The Effects of VR Interactive Games on Balance and Quality of Life Enhancement for Elderly in the Community

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Abstract

Thesis title: Examining the effectiveness of a virtual reality interactive game on physical fitness and quality of life in community-dwelling elderly people

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Background: Currently, community exercise courses are mostly guided by nurses and there are few opportunities for participating elderly people to interact with others during exercise. An interactive game was developed to allow elderly people participating in community activities to use game feedback to increase enjoyment and competitiveness in team games. Besides improving physical fitness, and increasing motivation and willingness to continue participating in exercise, this can also improve the quality of life.

Objective: To examine whether a virtual reality interactive game exercise can help improve the physical fitness and quality of life of elderly people.

Methods: Elderly people aged 65 years and above who participate in community activities were recruited and randomized into the experimental group and control group. The experimental group completed 36 episodes of exercise intervention using the interactive game, spread over 12 weeks, while the original routine exercise was used as the course content in the control group. Both groups underwent 36 episodes of intervention of one hour each time, thrice a week for 12 consecutive weeks. Assessments of functional physical fitness and satisfaction with quality of life were performed before and after intervention and the statistical significance was set as $p<0.05$.

Results: After 36 weeks of virtual reality interactive game interaction, the post-test scores for 2-minute step test ($p<0.001$), right chair sit-and-reach test ($p=0.010$), left chair sit-and-reach test ($p=0.002$), psychological quality of life ($p=0.033$), and environmental quality of life ($p=0.048$) of the experimental group were all significantly higher than those of the control group.

Conclusion: A 36-week course of virtual reality interactive game could significantly improve the physical fitness and psychological and environmental quality of life of community-dwelling elderly.

Keywords: virtual reality, interactive game, community-dwelling elderly, physical fitness, quality of life

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Introduction

Section 1 Research Background

The global phenomenon of population aging has become a universal trend and a future development. The World Health Organization (WHO) defined an "aging society" in 2002 as a society where the proportion of the population aged 65 and over reaches 7% of the total population. According to the statistics from the Population Division of the World Health Organization, the population of elderly individuals aged 65 and over has reached 720 million, accounting for approximately 9% of the global population. It is estimated that by the year 2050, the global population of elderly individuals will exceed 17% (WHO, 2020).In contrast, Taiwan has entered an aging society since 1993 when the proportion of elderly individuals reached 7% of the total population. By 2018, this proportion had reached 14%, transitioning into an aged society. According to the National Development Council of the Executive Yuan, it is estimated that by the year 2025, the proportion of elderly individuals will reach 20%, making Taiwan a super-aged society member. This indicates that within the next decade, one out of every five individuals in Taiwan will be elderly (National Development Council, 2020).

Comparing with other countries, France took 155 years (1864-2019) to transition from an aging society to a super-aged society, while Taiwan accomplished this transition in just 32 years (Economic Development Committee of the Executive Yuan, 2013). This is mainly due to the increase in life expectancy, decline in birth rates, and the increasing prevalence of late marriage and non-marriage among the population. Therefore, coping with the multiple problems caused by aging and the changes in social structure leading to increased demand for long-term care poses a serious challenge for rapidly aging Taiwan. According to global population statistics, approximately 30% of individuals aged 65 and above experience at least one fall annually (Bjerk et al., 2019). In Taiwan, the statistical report on the main causes of death among the population in 2020 revealed that falls were the second leading cause of mortality among individuals aged 65 and above (Department of Statistics, Ministry of Health and Welfare, 2020). In the health discourse of aging societies, fall prevention and management are among the most crucial topics. Falls among the elderly are associated with various risk factors such as poor posture control, diminished balance, muscle weakness, postural hypotension, underlying diseases, cognitive decline, medication use, environmental factors, and a history of previous falls (Wu et al., 2019; Huang et al., 2015). The occurrence of falls can lead to disability, hospitalization, long-term institutionalization, and even death. To prevent the increase of future financial burden on the country and to maintain national competitiveness, the Department of Health has set active aging and disability prevention as the main goals of elderly health policies. These policies include promoting physical fitness among the elderly, fall prevention strategies, encouraging social participation, preventive healthcare, and screening services (Ministry of Health and Welfare, 2020).

Recognizing that most elderly individuals live in communities, the government announced the Long-term Care 2.0 Ten-Year Plan in 2018, which includes the establishment of venues and bases in communities to provide services such as activities to prevent disability, health promotion, and exercise training courses for the elderly. This initiative actively promotes successful active aging with the goal of reducing the social costs associated with long-term care resulting from falls and ultimately improving the quality of life (Ministry of Health and Welfare, 2016; Chang & Chen, 2020). Scholars suggest that active participation in leisure activities and social engagement helps increase physical activity and interaction with the external environment, thereby enhancing the quality of life for the elderly (Chen et al., 2020; Lin, 2021; Bashkireva et al., 2018). Section 3 Analysis and Comparison of Quality of Life Scale Increase itionally, through the establishment of community-based exercise programs, various forms of exercise can improve physical function and maintain fitness. For example, balance and resistance exercises conducted 2-3 times a week for 15-90 minutes each time have been proven effective in improving muscle strength, balance, and fall prevention among the elderly (Chung et al., 2016; Lewis, Peiris, Shields, 2016; Sherrington et al., 2019).However, traditional structured exercises led by instructors can often be monotonous. Therefore, many scholars actively research interactive games that utilize physical and visual feedback to complement each other. These games provide training for coordination, enhance reaction movements, and improve balance abilities, thereby increasing the willingness of the elderly to engage in physical activities. It has been found that these interventions are beneficial in preventing falls among community-dwelling elderly individuals. Constructing simple task-based games not only motivates the elderly but also enhances their enjoyment and morale, and even reduces anxiety (Lim et al., 2015; Chen et al., 2015; Llorens et al., 2016; Neri et al., 2017; Chen, Hu, Wang, & Lin, 2018; Huang et al., 2019; Hsu & Lin, 2020). However, current interactive games on the market are limited by space constraints, allowing only 1-2 individuals to engage simultaneously in the same space. Therefore, establishing an interactive game mode using virtual reality that enables multiple participants to engage in exercise together fosters interaction and communication among participants. Through cooperation, support, competition, and communication, this approach not only increases the frequency of interactions between the elderly and others but also enhances the willingness of the elderly to participate in exercise, effectively training balance abilities, and maintaining the overall satisfaction of their quality of life.

Section 2 Research Objectives

The purpose of this study is to validate the effectiveness of virtual reality interactive gaming exercises in improving the physical fitness of the elderly and enhancing their quality of life.

Section 3 Research Questions and Hypotheses

Research Questions:

Does intervention with virtual reality interactive gaming exercises effectively improve physical fitness and quality of life among community-dwelling elderly individuals?

Hypotheses:

The use of virtual reality interactive gaming exercises contributes to improving physical fitness and quality of life among the elderly.

