, D.A.; Bemben, M.G. 2010.Predictors of balance in young, middle-aged, and late middle-aged women.***Journal of Geriatric Physical Therapy** , 33*, 110–117.
[32] Ryushi, T.; Kumagai, K.; Hayase, H.; Abe, T.; Shibuya, K.; Ono, A. 2000.Effect of resistive knee extension training on postural control measures in middle aged and elderly persons.***J Physiol Anthropol Appl Human Sci** , 19*, 143–149.
[33] Gillespie, L.D.; Gillespie, W.J.; Robertson, M.C.; Lamb, S.E.; Cumming, R.G.; Rowe, B.H. 2003.Interventions for preventing falls in elderly people.***Cochrane Database of Systematic Reviews*** . doi : 10.1002/14651858.CD000340. Available online: https://doi.org//10.1002/14651858.CD000340.
[34] Optale, G.; Urgesi, C.; Busato, V.; Marin, S.; Piron, L.; Priftis, K.; Gamberini, L.; Capodieci, S.; Bordin, A. 2010.Controlling memory impairment in elderly adults using virtual reality memory training: a randomized controlled pilot study.***Neurorehabil Neural Repair** , 24*, 348–357.
[35] Barnes, J.N. 2015.Exercise, cognitive function, and aging.***Adv Physiol Educ** , 39*, 55–62.
[36] Taaffe, D.R.; Irie, F.; Masaki, K.H.; Abbott, R.D.; Petrovitch, H.; Ross, G.W.; White, L.R. 2008.Physical activity, physical function, and incident dementia in elderly men: the Honolulu–Asia Aging Study.***The Journals of Gerontology Series A: Biological Sciences and Medical Sciences** , 63*, 529–535.
[37] Bowie, C.R.; Harvey, P.D. 2006.Administration and interpretation of the Trail Making Test.***Nature protocols** , 1*, 2277–2281.
[38] Nalivaiko, E.; Davis, S.L.; Blackmore, K.L.; Vakulin, A.; Nesbitt, K.V. 2015.Cybersickness provoked by head-mounted display affects cutaneous vascular tone, heart rate and reaction time.***Physiol Behav** , 151*, 583–590.
[39] Kirkham, R.; Kooijman, L.; Albertella, L.; Myles, D.; Yücel, M.; Rotaru, K. 2024.Immersive Virtual Reality–Based Methods for Assessing Executive Functioning: Systematic Review.***JMIR Serious Games** , 12*, e50282.
[40] Yan, Z.; Hu, L.; Chen, H.; Lu, F. 2008.Computer Vision Syndrome: A widely spreading but largely unknown epidemic among computer users.***Comput Hum Behav** , 24*, 2026–2042.
[41] Marklin Jr, R.W.; Toll, A.M.; Bauman, E.H.; Simmins, J.J.; LaDisa Jr, J.F.; Cooper, R. 2022.Do head-mounted augmented reality devices affect muscle activity and eye strain of utility workers who do procedural work? Studies of operators and manhole workers.***Hum Factors** , 64*, 305–323.
[42] Chang, K.; Hsu, T.; Wu, W.; Huang, K.; Han, D. 2016.Association Between Sarcopenia and Cognitive Impairment: A Systematic Review and Meta-Analysis.***Journal of the American Medical Directors Association** , 17*, 1164.e7–1164.e15. doi : 10.1016/j.jamda.2016.09.013. Available online: https://www.sciencedirect.com/science/article/pii/S1525861016304285.
[43] Yeung, S.S.; Reijnierse, E.M.; Pham, V.K.; Trappenburg, M.C.; Lim, W.K.; Meskers, C.G.; Maier, A.B. 2019.Sarcopenia and its association with falls and fractures in older adults: a systematic review and meta-analysis.***Journal of cachexia, sarcopenia and muscle** , 10*, 485–500.

[44] Meldrum, D.; Glennon, A.; Herdman, S.; Murray, D.; McConn-Walsh, R. 2012.Virtual reality rehabilitation of balance: assessment of the usability of the Nintendo Wii® Fit Plus.***Disability and rehabilitation: assistive technology*** , *7*, 205–210.

[45] Optale, G.; Urgesi, C.; Busato, V.; Marin, S.; Piron, L.; Priftis, K.; Gamberini, L.; Capodieci, S.; Bordin, A. 2010.Controlling memory impairment in elderly adults using virtual reality memory training: a randomized controlled pilot study.***Neurorehabil Neural Repair*** , *24*, 348–357.

[46] de Bruin, E.D.; Schoene, D.; Pichierri, G.; Smith, S.T. 2010.Use of virtual reality technique for the training of motor control in the elderly: some theoretical considerations.***Zeitschrift für Gerontologie und Geriatrie*** , *43*, 229–234.

[47] Sveistrup, H. 2004.Motor rehabilitation using virtual reality.***Journal of neuroengineering and rehabilitation*** , *1*, 1–8.

[48] Silsupadol, P.; Siu, K.; Shumway-Cook, A.; Woollacott, M.H. 2006.Training of balance under single-and dual-task conditions in older adults with balance impairment.***Phys Ther*** , *86*, 269–281.