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ORIGINAL ARTICLE

Virtual reality game-based training for preventing falls among community-dwelling older adults with mild cognitive impairment: a pilot randomized control trial study

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Abstract

Using a Virtual Reality (VR) game-based application represents an innovative approach to falls prevention in community aged care service. The study investigated the effects of VR training on falls prevention among community-dwelling older adults with mild cognitive impairment. A pilot randomized controlled trial was conducted to compare the effects of full-immersive VR training with group-based exercise (Baduanjin) training on falls prevention. Eighteen participants were recruited through convenience sampling and were randomly assigned to either the VR group or the non-VR exercise group. Both groups participated in 16 falls prevention training sessions over eight weeks. Participants, identified with mild cognitive impairment (MCI), underwent three fall risk measurements. They had been screened using Montreal Cognitive Assessment (HK-MoCA). The primary outcomes assessed included changes in physical risk factors of falls (i.e. functional mobility, walk speed and postural balance), and the secondary outcomes assessed included changes in executive function and fall efficacy. The measurement of physical outcomes was Time Up and Go test (TUG), Berg balance scale (BBS) and Six-minute Walk Test (6MWT). The participants' executive function and fear of falling were assessed through the Trail marking test (TMTA and TMTB) and the Fall Efficacy International scale (FES-I). The results showed that the VR group had significantly greater improvement than the non-VR group on measures of cognitive-motor performance, such as global cognition, functional mobility, balance and walk speed over time. However, no significant differences were observed between the two groups in executive functions and the fall efficacy. The study provides potential evidence that VR game-based cognitive-motor training can be effective for fall prevention in community dwelling older adults with MCI. However, the findings do not support significant improvements in secondary outcomes. Despite this, the growing trend of VR research suggests increasing interest and potential for future applications in aged care and rehabilitation services.

Keywords Full-immersive virtual reality (VR) · Cognitive-motor training · Community-dwelling older adults · Mild cognitive impairment (MCI) · Dementia · Falls prevention

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1 Introduction

In Hong Kong, approximately 26.4% of community-dwelling older adults experience falls annually (Leung 2019; Qian et al. 2020). A study involving 89,100 older adults from 2005 to 2014 revealed that approximately 32% had experienced a fall in the past 90 days (Qian et al. 2020). The nexus between dementia, mild cognitive impairment, and aging contributes to a significant increase in fall incidents. Existing literature indicates that there is not yet a consensus on a set of defining criteria for mild cognitive impairment and the definition of MCI is still controversial (Peterson et al., 2009). This study adopts the following as the primary defining criteria of MCI: subjective memory complaints, objective evidence of memory impairment for age, preserved cognitive functions, intact functional activities and absence of dementia (Graham et al. 1997). Cognitive functions and gait patterns, closely intertwined, serve as indicators of fall risk in older adults (Verghese et al. 2008). Navigating the real environment necessitates attention to safety, spatiotemporal orientation, cognitive judgment, and postural stability to prevent slips and trips. Executive function involves inhibitory control, sustained attention, cognitive flexibility, and working memory (Yogev-Seligmann 2008). These elements are crucial for ensuring normal and safe walking (Mirelman, 2016).

Existing literature underscores a robust relationship between executive function and falls, with executive dysfunction doubling the risk of future falls and increasing the likelihood of fall-related injuries by 40% in community-dwelling older adults (Muir, 2012). Older adults with MCI exhibit a higher prevalence of gait impairments and an increased risk of falling compared to their healthy counterparts (Verghese, 2008).

The pilot study adopts and modifies the framework developed by Montero-Odasso et al. (2020). Their initial framework, published in 2012, posited a bidirectional relationship, suggesting that low cognitive function predicts mobility decline, leading to falls with fractures. Conversely, mobility decline, characterized by a slow gait, predicts cognitive deterioration in older adults, accelerating the progression from cognitive impairment to dementia (Montero-Odasso, 2012). Given the close interrelation between cognition and gait, this research introduces novel perspectives with potential therapeutic implications. By altering cognitive function, fall incidents such as fractures and injuries (illustrated in Fig. 1 by the red and red dashed arrows) could be mitigated. The conceptual framework posits cognition as a fall risk factor in the management of falls among older adults with mild cognitive impairment and dementia (Liu-Ambrose, 2013).