Section 4 Conceptual Architecture

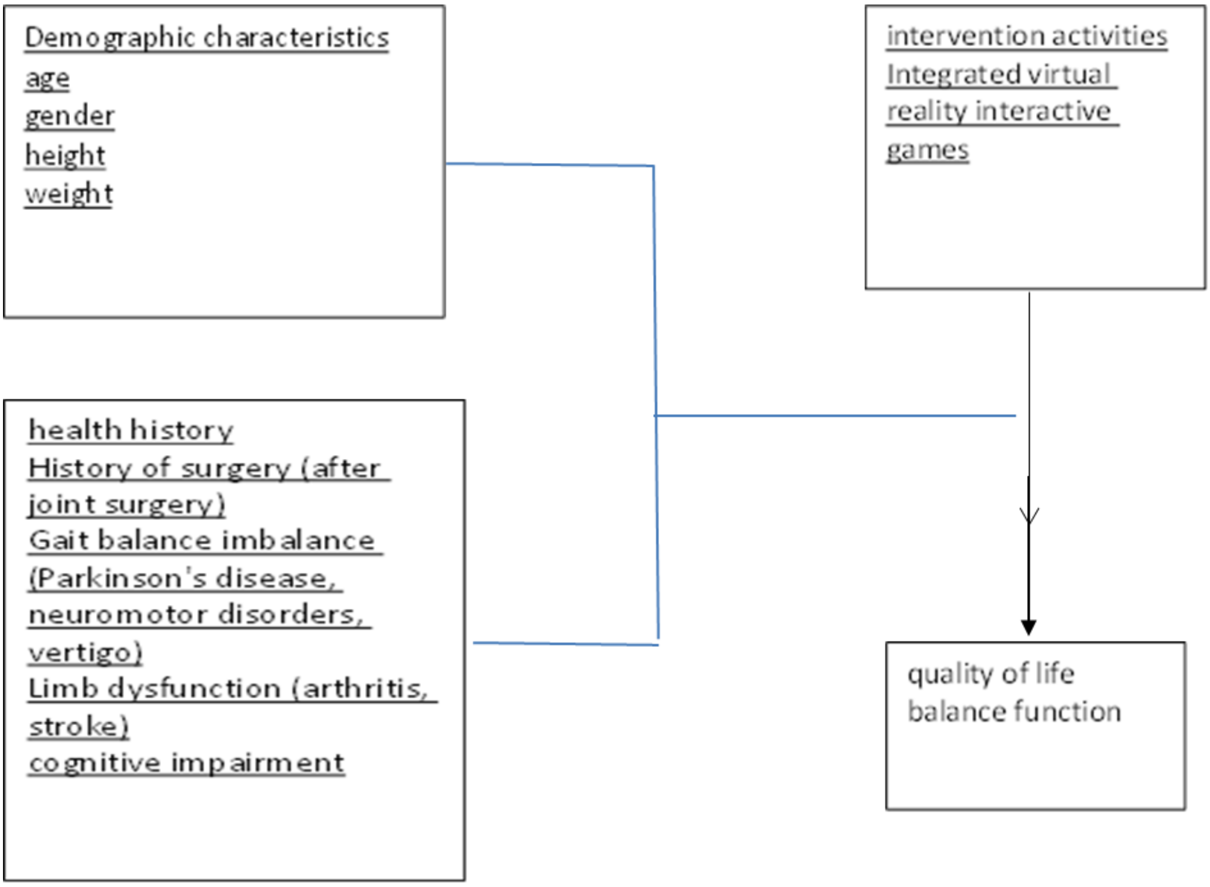

Figure 1 Conceptual architecture diagram

Literature Review

Section 1: Falls and prevention among the elderly

The World Health Organization defines "health" not only as the absence of disease or physical impairments but also encompasses physiological, psychological well-being, and happiness as integral components of overall health (WHO, 2022). However, numerous studies have indicated that as individuals age, their sensory-motor functions and neuromuscular systems gradually decline, leading to increased fatigue in lower limb muscles, reduced endurance for walking, and poor balance performance among elderly individuals. The decline in balance not only directly impacts their daily lives and independence but also increases the risk of falls, resulting in injuries, disability, and escalating healthcare costs and social burdens, and in severe cases, even death (Senefeld et al., 2017; Henry & Baudry, 2019; Li et al., 2018; Wu, 2021). Beyond physical injuries, the fear of falling and subsequent loss of confidence in walking and engaging in activities independently can also have psychological impacts on the elderly, leading to reduced quality of life. This issue has garnered significant attention from public health and geriatric medicine sectors worldwide, making fall prevention and effective maintenance of physiological functions essential for overall health and successful aging (Garatachea & Lucia, 2013; Shi et al., 2015; Noradechanunt et al., 2017; Steckhan et al., 2021).

Regarding the definition of falls, the Health Promotion Administration describes them as incidents occurring in any situation or setting where an individual unexpectedly loses balance and sits or falls to the ground, regardless of whether it results in physical injury (Chou, 2020). Increase itionally, the Ministry of Health and Welfare, in its "Health Promotion Administration: 2020 Healthy People White Paper," lists the prevention and treatment of falls and fractures among the elderly as one of its objectives (Ministry of Health and Welfare, 2020). The risk factors for falls can be categorized into four major factors: biological, behavioral, environmental, and socioeconomic. Biological factors include age, gender, balance ability, muscle strength decline, weakened protective reflexes, chronic diseases, and skeletal changes. Behavioral factors refer to factors that lead to falls due to behavior, such as medication use, alcohol consumption, and lack of exercise. Environmental factors include indoor and outdoor environments, such as damaged stairs, poor lighting, and lack of handrails or assistive devices. Socioeconomic factors include education level and social support (Chen et al., 2013). Among these, the primary reasons for falls among the elderly are often related to biological factors, particularly inadequate balance and muscle strength. These factors are also critical predictors of fall incidents among the elderly, underscoring the importance of appropriate exercise training in fall prevention. Additionally, the decline in physical function, insufficient physical activity, and increased sedentary behavior among the elderly are closely associated with falls. After experiencing a fall, individuals may restrict their activities due to fear of falling again, which further impacts their quality of life (Schoene et al., 2014).

Quality of life is a broad and complex concept that encompasses all factors affecting an individual's life, not just the prolongation of life, but also includes physiological, psychological, and social dimensions (Cai, Verza, & Bjerklund Johansen, 2021; M. Choi, Lee, Lee, & Jung, 2017). In recommendations for promoting health, delaying aging, and adapting to role changes among the elderly while enhancing quality of life, social participation is considered one of the best options. High levels of social participation have been associated with higher quality of life and life satisfaction (Dai et al., 2016; Hsu & Chu, 2022). Long-term and regular exercise has multiple benefits for the elderly, including improving cardiovascular function, maintaining independence, enhancing flexibility and balance, and improving psychological and cognitive function. Making new friends during exercise also promotes intergenerational interaction, thereby enhancing positive image and quality of life (Chou, 2020). The American College of Sports Medicine's exercise guidelines for older adults recommend diverse exercise programs, including aerobic exercise, flexibility training, balance exercises, and resistance training, to effectively maintain the fitness of older adults, prevent falls due to frailty, and avoid the crisis of disability and bed confinement. Therefore, how to maintain the physical function of the elderly, prevent and delay disability, reduce medical and social costs, and enhance quality of life has become an extremely important issue (Su, Hu, & Wu, 2020).

Section 2: Impact of Exercise Training on Elderly Lower Limb Balance

In Taiwan, it is well understood that regular exercise is the optimal strategy for improving the sensory motor system of the body and maintaining balance to prevent falls. With the aging process, balance ability gradually declines with age. Balance stability is controlled by the cerebral cortex and cerebellum, which interact through the central nervous system and sensory motor nerves (Rogge et al., 2018). Balance can be divided into dynamic and static balance. Dynamic balance refers to the ability to maintain balance while performing movements such as standing up, walking, and running. Static balance refers to the ability to maintain a specific posture without losing balance while stationary. Among these, dynamic balance, agility, and flexibility are most closely related to the risk of falls in older adults (Rikli & Jones, 2013).

In clinical practice, there are many simple and rapid scales used to detect balance function, such as the Timed Up and Go (TUG) test, Tinetti test, single-leg balance test, functional fitness, Berg Balance Scale, and Functional Reach Test (FRT). Among these, functional fitness, also known as the health-related fitness of older adults, is a common tool used in the community to assess the fitness of the elderly. It includes testing muscle endurance and strength, agility, flexibility, and body balance, aiming to assess whether the elderly have the basic physical activity ability to independently handle daily life functions. The test includes four directions with seven items: (1) Muscle endurance and strength testing: including sitting-to-standing and arm curls. (2) Flexibility testing:

including seated forward bend and back scratch. (3) Balance testing: including agility and dynamic balance testing, and static balance testing. (4) Cardiopulmonary endurance testing. The higher the level of physical activity, the better the health-related fitness, indicating a greater ability to manage daily life independently.

Several scholars have conducted research on introducing fitness, resistance band, and rehabilitation exercises into community centers. The results show significant benefits for elderly participants in terms of muscle strength, balance, flexibility, walking, and cardiopulmonary function. Therefore, intervention measures involving exercise training for older adults to strengthen balance, muscle strength, and flexibility are crucial for fall prevention (Chang et al., 2013; Ma et al., 2017; Chen et al., 2019; Jiang et al., 2020). The Health Promotion Administration of the Ministry of Health and Welfare also issued the "Falling Prevention Tips for Seniors" handbook in 2014. In addition to promoting fall prevention knowledge, the chapter on fall prevention exercise prescriptions introduces seven strength exercises, five balance exercises, three flexibility training, and three stretching exercises (Health Promotion Administration, Ministry of Health and Welfare, 2021), all of which help to train lower limb strength and improve balance. A complete exercise prescription design for the elderly. Domestic scholars have researched the correlation between walking in the elderly and quality of life, finding that older adults with higher levels of physical activity and better cardiopulmonary fitness have better quality of life. Therefore, it is recommended that older adults increase their physical activity to improve cardiopulmonary fitness, which helps promote physical and mental health and enhance quality of life (Lai et al., 2021). However, effective exercise must be integrated into daily life and sustained. Although community centers have relevant course content recommendations in the Long-Term Care 2.0 plan, there is a lack of consistent exercise training standards due to different funding sources and community attributes. Designing a set of virtual reality interactive games combined with exercise for use in community care centers can create a positive atmosphere through group activities, increasing the fun and competitiveness of participation, which helps older adults become more willing to participate in society, interact with others, and ultimately improve their quality of life.

Section 3: Application of Interactive Games in Exercise Prescription for the Elderly

In recent years, the development of interactive games has provided users with a variety of sensory simulations, including visual, auditory, and tactile sensations. This not only creates an immersive experience but also motivates continuous participation in activities through engaging and enjoyable means (Hsieh, 2014). Interactive gaming combines the concepts and characteristics of games with physical activities, leveraging multimedia functions such as images, graphics, text, and music. By integrating cognitive psychology training, it effectively enhances the attention of older adults. Through feedback provided by the system, learners are continually encouraged to change their behaviors, ultimately achieving learning goals (Lin & Lin, 2020). Virtual digital gaming involves generating three-dimensional virtual environments using computers, projected onto screens or large screens. By utilizing dynamic images, clear rules, and objectives, users can experience changes in different scenarios in a safe environment. This not only increases the motivation of the elderly to learn but also enhances their learning interest and motivation through game feedback mechanisms (Lin & Lin, 2020).