As cognitive impairment can predict functional instability, there is potential evidence to support the use of VR technology-based interventions in falls prevention. The study compared groups enrolled in an innovatively designed VR Cave Automatic Virtual Environment (CAVE) training program to those participating in traditional exercise training to enhance cognitive-motor interaction. The anticipated outcome was a potential reduction in falls and fractures among individuals with MCI (Fig. 1). Theoretically, VR intervention should improve both cognitive and motor functions simultaneously, slowing down cognitive decline and the clinical onset from MCI to dementia (Thapa et al. 2020). It was expected that the VR CAVE intervention would aid falls prevention and promote positive cognitive health outcomes. While there is some evidence supporting the efficacy of cognitive-motor interventions, such as VR interventions, in reducing the risk of falls in older adults with mild cognitive impairment and dementia, empirical research in falls prevention interventions for MCI remains scarce. Existing studies in the MCI and dementia population face challenges such as low response rates, cognitive decline, and small sample sizes. This intervention addresses a knowledge gap by presenting an alternative falls prevention program in aged care.

Traditionally, exercise-based interventions have been a well-established and effective strategy for preventing falls

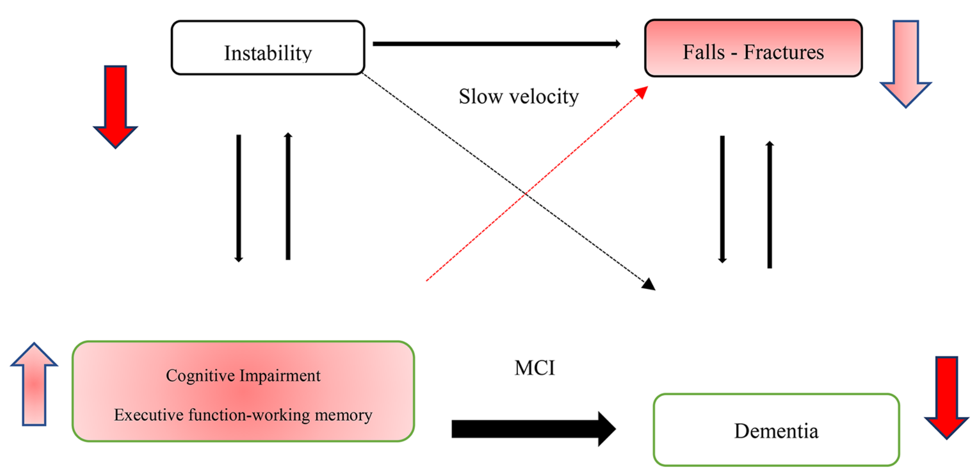

Fig. 1 Modified framework adapted from Montero-Odasso et al. (2020). Note: Alternating the performances on stability and cognition will reduce the rate of fracture and slow down the process of cognitive decline

among older adults in the community (Gillespie, 2009; Monter-Odasso, 2022). However, for older adults with cognitive impairment, relying solely on single-task (motor) interventions may prove inadequate and inconsistent, because executive dysfunction characterized by factors like low attention, exercise motivation, and cognitive learning capacity, tends to be underestimated in exercise-based training (Mirelam et al., 2020). In response to these limitations, an innovative full-immersive VR intervention is proposed as an alternative falls prevention strategy. This approach aims to stimulate participant's attention and slow down cognitive decline through a new VR simulation. It is anticipated that VR game-based intervention serve as an effective alternative, reducing fall risk factors by improving cognitive function, postural balance, and fall efficacy among older adults with MCI (Ge et al. 2018).

Due to the 2020–2022 Covid-19 outbreak, human-guided fall prevention programs were restricted or reduced in community healthcare services (Gao, 2020). This not only had adverse effects on older adults' physical activity and cognitive functioning, but also induced loneliness and social isolation. The emerging field of VR game-based training can be an alternative solution, providing a simulated virtual environment for older adults in the post-pandemic era. The use of VR interventions is becoming more affordable and attractive and may be a reasonable alternative to professionally led exercise programs for falls prevention. It exhibits promising potential as a user-friendly and interactive approach to falls prevention through the adoption of new VR CAVE technology. Therefore, the objective of this study is to pilot a VR game-based training program for falls prevention to reduce the risk of fall factors in older adults receiving community care service in Hong Kong.

2 Methods

2.1 Trial design

This pilot study was a randomized control trial study using convenience sampling to recruit participants. The trial was registered with ClinicalTrials.gov (*identifier number NCT05971420*). It was a comparison group design with 3-interval measurements from pre-test (T1), post-test (T2) and follow up (T3). Due to the 2020–2022 Covid-19 restrictions, the recruitment method for community-dwelling older adults from Hong Kong faced challenges and limitations. Participation of older adults in public services including community aged care services was limited and restricted; potential participants and other collaborative parties were more hesitant to participate in the research study. The study was required to have additional safety procedures and to fulfil infection control health policies to meet the requirements of the human ethics application from research institutions.

With permission and approval from all stakeholders, all training sessions, measurements, and clinical observations were taken either in the VR research centre at the Hong Kong Polytechnic University or at two District Elderly Community Centres (DECCs) in Hong Kong.

2.2 Participants

Fifty-five participants were screened in the study. They were invited for screening sessions of fall risks assessments co-organized by the research team and operators of aged care facilities. All participants received a formal invitation from respective centre staff or through a centre promotion leaflet for a pilot falls prevention research program held between June 2021 and September 2021. The participants gave informal consent to enrol in the study indicating interest to participate into the pilot study. They were worried about falling and had experienced falls because of general health decline in ageing. The research team provided clear explanations of the research purpose for the participants prior to the screening assessments. Eighteen participants were volunteers who met the selection criteria and randomly assigned into either the VR group or the non-VR exercise group. (Fig. 2).

2.3 Inclusion criteria

The participants met all the criteria of MCI. The inclusion criteria were (1) aged 65 to 85 years inclusive; (2) had a history of a fall within the past 2 years; (3) community-dwelling older adults; (4) identified MCI by a validated screening tool i.e. the Hong Kong Montreal Cognitive assessment test (HK-MoCA score ≤ 22); (5) able to commute independently to the VR research centre or the local community aged care facilities. These criteria were pre-set and chosen for a pilot randomized control trial RCT design.

2.4 Exclusion criteria

Participants were excluded if they had a medical diagnosis of unstable health conditions such as dizziness, Meniere's disease, epilepsy, Parkinson's disease, severe hearing impairment and visual impairments, or mental health challenges. These exclusions were for participants' safety to meet the requirements of the university ethics approval committee and agreement from all stakeholders.