Virtual Reality (VR) utilizes integrated graphics, sound, images, animations, and interactive devices, possessing three main characteristics: 1. Creating a virtual space through computer-generated images and audio-visual effects, allowing users to immerse themselves in imaginary scenarios; 2. Enabling user interaction with virtual scene objects, providing real-time feedback through different input devices (head-mounted displays, data gloves, position trackers), enhancing interactivity; 3. Combining virtual scenes with various input devices to fulfill sensory needs, creating an immersive experience that connects and resonates with users. Semi-immersive virtual reality scenes, complemented by projection display systems, multi-channel sound, and multi-dimensional interactive systems, satisfy users' visual, auditory, and tactile sensory requirements. This often requires 2-3 or even multiple projection channels seamlessly stitched together to form a large projection surface, providing high-resolution two-dimensional or three-dimensional images and creating a semi-immersive virtual reality system experience environment. Flight simulators are examples of semi-immersive virtual scenes that rely on large-screen displays and powerful projection systems and monitors to provide an immersive atmosphere while allowing users to remain aware of the existence of the real world (Zhang, 2018). Clinically, virtual reality has been proven to be an effective device for treating patients with balance disorders (Griswold et al., 2014). It simulates various sensory perceptions of humans and images and sound effects similar to real environments, and uses sensors to detect physiological responses feedback to the simulator. This creates real-time interaction between humans and machines, allowing users to control virtual characters' actions through movements similar to actual exercise, providing interactive experiences with audiovisual feedback gaming. The complementary functions of objects and image feedback can enhance and improve users' balance abilities (Huang et al., 2022). During the process, users perform actions in front of receivers (infrared, heat sensing, etc.) facing the screen, allowing the receivers to send feedback to the cloud to identify identities and detect positions. Through sensing movements and measuring physical activity performance, interactive and operational effects are achieved. Currently available interactive games on the market, such as commercial developments like Wii Fit, Nintendo, Xbox, etc., can provide specific balance training for users. The system of interactive games can promote better posture control than traditional exercises, and the energy expended by participating in games is equivalent to light to rate-intensity activities. It can incorporate various exercise control challenges into games, allowing participants to move their bodies interactively with the game. In addition to maintaining the original context and spatial perception, functional fitness training, maintaining correct physical movements, and improving social interaction with others are also enhanced through gaming. This effectively increases motivation and enjoyment, improves the activity and balance abilities of the elderly, reduces the risk of falls, and maintains independence (Hsieh, 2014; Hupin et al., 2015; Nicholson et al., 2015; Chen & Yu, 2016; Taylor et al., 2018; Chen & Gong, 2019; Lai, 2020; Phirom et al., 2020).

In recent years, recognizing Taiwan's gradual aging population, efforts have been made in communities to promote physical fitness activities for the elderly. With rapid technological advancements, activity designs should evolve accordingly. By integrating VR interactive games as a medium, the willingness of the elderly to participate in activities can be increased, along with enhanced interaction with others and the achievement of confidence and satisfaction through completing tasks (Lin & Lin, 2020). Several scholars have conducted research on interventions with virtual reality or interactive games for elderly residents in institutions (day care centers, rehabilitation homes) or patients with stroke or muscular dystrophy, and found that these interventions are helpful for improving balance and lower limb posture (Donath et al., 2016; Xu, 2020; Zhong, 2020; Du, 2021). However, there is limited research on the elderly in community care centers. Observing existing exercise programs in community centers, they typically involve small group sessions with one instructor demonstrating exercises to the elderly. This method does not allow the elderly to see if their movements are correct and lacks interaction with other participants. If VR interactive games can be introduced into exercise programs, allowing the elderly to participate in exercise games and interact with others, it not only increases the willingness of the elderly to continue exercising but also boosts their confidence and sense of fulfillment through game achievements, thereby achieving the goal of healthy aging.

Section 4: Literature Summary

From the synthesis of the above literature, it is evident that the primary goal of "healthy aging" is to maintain and enhance the physical function of the elderly population, enabling them to lead happy, satisfying, and fulfilling lives. The decline in functional abilities and the increase in sedentary behavior among the elderly are closely related, making it crucial to address how to maintain their physical function, prevent or delay disability, reduce medical and social costs, and improve quality of life. Regular exercise is recognized as the best strategy for improving the sensory-motor system and maintaining balance to prevent falls. By designing group activities that increase the atmosphere of group activities and incorporating game feedback and interactive processes with others, participants can become highly engaged and focused within the social group. They can feel relaxed, relieved of stress, and experience mood changes during facility activities. This increases motivation and willingness to continue participating in exercise and accomplishing tasks during the game, boosting confidence among the elderly and consequently enhancing their quality of life by redefining the value and meaning of life.

Chapter 3: Research Methodology

Section 1: Research Design

This study adopts an experimental design with a pre-test and post-test for two groups. Convenience sampling is utilized as the sampling method, and data collection is conducted through questionnaires and measurement evaluation scales. The research investigates the intervention of integrating VR interactive games to assist in improving balance function and lower limb strength among the elderly, thereby enhancing their quality of life. The proposed intervention research framework is depicted below (Figure 2).

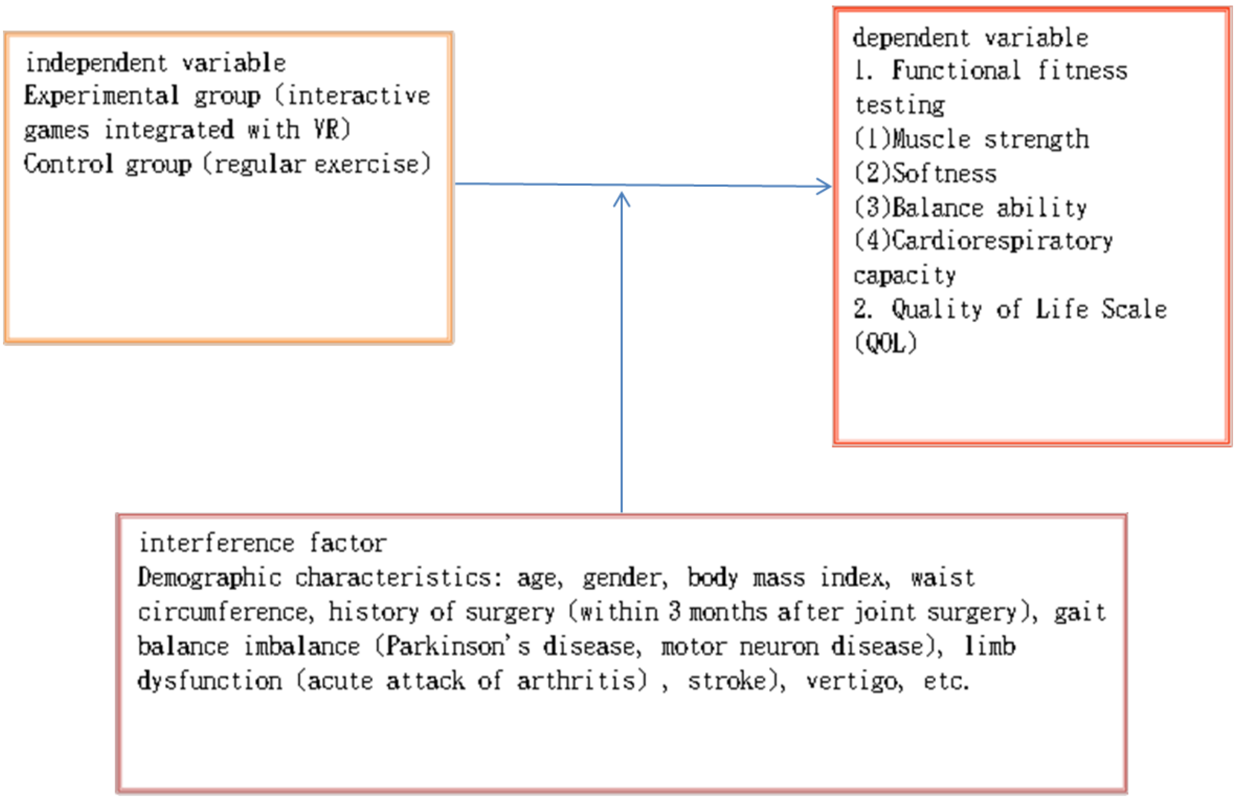

Figure 2 Research framework diagram of using virtual reality interactive games to improve balance and quality of life of community elders

Section 2: Research Site, Participants, and Ethical Considerations

Research Site:

This study will be conducted among community-based activities and voluntary participants aged 65 and above.

Research Participants:

The sample size for this study is calculated using G-power 3.1.9.7 statistical software to determine the effect size. According to Cohen (1988), effect sizes are categorized as large (0.80), medium (0.50), and small (0.20). Since most research results have an effect size of 0.50, this study sets the criterion of at least a medium effect size. With α=0.05, statistical power (power)=0.80, and effect size set at 0.5, the estimated sample size is 60 individuals. Considering potential changes in the elderly or refusal to participate, a dropout rate of 15% is estimated. Therefore, a total of 70 elderly individuals from community-based activities will be recruited for this study. The inclusion criteria for this study are as follows: (1) aged 65 and above, (2) able to communicate in Mandarin or Taiwanese and willing to complete interviews or self-administered questionnaires, (3) no mobility impairments (e.g., stroke, Parkinson's disease, motor neuron diseases), (4) no severe cardiovascular diseases, (5) no degenerative joint diseases or acute attacks in the past three months, (6) lower limb joint surgery performed more than three months ago, and (7) no dizziness or any unstable health conditions that hinder exercise.

During the study period, participants who do not engage in physical activity for more than three weeks or have missing pre-test or post-test data will be excluded from the statistical analysis.

Ethical Considerations:

Prior to conducting the study, the research proposal will be submitted to the Institutional Review Board (IRB) for review and approval. Approval was obtained from the Taipei Medical University Joint Institutional Review Board (TMU-JIRB) on November 24, 2022, with the approval letter numbered N202210004 (see Appendix 1). This study aims to investigate the effects of VR interactive games as part of exercise prescriptions on the balance function and lower limb strength of elderly participants.