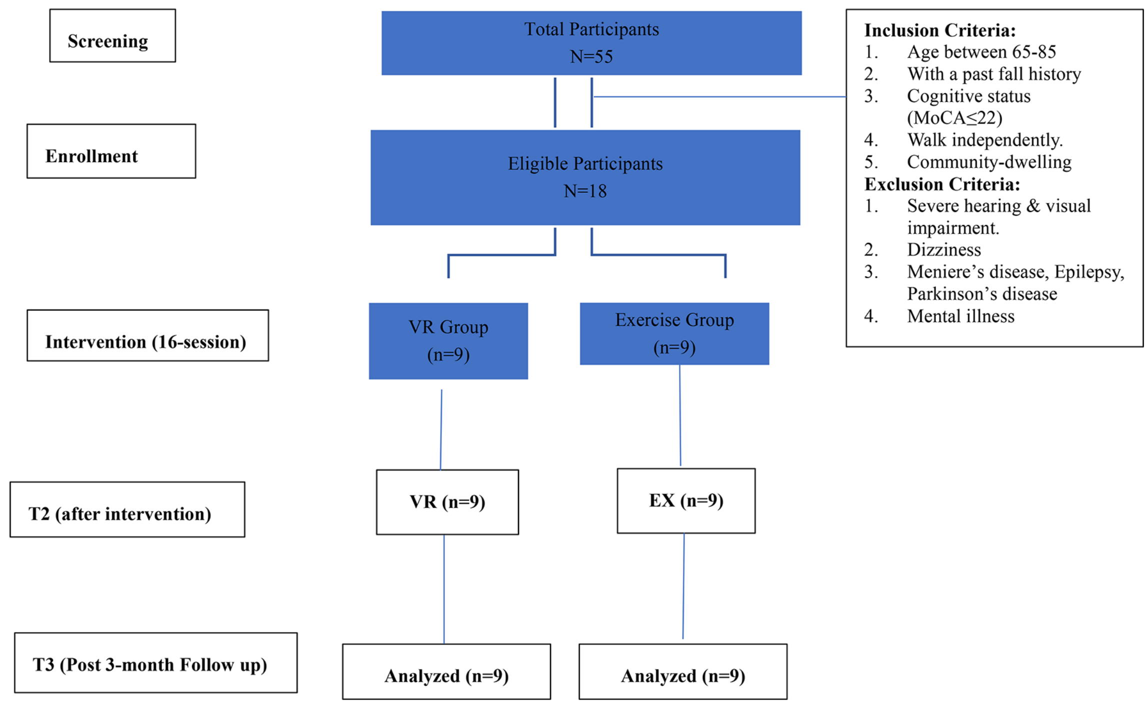

Fig. 2 Flow chart of the pilot randomized control trial study

2.5 Intervention

The comparison groups involved VR activity-based and exercise-based (Baduanjin) falls prevention groups. The program, **VirCube VR for Rehab program**, was locally designed in Hong Kong and managed by the Department of Rehabilitation Sciences of The Hong Kong Polytechnic University. All research coordination and communications and operational management were fully supported by the research team of the Department of Rehabilitation Sciences.

Originally, the **VirCube VR for Rehab program** was funded for research purposes under the Department of Rehabilitation Sciences of the Hong Kong Polytechnic University. It was a VR & AR (Augmented Reality) platform that allowed participants to fully immerse and interact with VR in a simulated Cave Automated Virtual Environment (CAVE) platform. The training program could apply to many service targets such as children with learning difficulties and older adults. To match the aims of the pilot study, VR games activities were chosen for simulated cognitive-motor training in the VR group. The VR training modules for this study included a fire drill, a walking exercise, balancing game activities and community shopping practices. These training modules involved dual task components; the participant was expected to train up his/her physical and cognitive motor performances in an 8-week VR activity-based program. VR group participants received 2-sessions per week, 16 training sessions in total. Each session consisted of three to four training modules. Each module took 10 min to complete with a short break before the next module. Each training session therefore lasted approximately 45 min. All VR training sessions were structured and supervised by the research team. The set up and application of the **VirCube** VR for Rehab program was modified and designed for VR group training (additional file 1 & 2).

The non-VR exercise group participants received 16-session group exercise training in eight weeks held in DECCs. The exercise group used a traditional Chinese Qigong Baduanjin exercise incorporating a fall prevention education strategy. Based on evidence in reviewed literature, the Baduanjin exercise had success in improving the balance function of older adults and positive effects on reducing their fall risks (Zhang 2022; Xia, 2021; Cheng, 2023). The participants learned and practised Qigong exercises for 20 min per session to train up the balance function, breathing exercises and body coordination. In addition, they learned some practical tips for preventing falls and understanding of falls scenarios to improve problem-solving skills and provide cognitive stimulation training. Each session lasted for about 45 min and the exercise group was led by a trained research staff member. After completing the group training exercise, the participants took the post-test and follow-up measurements at their respective centres. All repeated measurements were administered by a principal investigator and two research occupational therapists.