Section 3: Intervention Tools

Hardware Setup:

The study utilizes four main devices, including Bluetooth-enabled three-axis inertial sensors (Inertial Measurement Unit, IMU), an LED projector, a tablet computer, and a laptop computer to interface between the tablet and projector. The virtual airplane game, designed by the researchers, is downloaded onto the tablet and projected onto a blank wall using the projector. Participants wear a waist protector embedded with IMU sensors, which are connected via Bluetooth to control the aircraft in the virtual game. The sensors collect data on the maximum displacement of the participant's body midline and angles, which are used to determine the participant's movements and position. By moving their body in different directions, participants complete various game tasks to engage in balance training.

Section 4 Intervention Methods

Virtual reality (VR) technology is employed to simulate normal functional limb movements, with motion sensing systems using infrared sensors to detect and provide feedback on body movements for kinematic analysis. The system calculates the position and velocity of the body to generate kinematic values for clinical functional assessment forms. 3D scenes and interactions are designed, with researchers guiding the elderly participants through large joint body movements. During the process, data on force distribution or behavioral patterns are identified and analyzed. The game training is divided into three stages based on different body weight distributions:

Stage 1 (first four weeks): Participants stand with feet parallel and perform forward leaning, backward leaning, left bending, and right bending according to the game content.

Stage 2 (middle four weeks): Participants stand with feet parallel in a slight squatting position and perform forward leaning, back

Stage 3 (last four weeks): Participants stand with feet apart and perform forward leaning, backward leaning, and left-right bending.

The balance game training plan is divided into three difficulty levels: low, medium, and high. The system continuously records the angle of body movement during each exercise session, and pre- and post-training data results are analyzed and compared at the end of the training period.

The study spanned three months, with pre-tests conducted within the first two weeks befor the first session and post-tests within two weeks after the 36th session. Functional physical fitness and quality of life assessments were conducted for both groups befor and after each session. Upon completion of the overall program, the researchers provided comprehensive feedback on the study's results.

Exercise Protocol:

Both groups initially engaged in modal rate-intensity exercise. The experimental group underwent a 12-week intervention program, consisting of 3 sessions per week, totaling 36 sessions. Each session lasted 60 minutes and included the following components:

Warm-up exercises (10-15 minutes)

Main exercise activity (30 minutes)

Cool-down exercises (5-10 minutes), with a 10-minute break in between

To mitigate potential risks associated with exercise training, blood pressure measurements were taken befor each session. Participants engaged in exercises under the guidance of research personnel. If participants felt unwell on a given day, they were allowed to skip the session. In case of any discomfort during the activity, the training was immediately halted.

Hardware and Software Setup:

The intervention utilized a touch-enabled 11-inch tablet computer loaded with the research game system, serving as the interface for participants to interact with the VR interactive game. A laptop computer facilitated the connection between the tablet and projector. The game content could only be downloaded and used on the tablet or Android smartphones. To allow elderly participants to see the game's effectiveness during the activity, the tablet was wirelessly connected to the laptop and projected onto a white wall in the same Wi-Fi environment.

Game Implementation:

The game design included four aircraft, each representing a participant in the group. Before starting the game, the game and sensors were paired via Bluetooth. The sensors were securely placed on the waist belt at the lumbar spine level. Participants underwent posture corrections, including left-right bending, forward bending, and backward leaning, to ensure accurate sensor data capture. Once all participants completed the calibration, the game training for that session began, with three game records per activity.

During the game, coins and meteors appeared in eight directions on the screen. Participants earned points by moving their bodies to collect coins and avoid meteors. After each session, scores were summarized and ranked to motivate participants. The recorded body angle data were stored in the backend cloud platform for post-game analysis.

During the VR interactive game training, participants were instructed to stand with their feet shoulder-width apart and move their upper bodies according to the music and game screen cues. They were encouraged to stretch and bend their arms along with their bodies' forward, backward, left, and right movements to increase upper body activity and effectively maintain body balance. Participants with weaker lower limbs could use the backrest of a chair for support to prevent accidents.

Figure 3 Research equipment laptop and touch tablet connected to projecto

Figure 4: Startup screen of virtual reality interactive game system

Figure 5 Virtual reality interactive game activity screen

Figure 6: Photos of the elderly participating in activities and using chair backs to prevent falls

Control Group Intervention

The control group maintained their regular aerobic exercise regimen, led by a fitness instructor, three times a week for 1 hour per session. The structure of each session was as follows:

Warm-up Exercises: 10-15 minutes

Main Exercise Activity: 30 minutes

Cool-down Exercises: 5-10 minutes, including a 10-minute break

Over the course of 36 sessions, the control group participated in a variety of exercises, including resistance band training for 12 sessions, chair yoga for 12 sessions, and aerobic exercise for 12 sessions. Apart from these structured exercise sessions, both groups did not engage in any other physical activities during the 36-week period.

Figure 7 Photos of elders in the control group participating in activities

Section 5 Evaluation Tools

This study aims to understand the impact of intervention on the functional fitness and quality of life of elderly participants befor and after the intervention. The assessment tools used include functional fitness tests and a quality of life questionnaire, along with the collection of basic participant information. Both groups underwent pre-tests befor the intervention, which included a fall risk assessment, functional fitness assessment, and quality of life satisfaction survey. After completing the 12-week, 36-session intervention, post-tests were conducted to measure the effectiveness of the intervention.

1. Basic Participant Information:

Includes gender, age, exercise habits, self-perceived health status questionnaire, and Body Mass Index (BMI).

2. Functional Fitness Tests:

(a) Chair Stand Test:

Measures lower body strength/endurance.

Participants sit in a chair without armrests and stand up as many times as possible within 30 seconds.

(b) Chair Sit and Reach Test:

Assesses lower body flexibility.

Participants sit on the edge of a chair with one knee bent at 90 degrees and try to reach their toes with their hands. The distance between the fingertips and toes is measured.

(c) 8-Foot Up-and-Go Test:

Evaluates agility and dynamic balance.

Participants sit in a chair, stand up upon hearing a signal, walk around a designated point 8 feet away, and return to the chair. The time taken to complete the task is recorded.

(d) 2-Minute Walk Test:

Measures aerobic endurance.

Participants walk in place for 2 minutes, and the number of times the knees are lifted to a specific height is counted.

3. Quality of Life Questionnaire:

Administered using the "Taiwanese version of the World Health Organization Quality of Life Questionnaire-Brief Form (WHOQOL-BREF Taiwanese version)."

Consists of 28 questions divided into four domains: physical health, psychological health, social relationships, and environment.

Each question is scored on a Likert scale ranging from 1 (very poor) to 5 (very good), with higher scores indicating better quality of life. Demonstrates good reliability with Cronbach's α and split-half reliability of 0.92 and 0.93, respectively.

Section 6 Data Processing and Statistical Analysis

After data collection, the collected data will be coded, documented, and analyzed using the Statistical Package for the Social Sciences (SPSS) 19.0 Chinese version software. Both descriptive and inferential statistics will be employed. A significance level of $p < .05$ will be used to determine statistical significance.

1. Descriptive Statistics:

Categorical variables of demographic data for both experimental and control groups will be presented as percentages, while continuous variables will be described using means and standard deviations.

2. Inferential Statistics:

(a) Independent t-test or Mann-Whitney U test:

Analyze the differences between the experimental and control groups in variables such as balance function, muscle strength, flexibility, cardiovascular capacity, and quality of life befor intervention. A Shapiro-Wilk test will be conducted to check for normal distribution. If the data is normally distributed, an independent t-test will be used; otherwise, the Mann-Whitney U test will be employed.

(b) Chi-Squared Test:

Analyze the homogeneity of basic demographic characteristics (age, gender, education level, marital status), exercise habits, duration of each exercise session, and experience of falling in the past year between the two groups.

(c) Dependent Samples t-test or Wilcoxon Signed Rank Test:

Analyze the differences in variables such as balance function, muscle strength, flexibility, cardiovascular capacity, and quality of life within each group 之前 and after the intervention. A Shapiro-Wilk test will be conducted to check for normal distribution. If the data is normally distributed, a dependent samples t-test will be used; otherwise, the Wilcoxon signed rank test will be employed.

(d) ANCOVA Analysis using Intention-to-Treat Analysis:

ANCOVA will be employed to compare the post-test scores between the experimental and control groups while controlling for pre-test scores. This analysis will utilize intention-to-treat principles.