2.6 Procedure

The **VirCube VR** for Rehab program and VR CAVE equipment were set up in the VR research centre at the Hong Kong Polytechnic University. The research team would arrange a pickup service, particularly for the first VR session which provided a demonstration and trial run service including how to wear VR 3D eyewear and motion trackers. Before the first VR session, participants were given a simple demonstration, VR trial and a briefing on safety precautions to make sure the participants could undergo the VR Cave program without motion sickness or physical complaint.

For each session, group participants were kept under close supervision and supported by the trained researchers. They were allowed to take a rest or stop at any time if necessary or before the next training. The VR research centre and community aged care centres were considered a safe environment and comfortable for all participants. After each training session, the trained researchers asked the participants' feedback on experiencing full immersive VR game activities or practicing Qigong group exercise training. Photos A to F display the training activities of the exercise group (additional file 3).

2.7 Data collection methods

All participants were assessed, and provided information including demographic and health information, at the screening assessment at community aged care centres. The basic information included age, gender, living status, education level, falls history and number of chronic illnesses, cognitive status, and other health outcomes (e.g. body mass index, chronic pain, and other health conditions). The primary outcome measurements focused on physical risk factors of falls (WHO, 2008). The secondary outcome measurements focused on level of cognitive functions and fear concerns (Scheffer, 2008; Yardley, 2005).

2.8 Physical measures

The primary outcomes measured the physical risk factors and determinants of falls risk level by assessing postural balance, walking speed and functional mobility at 3-time intervals (pretest T1, post-test T2 and post 3-month follow up T3). We included three validated assessment tools, Berg Balance Scale (BBS), 6-minute walk test (6MWT) and Time Up and Go test (TUG), to predict the fall risk, and measured changes in each group (Bandara et al. 2020).

The BBS assessed the balance level of participants. It consisted of 14 predetermined tasks; each scale ranged from 0 (unable) to 4 (independent). The higher the score, the better the balance. Originally, this scale was designed for older adults aged 65 or above. The cut off score below 45 indicated individuals with a greater risk of falling. A score below 51 with a history of falls indicated a predictive risk of fall (Muir et al. 2008).

Another fall risk assessment was made using the TUG test. The participants were asked to get up from a chair, walk 3 m, turn around, walk back to the chair, and sit down, and the time taken was recorded (Bischoff et al. 2003). Older adults aged between 65 and 85 living in the community were expected to be able to perform the TUG test within 12 s, which indicated a reduced risk of fall. Shorter walking time for participants indicated lesser fall risk. Additionally, the 6MWT measured the participants' exercise capacity, a longer walking distance being associated with better cognitive function (Makizako et al. 2013; Ahmadi et al. 2024). The cutoff for increased a fall risk was 6MWT < 300 m, for example (Aida et al. 2022).

2.9 Cognitive measures

Cognitive function was measured using HK-MoCA. This sensitive assessment tool covered four domains including attention, executive functions/language, orientation, and memory. The total score ranged from 0 to 30, with a higher score indicating better cognitive function. This screening tool has demonstrated validity in detecting older adults with mild cognitive impairment (Wong et al. 2018; Yeung et al. 2020). For a cutoff point, a score of 22 or below indicated a mild cognitive impairment (Wong et al. 2009). In addition, the executive function, including working memory, cognitive flexibility and processing skills for the participants were measured by Trail Making Tests (TMT-A and TMT-B) to measure the cognitive performance in two intervention groups (Tom, 2004; Lei and Erin 2000). TMT is a well-established cognitive task, TMT-A being used to measure the processing speed, and TMT-B used to measure cognitive flexibility or switching ability.

2.10 Fall efficacy

Fear of falling was measured by the Fall Efficacy International Scale (FES-I). It was a 16-item questionnaire where participants were instructed to score their concern of falling during an activity on a 4-point Likert scale with 1 as 'not concerned at all' and 4 as 'very concerned'. The item scores were summed up to obtain a total, with the higher the score, the higher the fear of falling. The cutoff score of community-dwelling older adults was divided into three levels: a score 16–19 indicating low concern of falling; 20–27 indicating moderate concern; and 28–64 indicating high concern (Yardley et al. 2005). The study used the validated FES-I tool to compare the level of fall concerns between groups.

2.11 Statistical analysis

The primary outcomes measured the changes of physical risk factors (i.e. postural balance, walk speed and functional mobility), and secondary outcomes measured the changes in executive function and fall efficacy at assessments time points. The statistical outcomes were analysed using SPSS version 27 and a p significance value set < 0.05. Eligible participants' information was summarized using descriptive statistics (Table 1.). The baseline demographic characteristics of participants included age, gender, educational level, living and cognitive status, history of falls and other health history such as chronic pain, osteoporosis, and fracture.

To compare the health outcomes between two groups from pre-test, post-test and follow up, the repeated measures analysis of variance (ANOVA) was used for data analysis. The time factor was used as the independent variable, the dependent variables including cognitive, fall efficacy and physical risk factors.

Table 1 Demographic characteristics of the participants ($n=18$)

Characteristic	VR Group ($n=9$)	Exercise Group ($n=9$)	*P value
Age (years), M (SD)	73.67(6.144)	80.00(4.359)	0.023*
Sex, n (%)			0.150
Male	0	2(22.2%)	
Female	9(100%)	7(77.8%)	
Education Level (years), n (%)			0.461
Primary or below	5(55.6%)	7(77.8%)	
Secondary or above	4(44.4%)	2(22.2%)	
Living Status, n (%)			0.372
Live alone	3(33.3%)	5(55.6%)	
With family/carer	6(66.7%)	4(44.4%)	
History of Fall, n (%)			0.661
< 12 months	8(88.9%)	5(55.6%)	
> 12 months	1(11.1%)	4(44.4%)	
Number of Chronic Illness			0.097
0	1(11.1%)	0	
1–2	3(33.3%)	5(55.6%)	
3 or above	5(55.6%)	4(44.4%)	
Body Mass Index (BMI)			0.141
Normal	5(55.6%)	6(66.7%)	
Overweight	4(44.4%)	3(33.3%)	
History of Chronic Pain, n (%)			0.661
Yes	4(44.4%)	5(55.6%)	
No	5(55.6%)	4(44.4%)	
History of Fracture, n (%)			0.128
Yes	4(44.4%)	1(11.1%)	
No	5(55.6%)	8(88.9%)	
History of Osteoporosis, n (%)			0.555
Yes	1(88.9%)	2(22.2%)	
No.	8(11.1%)	7(77.8%)	
History of OA knee, n (%)			0.165
Yes	5(55.6%)	2(22.2%)	
No	4(44.4%)	7(77.8%)	

Pearson's chi-square (two-sided) was used for categorical data. *$p < .05$.

3 Results

3.1 Characteristics of the participants

Eighteen participants were randomly assigned into groups and were given an informed consent to enrol in the study (Fig. 2). All participants successfully completed all measurements, with a mean age of 76.84. 88.9% of the participants were female; 33.3% of the participants had an education level of secondary or above; and 44.4% of the participants were living alone. They were identified with mild cognitive impairment (mean score HK-MoCA = 18.28 below cutoff score 22), and most with the history of a fall in the last 12 months (72.2%). In the participants' group 50% reported chronic pain and an average 3 or more chronic illnesses, and 27.7% had a history of fracture due to a fall.

As shown in Table 1, there were no significant differences between the two groups in the demographic information except older age in the exercise (EX) group. All participants were female in the VR group, and only 2 participants were male in the EX- group. The VR group had a comparatively higher education level with secondary level, but a higher incidence rate for a history of falls (< 12 months), fracture and OA knee than the EX-group. Both groups showed a higher incidence of being overweight (VR = 44.4%, EX = 33.3%) and chronic pain (VR = 44.4%, EX = 56.6%) than baseline measurements.