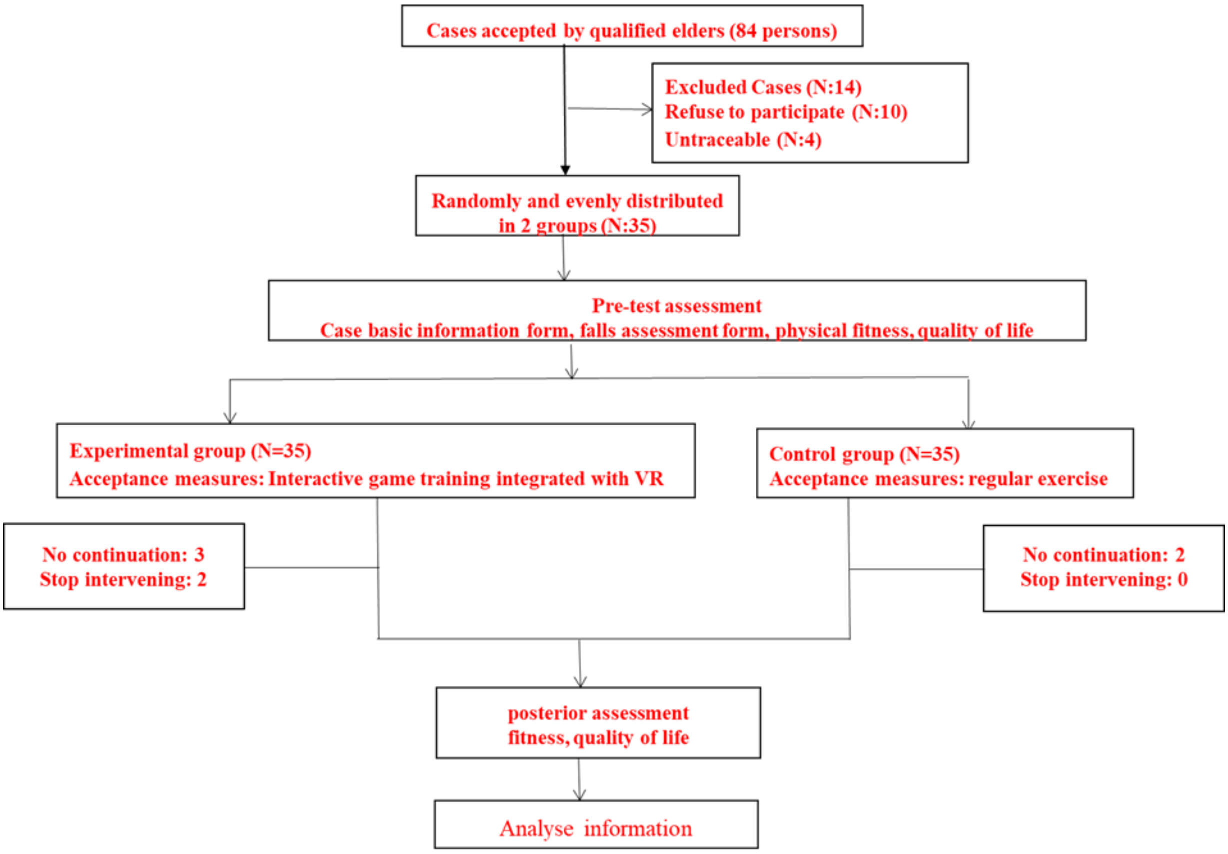

Figure 8. Flowchart of the application of virtual reality interactive games to the lower limb balance of community elders

Research Results

This study involved the intervention of the experimental group using virtual reality interactive games, while the control group underwent exercise interventions led by original instructors. Both groups participated in modal rate-intensity sessions three times a week for 12 weeks, totaling 36 sessions. Testing was conducted befor and three months after the completion of the program. A total of 84 participants were recruited from two community care activity centers in Taipei City, but 14 participants were excluded due to personal reasons or inability to consistently monitor data due to illness. Ultimately, data from 70 participants who completed at least 30 sessions were analyzed.

Regarding participant attrition, the experimental group initially recruited 35 participants. However, during the 12-week, 36-session program, five participants were absent for over one-third of the sessions (12 sessions) due to health issues or personal preferences, rendering their data unusable. The experimental group experienced a dropout rate of 14.28%. The control group initially recruited 35 participants, but only 33 completed the post-intervention assessment. Two participants were excluded from the analysis due to absence for over one-third of the sessions. The dropout rate for the control group was 8.57%. Both groups had dropout rates within the predetermined range of 15% set befor the study.

The study spanned 36 sessions from February 13th to May 31st, [insert year]. Data from participants who attended less than 12 sessions were excluded from statistical analysis. Thus, statistical analysis was conducted on data from 30 participants in the experimental group and 33 participants in the control group.

Section 1: Participant Demographics

This study recruited a total of 70 participants, with 35 participants in both the experimental and control groups. Among them, 63 participants completed the entire study, with 30 participants in the experimental group and 33 participants in the control group. The average age of the experimental group (30 participants) was 77.7 years, with the majority being female (96.7%) and married (90.0%). See Table 4-1 for details. Assessment of demographic data in both groups showed no significant differences. Independent samples t-tests or Mann-Whitney U tests and chi-squared tests were used to analyze demographic data, revealing no significant differences between the two groups' demographic characteristics, as shown in Table 2.

Table 2 Basic information table of elderly subjects of virtual reality interactive games

	Test group (N=30)	Control group (N=33)	*t* value (*p*) or *Z* value (*p*) or Chi-square value (*p*)*
Demographic variables			
age	77.7 ± 5.8	74.4 ± 8.3	1.78 (0.080)‡
Gender: emale)	29 (96.7%)	30 (90.9%)	0.88 (0.614)
marriage			2.00 (0.615)
unmarried	0 (0%)	2 (6.1%)	
Married	27 (90.0%)	27 (81.8%)	
Widowed	3 (10.0%)	4 (12.1%)	
BMI	27.0 ± 3.5	25.4 ± 3.8	1.77 (0.077)§
height	150.5 ± 5.2	152.5 ± 7.0	-1.29 (0.201)†
weight	61.0 ± 6.5	59.2 ± 9.8	0.86 (0.393)ʃ

‡Shapiro-Wilk test: *P*=0.055，Using independent sample t test

Based on descriptive statistics, it was confirmed that in the control group, the highest education level was junior high school graduation, with 13 individuals (43.3%), followed by 11 individuals (36.7%) who graduated from elementary school. All elderly participants had a habit of exercising, with 30 individuals (100%) regularly attending exercise classes at the activity centers. Seven individuals (23.3%) reported experiencing falls in the past year. Regarding exercise frequency, 6 individuals (20.0%) exercised fewer than three days per week, while 24 individuals (80.0%) exercised at least three days per week. Moreover, all participants exercised for at least 30 minutes each time. In the control group, the highest education level was high school or vocational school graduation, with 14 individuals (42.4%), followed by 10 individuals (30.3%) who graduated from junior high school. Thirty-two individuals (97.0%) had a habit of exercising, primarily by attending exercise classes at the activity centers. Eight individuals (24.2%) reported experiencing falls in the past year. Regarding exercise frequency, 11 individuals (33.3%) exercised fewer than three days per week, while 22 individuals (66.7%) exercised at least three days per week. The majority, 30 individuals (90.9%), exercised for at least 30 minutes each time. See Table 3 for details.

Table 3 Descriptive Statistics

	Test group (N=30)	Control group (N=33)	Chi-square value (*p*)
Education level			11.742 (0.014)
Not reading	0 (0%)	2 (6.1%)	
Elementary school	11 (36.7%)	4 (12.1%)	
Junior high school	13 (43.3%)	10 (30.3%)	
High school	6 (20.0%)	14 (42.4%)	
University	0 (0%)	3 (9.1%)	
Exercise habits			1.949 (0.321)
No habit	0 (0%)	1 (3.0%)	
Less than 3 times a week	6 (20.0%)	10 (30.3%)	
More than 3 times a week	24 (80.0%)	22 (66.7%)	
Each exercise time			6.326 (0.039)
less than 30 minutes	0 (0%)	3 (9.1%)	
more than 30 inutes	22 (73.3%)	15 (45.5%)	
30-60 minutes	8 (26.7%)	15 (45.5%)	
Falls experience in the past year			1.034 (0.669)
No falls	23 (76.7%)	25 (75.8%)	
≤3 次	6 (20.0%)	5 (15.2%)	
>3 次	1 (3.3%)	3 (9.1%)	

Section 2: Comparison of Functional Fitness

1. Analysis of Demographic Data

Before the intervention of virtual reality interactive gaming, the participants' functional fitness, including height, weight, lower limb muscle endurance, lower limb flexibility, and agility, were assessed descriptively.

In the pre-test assessment, there were no significant differences between the experimental group and the control group in terms of fitness and quality of life, as indicated by independent samples t-tests, as shown in Table 4.

2. Comparison of Pre-test and Post-test within the Experimental and Control Groups

The results of dependent samples t-tests (Table 5) showed statistically significant improvements in four assessment outcomes in the experimental group, including the 2-minute step test ($p < 0.001$), left and right chair sit and reach ($p < 0.001$, $p = 0.003$), and psychological quality of life ($p = 0.008$).

In the control group, there was a statistically significant improvement in one assessment outcome, the 30-second chair stand test ($p = 0.001$).