3.2 Baseline data

As shown in Table 2, there were no significant differences ($p > .05$) between the two groups in all outcome measurements before intervention. The HK-MoCA mean score = 18.28 for cognitive status in the participants' groups indicated a major risk of cognitive decline such as mild cognitive impairment and dementia. The cut-off score of HK-MoCA standardized tool was 22, indicating a higher risk of cognitive impairment, recommended for further medical investigation (Sarah et al., 2005; Yeung et al. 2020). For the physical risk measurements, the functional mobility (TUG, mean score = 12.47) and the balance level (BBS, mean score = 50.39) indicated that the participants in two groups had a moderate and predictive risk of fall. For a fear of falling, the fall efficacy score (FES-I, mean score = 40.39) indicated a high concern of falling when FES-I > 28. Regarding the results of executive function (TMTA/B) and walk speed

Table 2 Baseline outcome measures of participants ($n = 18$)

Outcomes, M[a] + SD[b] Variables	All ($N = 18$)	VR Gp ($n = 9$)	Exercise Gp ($n = 9$)	P value
Cognition: HK-MoCA[c]	18.28(3.611)	19.89(1.616)	16.67(4.387)	0.055
Executive Function				
Trail Making Test A (TMT-A)	82.096(42.461)	79.194(50.291)	84.998(35.820)	0.782
Trail Making Test B (TMT-B)	159.371(94.716)	147.362(102.920)	171.380(90.258)	0.606
Time Up and Go Test (TUG)	12.472(2.420)	12.165(2.825)	12.780(2.062)	0.605
Berg Balance Scale (BBS)	50.39(4.217)	50.89(4.755)	49.89(3.822)	0.630
6-minute walk test (6MWT)	306.766(49.247)	301.833(57.231)	311.700(42.703)	0.684
Fall Efficacy Scale International (FES-I)	40.39(11.030)	43.67(5.635)	37.11(14.234)	0.217

M[a]: Mean. SD[b]: Standard Deviation. P value < 0.05

HK-MoCA[c]: Hong Kong- Montreal Cognitive Assessment

Table 3 Comparison of outcome measures between and within groups (VR $n = 9$, EX $n = 9$)

Outcome measures	Group	T1 Pre-test	M + SD Post-test T2	T3 Follow up	Multivariate	Univariate Within group	$*P < .05$ Between group
Cognition (HK-MoCA)					0.010*	0.335	0.002**
	VR	19.88(1.616)	23.78(3.930)	23.89(4.457)			
	EX	16.67(4.387)	18.44(4.216)	18.33(4.717)			
Executive Function							
TMT-A	VR	79.19(50.291)	62.23(22.670)	48.80(19.714)	0.110	0.103	0.227
	EX	84.99(35.820)	95.32(48.893)	89.37(44.374)			
TMT-B	VR	147.36(102.920)	112.12(74.661)	99.05(32.0263)	0.131	0.310	0.585
	EX	171.38(90.258)	160.75(106.897)	191.34(92.879)			
Balance Level BBS					0.130	0.027*	0.010*
	VR	50.89(4.755)	52.22(4.577)	53.00(3.240)			
	EX	49.89(3.822)	47.44(3.245)	51.00(3.000)			
Walk Speed 6MWT					0.352	0.128	0.061
	VR	301.83(57.231)	347.89(71.416)	357.26(60.773)			
	EX	311.70(42.703)	322.05(44.923)	312.82(47.396)			
Functional Mobility TUG							
	VR	12.16(2.825)	9.48(2.729)	9.14(1.839)	0.074	0.131	0.002**
	EX	12.78(2.062)	12.60(3.215)	11.16(2.587)			
Fear of Fall (FES-I)							
	VR	43.67(5.635)	41.89(11.230)	34.11(12.534)	0.339	0.728	0.063
	EX	37.11(14.234)	39.78(10.883)	32.56(10.406)			

Outcome measure: A better outcome is represented by an increase in HK-MoCA, BBS and 6MWT; decrease in TMT-A &TMT-B, TUG, and fall efficacy.

M = mean. SD = Standard Deviation.