Table 4 Functional fitness pre-test of the experimental group and the control group

	Test group (N=30)	Control group (N=33)	*t* value (*p*) or Z value (*p*)
pretest assessment			
BMI	27.0 ± 3.5	25.4 ± 3.8	1.77 (0.077)§
30 seconds sit and stand	16.3±4.6	17.7±5.2	-1.19 (0.234)§
2 minutes to step	96.0±20.7	92.5±25.4	0.60 (0.548)‡
The seat body bends forward (right)	2.9±10.1	2.6±12.0	0.25 (0.799)§
The seat body bends forward (left)	1.2±11.2	1.4±13.4	-0.08 (0.935)‡
Get up and walk Around at 2.4 meters	8.5±3.2	8.4±3.6	0.70 (0.483)§
Physiological quality of life	10.8±1.4	11.4±1.5	-1.75 (0.086)‡
Psychological quality of life	11.1±1.8	11.7±1.8	-1.28 (0.200)§
Quality of social life	11.2±1.9	11.4±1.1	-0.652 (0.515)§
Environment quality of life	10.6±2.2	10.3±2.0	0.090 (0.928)§

‡ Using independent sample t test

§Using the Mann-Whitney U test

Table 5 Intra-group pre- and post-test comparison between the experimental group and the control group

	Test group (N=30)				Control group (N=33)			
	pretest	posttest	score difference (Pre-test-Post-test)	*t value* (*p*) 或 S value (*p*)	pretest	posttest	score difference (Pre-test-Post-test)	*t* value (*p*) or S value (*p*)
	Mean ± standard deviation				Mean ± standard deviation			
BMI	27.0 ± 3.5	26.9±3.6	0.1±1.0	16.5 (0.741)	25.4 ± 3.8	25.3±3.7	0.1±0.4	75 (0.071)
30 seconds sit and stand	16.3±4.6	17.1±4.4	-0.9±3.1	-56.5 (0.174)	17.7±5.2	18.5±4.9	-0.8±1.5	-83.5 (0.001)
The seat body bends forward (right)	96.0±20.7	121±25.7	-26.6±31.2	-4.67(<0.001)§	92.5±25.4	98±20.2	-3.8±15.0	-1.47(0.151)§
The seat body bends forward (left)	2.9±10.1	7.3±9.6	-4.4±7.4	-140 (<0.001)	2.6±12.0	2.9±12.3	-0.3±2.8	0 (1.000)
Get up and walk Around at 2.4 meters	1.2±11.2	5.9±9.6	-4.9±8.1	-3.29 (0.003)§	1.4±13.4	2.9±13.2	-0.2±1.5	-0.79(0.433)§
Physiological quality of life	8.5±3.2	8.3±2.4	0.2±2.9	33 (0.507)	8.4±3.6	8.2±3.4	0.1±0.7	39 (0.384)
Psychological quality of life	10.8±1.4	11.1±1.4	-0.1±0.4	-1.31 (0.202)§	11.4±1.5	11.3±1.4	0.0±0.1	1.00(0.325)§
Quality of social life	11.1±1.8	11.3±1.7	-0.2±0.3	-18 (0.008)	11.7±1.8	11.7±1.9	-0.0±0.1	-0.5 (1.000)
Environment quality of life	11.2±1.9	11.3±1.8	-0.1±0.4	-1.5 (0.500)	11.4±1.1	11.4±1.1	0.0±0.0	-*
The seat body bends forward (right)	10.6±2.2	10.6±2.2	-0.0±0.1	-1.5 (0.500)	10.3±2.0	10.3±2.0	0.0±0.0	-*

§The Wilcoxon sign test is used, and the rest uses the dependent sample t test.

3. Comparison of Post-test between Experimental and Control Groups

Due to significant differences in demographic data and pre-test assessments between the experimental and control groups, particularly in the education level variable, and considering age as an important control variable, analysis of covariance (ANCOVA) was conducted to compare the post-test scores between the experimental and control groups. Age, education level, and pre-test scores were controlled for in the analysis. Intention-to-treat analysis was used.

The results of ANCOVA analysis (Table 6) revealed that the post-test scores of the experimental group were significantly higher than those of the control group in five assessment outcomes, including the 2-minute step test ($p < 0.001$), right chair sit and reach ($p = 0.010$), left chair sit and reach ($p = 0.002$), psychological quality of life ($p = 0.033$), and environmental quality of life ($p = 0.048$). Additionally, the differences in fitness (except for the 30-second chair stand test) and quality of life had effect sizes (partial eta squared) ranging from 0.011 to 0.267, indicating moderate to substantial intervention effects. These results suggest that the intervention in this study was more effective in improving the aforementioned fitness and quality of life compared to regular community activities.

Table 6 Post-test comparison between the experimental group and the control group

	StatisticsF /(*p*)	**effect size (partial eta squared)**
BMI	0.195 (0.661)	0.003
30 seconds sit and stand	0.015 (0.904)	**0.000**
The seat body bends forward (right)	21.154 (<0.001)	0.267
The seat body bends forward (left)	7.091 (0.010)	0.109
Get up and walk Around at 2.4 meters	10.294 (0.002)	0.151
Physiological quality of life	0.667 (0.418)	**0.011**
Psychological quality of life	0.956 (0.332)	**0.016**
Quality of social life	4.766 (0.033)	0.076
Environment quality of life	1.405 (0.241)	**0.024**
The seat body bends forward (right)	4.080 (0.048)	0.066

Note:This analysis uses ANCOVA to control the pretest scores and other significant influencing factors in the pretest. The control variables include: age, education level, and pretest scores of each variable.

Section 3: Analysis and Comparison of Quality of Life Questionnaire

Upon statistical analysis of pre-test and post-test scores (Table 7), it was found that in the experimental group, there was a difference of 0.4 points in the physical domain (p = 0.202), no difference in the psychological domain (p = 0.008), a difference of 0.2 points in the social relationships domain (p = 0.500), and no difference in the environmental domain (p = 0.500). In contrast, in the control group, there was a difference of 0.4 points in the physical domain (p = 0.325), no difference in the psychological domain (p = 1.000), and no difference in the social relationships and environmental domains. The results indicate a significant change in the quality of life in the physical domain for the experimental group.

Table 7 Analysis and comparison of pre- and post-test on the quality of life within the group after the experiment

	Test group (N=30)				Control group (N=33)			
	pretest	posttest	score difference (Pre-test-Post-test)	*t* value (*p*)	pretest	posttest	score difference (Pre-test-Post-test)	*t* value (*p*)
	Mean ± standard deviation				Mean ± standard deviation			
Physiological quality of life	10.8±1.4	11.1±1.4	-0.1±0.4	-1.31 (0.202)	11.4±1.5	11.3±1.4	0.0±0.0	1.00 (0.325)
Psychological quality of life	11.1±1.8	11.3±1.7	-0.2±0.3	-18 (**0.008**)	11.7±1.8	11.7±1.9	0.0±0.0	-0.5 (1.000)
Quality of social life	11.2±1.9	11.3±1.8	-0.1±0.4	-1.5 (0.500)	11.4±1.1	11.4±1.1	0.0±0.0	-*
Environment quality of life	10.6±2.2	10.±2.2	0.0±0.1	-1.5 (0.500)	10.3±2.0	10.3±2.0	0.0±0.0	-*

*Since all subjects have the same score, the t test cannot be performed.

Chapter 5: Discussion

Section 1: Exploration of the Application of Virtual Reality Interactive Games in Community Care Centers

Virtual reality interactive games have become increasingly popular across all age groups, with more and more seniors incorporating interactive gaming into their daily lives or leisure activities. Apart from entertainment, these games also address the health care needs of seniors, representing the latest trend in digital game development. Through digital technology environments, games are designed to immerse seniors in experiences that allow them to fully engage and resonate. Numerous studies have demonstrated that virtual reality game training can improve balance ability. Currently, Kinect, Wii, and VR interactive sensory games are widely used for strength, balance, and muscle training, all of which have shown significant effects. For instance, researchers such as Nicholson et al. (2015) conducted studies on community elders using unsupervised Wii balance games three times a week for 30 minutes each, and researchers like Chen, Zhang, Wang, and Lu (2019) have trained special populations such as individuals with cerebral palsy, chronic stroke patients, and depression patients using sensory games, all with consistent results showing improvements or maintenance of balance. In 2016, HTC Corporation and Valve Corporation demonstrated through immersive virtual reality game training that users could experience a virtual world as if they were actually there. By making the games enjoyable, participation and motivation are increased, achieving effects that are not easily achieved through traditional exercise, thereby fostering a habit of regular exercise. Increase itionally, by forming alliances with others through interactive virtual reality games, not only is the fun increased, but also the sense of accomplishment upon completing game objectives, thereby enhancing quality of life and achieving the goal of healthy aging.

This study initially targeted websites and platforms specifically designed for or targeted at older adults to find digital games recommended on these platforms. Subsequently, games suitable for older adults recommended on non-elderly websites were also collected. Finally, a virtual reality interactive game suitable for use by older adults aged 65 and above in community centers was innovatively created by integrating popular games currently available in the market. The study designed a virtual airplane game, allowing for interactive and group gameplay, enabling four older adults to simultaneously participate in competitive activities. After 36 sessions, significant changes were observed in the experimental group in the 2-minute step test ($p<0.001$), left and right chair stands ($p<0.001$, $p=0.003$), and psychological well-being ($p=0.008$). During the exercise, older adults experienced feelings of happiness, excitement, nervousness, and anticipation. However, if the game ended with unsatisfactory scores or due to delays caused by network connectivity issues, feelings of confusion, dissatisfaction, complaints, and low mood emerged. Each gaming session prompted older adults to remember their scores and engage in discussions with others. Through continuous self-challenges in the game, participants not only increased their willingness to engage in exercise but also enhanced their confidence and positive feelings by achieving game objectives. The game content was based on the recommendations of the American College of Sports Medicine for older adults engaging in regular physical activity, including strength training, balance exercises, flexibility exercises, and aerobic or endurance activities. In the game, older adults were required to stand with their feet stationary while moving their upper body in response to music and game elements such as coins and asteroids on the screen. They also had to raise their hands and perform stretching, bending, twisting, bending forward, arching backward, and leaning side to side to hit coins and asteroids. This not only increased the frequency and opportunities for upper body movement but also trained flexibility and balance. Considering the economic benefits and sustainability of exercise execution, the integration of the virtual airplane game created in this study with exercise programs provides a necessary measure for older adults in community centers to engage in regular health-promoting exercise and prevent or mitigate disability. Additionally, the system required participants to perform maximum body movements in all directions before each intervention session. The purpose was to record the maximum range of individual body movements and use them in training to achieve personalized and precise exercise interventions, thereby maximizing the benefits of improving physical fitness.

Section 2 The impact of virtual reality interactive game intervention on the physical fitness of the elderly

Although there is existing literature on interactive games for elderly training, most studies focus on residents of institutions such as day care centers, nursing homes, and rehabilitation centers (Hsieh, 2014; Chung, 2020; Du, 2021). Nowadays, community centers typically offer exercise programs led by sports professionals or instructors for elderly participants, including activities like Ba Duan Jin, chair yoga, step aerobics, fitness, resistance band exercises, and rehabilitation exercises (Chen et al., 2019; Jiang et al., 2020). However, these activities often involve older adults lining up facing the instructor and following instructions, which may not foster a positive and engaging group atmosphere.

This study primarily utilized virtual reality interactive games for training. It employed a three-axis inertial sensor to monitor body angle changes during exercise. Older adults wore a waist protector embedded with sensors, which connected via Bluetooth to control a virtual aircraft in the game. Participants moved their bodies forward, backward, left, and right to collide with asteroids and coins in different directions, challenging their balance with varying levels of difficulty such as standing with feet parallel, slightly squatting with feet parallel, and standing with feet apart. 增加 itionally, participants were required to raise their hands and perform stretching and bending movements in sync with body movements in the game. This not only increased upper body movement opportunities but also effectively maintained body balance, reducing the risk of falls during the game. Researchers like Fang et al. (2016) found that using virtual reality Wii Fit games for training for more than 6 weeks can improve dynamic balance ability in older adults.

In this study, a custom-designed virtual airplane game allowed elderly participants in community center activities to effectively train balance and improve flexibility during exercise. By following game instructions for forward and backward movements, participants could earn scores and complete tasks successfully. After 36 sessions, significant improvements were observed in elderly participants who engaged in virtual reality interactive games, particularly in the 2-minute step test ($p<0.001$) and left and right chair stands ($p<0.001$, $p=0.003$). ANCOVA analysis revealed differences in physical fitness (except for the 30-second chair stand) and quality of life, with effect sizes (partial eta squared) ranging from 0.011 to 0.267, indicating moderate to substantial intervention effects. These findings demonstrate that the virtual reality intervention in this study outperformed conventional center-based activities in enhancing physical fitness and quality of life.

Section 3: The impact of virtual reality interactive game intervention on the quality of life of the elderly

After 12 weeks and 36 sessions of intervention using the virtual reality interactive game designed in this study, elderly participants were able to increase their willingness to engage in physical activity and social interaction through participation in the game, thereby expanding their interpersonal relationships and interactions with the community environment. The research results also revealed that the experimental group had significantly higher post-test scores in psychological well-being ($p=0.033$) and environmental well-being ($p=0.048$) compared to the control group. This aligns with literature suggesting that the quality of life of older adults is influenced by their health status, activities, and functional status. Active social participation and positive interactions with others can contribute to a satisfying and happy old age (Chen et al., 2018; Chou, 2020).Although virtual reality interactive games currently available on the market can target specific balance training for users, they are limited to single-player or multiplayer models. In contrast, the game software developed in this study allowed up to four elderly individuals to exercise simultaneously, forming a small group activity. At the end of each game, the results were provided, motivating participants to engage in the game through competition and evaluation among themselves. This not only satisfied their sense of honor but also encouraged them to continue participating in the game activities. From the 6th week onwards, the stability of elderly participants' engagement in the activities was generally established. They tended to form groups with friends to play the game and would inquire about and remind each other of the next activity time. Peer encouragement and invitations played a crucial role in sustaining their participation. Increase itionally, participants became more interested in the activity as they interacted with peers, forming friendships and forming small groups. Even those who were initially reluctant to participate or found the activity uninteresting eventually became regular participants due to peer invitations and increased interest. This program not only provided balance training for community-dwelling elderly but also created a pleasant and positive atmosphere through the design of virtual reality interactive games, promoting high engagement and focus on the activities. This is consistent with scholars' suggestions that community centers can increase participants' engagement and relaxation through the design of group activities, leading to changes in mood and stress relief during center activities (Chuang et al., 2021).

Figure 9: Presentation and ranking of scores after the elders participated in the activity

Section 4: Study limitations and Future Recommendations

Virtual reality interactive game training can utilize changes in position control and audiovisual stimulation to enhance activity performance, allowing the elderly to focus their attention on experiencing the game during training and strive to achieve game objectives. In this process, virtual reality interactive games provide a rich, stimulating, and challenging environment that helps maintain dynamic and static balance and agility. Most elderly participants in the study found this to be an enjoyable activity.

This study involved collaboration between a gaming company, a company providing hardware sensors, and participants in community activity programs to innovate a team-based game software suitable for the elderly. During the process, several limitations were identified:

Sensor and Game Identification Pairing:The pairing of sensors and game identities via Bluetooth was random, leading to complaints from the elderly about the inability to select their preferred colors for their aircraft.

Setup Process:Prior to activities, setting up the game required connecting a tablet to a laptop and projecting it onto a wall approximately 1 meter away. The colors of the four aircraft in the game were too similar, making it difficult for participants to identify their own color during rapid body movements.

Technical Issues:Connectivity issues and delays between the game system and sensors were common. Testers had to ensure that the module vibrated during pairing, leading to delays and frustrations among the elderly participants, especially when community activity schedules were tight.

To address these issues, a user-friendly model with enhanced motivation and ease of operation should be developed for the elderly. Developing a community-based digital learning support system is a worthwhile future direction. Although age-related decline in physical function is inevitable, weekly VR interactive game exercise training can improve strength, flexibility, and balance in the elderly, enhancing their activity capacity and quality of life.Furthermore, integrating virtual reality interactive games into regular community activity programs led by professionals can foster enthusiasm and motivation among the elderly through peer companionship and encouragement. The innovative and visually engaging feedback exercise in the virtual reality interactive game designed in this study offers a novel direction and mindset for exercise training tailored to community-dwelling seniors.

Chapter 6 Conclusion

The 36-week course activities of virtual reality interactive games can significantly improve the physical fitness, psychological and environmental quality of life of the elderly in the community.

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Appendix1-TMU-JIRB

TMU-JIRB Form071/20200317

Taipei Medical University

Certificate of TMU-JIRB Approval

Issue Date: 2022/11/23

TMU-JIRB No.: N202210004
Protocol Title: A community achievement-based game exploring the effect of interactive VR on the balance and quality of life of the elderly
Principal Investigator: Chueh-Ho Lin
CO- Investigator: Yu Ching Tseng
Study Site:Taipei Medical University,Nangang Community Center,Liuzhangli church stronghold
Protocol Version/Date:Version 1.0/20220816
Informed Consent Forms:Version 6/20221026
Case Report Forms:Version 1 / 2022/08/16

The above study has been approved by Full-board review process of the TMU-Joint Institutional Review Board in meeting #111-11-3(date:2022/11/22), duration of validity is from 2022/11/23 to 2023/11/22, and must be monitored by TMU-JIRB.

According to Ministry of Health and Welfare and the relevant regulations, follow-up procedures and requirements are as below:

1. Continuing Report: Frequency of the report of this trial/study is every 12 month, and should be submitted to TMU-JIRB for review 2 months prior to expiry date (2023-09-22) or the trial/study must be pending.
2. Final Report: The report should be submitted to TMU-JIRB for review once completed TMU-JIRB may withdraw the approval of the trial/study if the report didn't submitted within 3 months from the date of validity and will suspend PI from new application for 3 months per TMU-JIRB SOPs.
3. SAE: Serious Adverse Event(s) (SAE) Report: SAE report(s) should be submitted to related authorities according to "Regulations for Good Clinical Practice" as well as "Procedures for Reporting Serious Adverse Drug Reaction" by MOHW.

Chairman:

臺北醫學大學暨附屬醫院
聯合人體研究倫理委員會
Taipei Medical University
Joint Institutional Review Board

本會組織與執行皆符合適用法規
The TMU-Joint Institutional Review Board performs its functions according to written operating procedures and complies with GCP and with the applicable regulatory requirements.

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Appendix 2 Subject Consent Form

TMU-Joint Institutional Review Board

Subject Consent Form

Project Title: Investigating the Effects of VR Interactive Games on Balance and Quality of Life Improvement among Community Elderly
Executing Unit: Master Program in Long-Term Care, Taipei Medical University **TEL：** **Sponsoring Unit/Pharmaceutical Company: None** **Principal Investigator: Dr. Juei-He Lin Title: Associate Professor and Director** **Contact Number: (02) 2736-1661 ext. 6325"** **Co-Principal Investigator: Yu-Ching Tseng Title: Student** **Contact Number: 0920702379 24-Hour Emergency Contact: N/A** **Mobile: N/A**
Participant Name: **Gender:** **Age:** **Medical Record Number:** **Mailing Address:** **Phone Number:**
Emergency Contact Name/Relationship to Participant: **Mailing Address:** **Phone Number**
1.Trial/Research Background and Status of Trial/Research Drug/Medical Device/Product: The primary goal of "healthy aging" is to maintain and enhance the physical function of the elderly population, enabling them to lead happy, fulfilling, and satisfying lives. The decline in physical function and increased sedentary behavior among older

adults are closely related, making it crucial to address how to maintain elderly physical function, prevent or delay disability, reduce healthcare and social costs, and enhance quality of life. Regular exercise is the best strategy to improve the sensory motor system and balance to prevent falls, and existing community-based exercise programs often lack sufficient interaction for participants and can become monotonous, reducing the willingness of older adults to participate. By developing interactive games, participants in community-based activities can use game feedback during exercise training to clearly understand their physical condition, correct incorrect exercise postures, increase motivation and willingness to participate in exercise, accomplish tasks during gameplay, boost confidence, and ultimately enhance quality of life by redefining the value and meaning of life

2. Trial/Research Purpose

It is verified that interactive game sports integrated with VR can help improve the balance function and quality of life of the elderly.

3.Inclusion and Exclusion Criteria:

Inclusion Criteria:

Elderly individuals aged 65 and above who actively participate in community-based activities.

Exclusion Criteria: Participants who have neurological or musculoskeletal disorders, undergone joint surgery within the past 3 months, have gait or balance disorders, have limb functional impairments (such as acute arthritis flare-ups or stroke), or experience dizziness that prevents them from participating in this study.

4.Trial/Research Procedure and Relevant Coordinated Examinations:

Participants aged 65 and above who consent to participate in the study will undergo a baseline assessment lasting approximately 30 minutes, including recording of basic demographic information and pre-tests such as functional fitness and quality of life assessments. The experimental group will receive a total of 12 weeks of exercise intervention, three times a week, with each session lasting approximately 60 minutes, including warm-up exercises (10-15 minutes), main exercises (30 minutes), and cool-down exercises (5-10 minutes, with a 10-minute break in between). The control group will maintain their existing exercise regimen of three sessions per week. The study will be conducted over three months, with follow-up assessments conducted in the first and twelfth weeks, measuring functional fitness and quality of life scores for both groups. After 12 weeks of intervention, the research findings will be analyzed, and feedback will be provided by the researchers.

The experimental group will utilize virtual reality (VR) technology, employing motion sensors and screen feedback to analyze body movements and calculate kinematic values for clinical functional assessments. 3D scenes and interactive characters will be designed to guide participants through exercises, with difficulty levels ranging from low to high, including tasks such as standing with forward lean, walking in a straight line, walking in a figure-eight pattern, and single-leg standing for balance training. Training progress will be individually tailored based on participants' performance. Participants will advance to the next game level when they achieve a score of 80/100 or higher in the current level.

5.Potential Side Effects, Risks, and Handling Methods:

This study poses minimal risk to participants, and research personnel will be present throughout the experiment to ensure participant safety. If any discomfort arises, the experiment will be immediately halted. The primary intervention of this study involves combining balance exercises with VR gaming, thus minimizing risks. Additionally, to ensure the safety of participants during VR interactive game training, research personnel will accompany participants throughout the experiment to prevent accidents. The activity venue will be free of exposed wires and dry floors to minimize potential hazards. In the event of an accident, necessary medical measures will be provided, and Dr. Jian-Hong Lai, the physician associated with this project, will be contacted to ensure appropriate care.

6.Expected Outcomes of the Trial/Research and Potential Commercial Benefits:
The development of interactive games aims to provide elderly participants in community-based activities with engaging exercise training. The future expansion of this program to community centers nationwide may yield commercial benefits through the sale or licensing of the developed VR interactive gaming platform.

7.Other Possible Treatment Options and Explanation:

None

8. Taboos or Restricted Activities During the Trial/Research in Progress:

There are no taboos or activity restrictions during the course of the study.

9. Confidentiality and Handling of Data and Samples After the Trial/Research:

Taipei Medical University will treat your data as confidential to the extent regulated by law. 您 also understand that the project sponsor (if any), the Ministry of Health and Welfare, and the Joint Institutional Review Board of Taipei Medical University and its affiliated hospitals have the right to review your data, and will adhere to ethical confidentiality standards.

For the examination results obtained during the study, researchers will use a research number instead of your name to collect data. Apart from the authorized institutions mentioned above, we will carefully safeguard your privacy. Even if the trial/research results are published, your identity will remain confidential.

☐Regarding the preservation and handling of samples/data during and after the trial/research, after the conclusion of the study, relevant data related to your participation in the research will be stored in the Research Office of the Master

Program in Long-Term Care at Taipei Medical University, and will be kept for 2 years by the principal investigator of this study. Upon expiration of the storage period, we will proceed to destroy your research-related data based on your preference.

☐Understood, you disagree with other institutions or individuals handling your data. In this case, the data will be responsibly destroyed by the principal investigator of the project. Thank you for letting us know.

10. Participant Withdrawal and Termination of the Trial/Research, and Handling of Personal Samples and Data:

You are free to decide whether to participate in this trial/research, and you may withdraw your consent and discontinue your participation at any time during the trial/research, without any need for explanation. Your decision to withdraw will not result in any discomfort or affect your rights to participate in future activities. Additionally, you understand that the principal investigator or sponsoring company may also suspend/terminate the trial/research if necessary, but your participation in community-based activities will not be affected. If you choose to withdraw from the trial/research, all measurement data and information provided by you will be destroyed upon notification of your withdrawal by the trial/research personnel.

11. Compensation for Damage and Insurance of the Trial/Research:

If the use of exercise modules or related matters according to the trial/research protocol results in adverse reactions, side effects, or injuries, Eligo Health Technology assumes full responsibility for compensation for damages. If any adverse reactions, side effects, or injuries occur as a result of the trial/research protocol established in this study, please immediately notify the principal investigator.

Signing this consent form does not waive any of your legal rights.

(1) This project ☐ is ■ not insured. If you are unwilling to accept such risks, you may decide not to participate in this project or withdraw midway without any reason, and this will not affect any of your rights.

12.Participant Rights and Obligations:

(1) All expenses related to the clinical trial/research will be covered by this project.

(2) This trial/research

☐ Provides ☐ Transportation Expenses (Please specify the amount for each instance, and if different payments are made for different participation contents, please specify separately)

☐ Nutrition Expenses (Please specify the amount for each instance, and if different payments are made for different participation contents, please specify separately)

☐ Gifts (Please specify the type, quantity, or value)

Provided according to your participation progress/ratio, and no return is required upon withdrawal.

■ No subsidies or gifts will be provided. Your assistance is voluntary.

(3) During the trial/research process, any significant findings related to your health or illness that may affect your willingness to continue participating in the clinical trial/research will be promptly provided to you.

(4) To conduct research work, you must participate in activities at the community center. If you have any questions or concerns now or during the research period, please feel free to contact the staff at the community center.

(5) If you have any doubts about the nature of the research work, have opinions about the rights of participants, or suspect that you have been harmed by participating in the trial/research, please contact the Joint Institutional Review Board of Taipei Medical University and its affiliated hospitals at any time, at telephone: (02)66382736 ext. 1728 or Email: tmujirb@gmail.com.

(1) (6) In addition to the above situations, if you or your legal representative, guardian, assistant, or person with consent authority have any questions or concerns about the current, future, or past research and wish to discuss and resolve them, please feel free to contact the Joint Institutional Review Board of Taipei Medical University and its affiliated hospitals. We will provide a personnel unrelated to the research to provide information. If necessary, please contact the Joint Institutional Review Board of Taipei Medical University and its affiliated hospitals (telephone: (02)66382736 ext. 1728 or Email: tmujirb@gmail.com).

13. Researcher Declaration:

I certify that either myself or a member of my research team (authorized representative conducting this procedure) has thoroughly explained the purpose, procedures, potential risks, and benefits of participating in this trial/research, as well as currently available alternative treatments. 全部 questions raised by the participants have been addressed accordingly.

Researcher explaining the informed consent form

Printed : ______________________

Signature: ______________________

Date: ______________________

Participant Declaration:

The above information has been explained to me, and I have had the opportunity to ask questions regarding this project. I understand and agree to participate in this research project, and a copy of the consent form has been provided to me. If I have any questions in the future, I may contact [Full Title of the Institution] at [contact details].

Participant Name (Printed): ___________________________

Date of Birth: ____Year____Month____Day

Signature: _________________________

Date: _________________________

Legal Guardian/Custodian/Assistant (if applicable) Name (Printed):

____

Relationship with the Participant: _________________________

Signature: _________________________

DATE _________________________

If you are not the participant or their legal guardian but are required by circumstances to sign this consent form on behalf of the participant or their legal guardian (temporarily unable to sign), please print your name in block letters and indicate your relationship with the participant:

(Printed): ______________________

Relationship with the Participant: ______________________ (For individuals with consent authority, please refer to the regulations applicable to the trial/research)

National Identification Number: ______________________

Contact Phone Number: ______________________

Mailing 增加 ress: ____

Signature: ______________________

Date: ______________________

Witness to Oral Consent:

(If the participant is unable to read the above content and it has been verbally explained by the research personnel, another witness must be present.)

I hereby certify that the principal investigator and research personnel have provided a complete explanation of the contents of this trial/research to the participant.

Witness 名稱 (Printed): ______________________ (Research-related personnel are not eligible as witnesses)

National Identification Number: ______________________

Contact Phone Number: ______________________

Mailing 增加 ress: ____

Signature: ______________________

Date: ______________________

◎ When the participant, legal guardian, custodian, assistant, or person with consent authority is unable to read, the witness should be present to participate in all discussions regarding the participant's consent. The witness must ensure that the consent of the participant, legal guardian, custodian, assistant, or person with consent authority is given freely and voluntarily. After obtaining consent, the participant should sign the consent form and indicate the date. No trial/research-related personnel are permitted to act as witnesses.

Host Signature:

Project Host / Co-Principal Investigator Name (Printed): ______________________

Signature: ______________________

Date: ______________________