**P* value: significant at < 0.05 level of significance.

***P* < .005.

(6MWT) measurements used for baseline comparison, there were no specific standardized cutoff scores, and interpretation was needed for community dwelling older adults with MCI.

3.3 Primary outcomes

Table 3 shows that results for the HK-MoCA, TUG and BBS tests are all significant regarding improvement after VR intervention. The overall outcomes of the study are illustrated in the table of multivariate and univariate of dependent variables between groups and time effects (Table 3). The primary outcomes including functional mobility ($p = .002$), and balance ($p = .01$) both indicated greater improvement effects in VR group. For the physical outcome measures, the balance mean score (BBS, at post-test = 52.22 and follow up = 53.00) indicated less predictive risk of falls (BBS score > 51) in the VR group. In addition, the mean score of functional mobility of the VR group at post-test (9.48s) and follow up (9.14s) below 12s indicated a lessor risk of falls compared with the EX-group (TUG = 12.60s). Although there was no significant difference on walk speed (6MWT, $p = .061$) between the two groups and times interactions, the mean score of VR group showed improvement across three time points. Therefore, the results of physical outcomes showed better improvement and lesser predicted fall risk in the VR intervention group.

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3.4 Secondary outcomes

There was significant difference in cognition (HK-MoCA, $p = .010$) between the two groups and times interactions (Table 3.). The mean scores (HK-MoCA) of the VR group at post-test (23.78) and follow up (23.89) were above the cut-off point > 22, indicating a greater improvement on cognition than the EX-group. However, The executive functions results showed no significant difference between two groups, although the VR group showed greater improvement than the EX group at post three month follow up. For instance, the VR group (TMT-A, mean difference=−30.39s; TMT-B mean difference=−48.31s) showed faster performances than the EX-group (TMT-A, mean difference = +4.38s; TMT-B mean difference = +19.96). Lastly, there was no significant difference in fall efficacy level (FES-I, $p = .339$) between groups and times interactions. Table 3 shows the mean score of fall efficacy between groups and indicated no significant decrease in fear of falling (FES-I > 28) after intervention and follow up. The results indicated that the VR group had better improvement on cognition, but no evidence supported the changes of executive functions and fall efficacy in the two groups.

4 Discussion

4.1 Overview

The pilot study showed promising effects on falls prevention using a VR game-based application (VR CAVE program) for the participants from Hong Kong. Both groups reported no fall incident after intervention (T2) and at follow up (T3) period. The results supported that the full-immersive VR intervention had better training outcomes than non-VR exercise training. Consistent with existing literature (Kim et al. 2019; Kwan et al. 2021), the VR CAVE pilot program proved a useful potential falls prevention training program for Chinese older adults with MCI in Hong Kong.

4.2 Full immersive VR CAVE training on falls prevention

To the best of our knowledge, this was a pioneer research project using a VR CAVE program on falls prevention for older adults with mild cognitive impairment from Hong Kong. The **VirCube** in the Rehab program was primarily designed for VR simultaneous cognitive-motor games and recreational purposes, and open for different client service targets. The study piloted use of the VirCube program, using adapted VR games and training activities, for falls prevention for older adults in Hong Kong. Our results were consistent with recent reviews, in that it supported the promising evidence on VR CAVE intervention in falls prevention, and showed greater effects on cognitive motor outcomes than the exercise-based training program (Law et al. 2014; Stanmore et al., 2019). Accordingly, the VR CAVE technology intervention was innovative and useful for an older population, demonstrating immense potential development in a post pandemic era.

With similar findings to existing literature, the study piloted a falls prevention training program using a flexible VR training schedule as 2 to 3 sessions per week, each VR session within 45 min, 16 training sessions in total (Law et al. 2014; Yang et al. 2020). Due to the unexpected circumstances during the pandemic in Hong Kong, the study allowed participants the flexibility to complete the 16 sessions over a period longer than 8 weeks. The VR participants reported that a wearable 3D stereoscopic was handy and much more comfortable than a head-mounted headset, and the new headset eliminated VR simulator sickness during VR CAVE training. Throughout the intervention period, the feedback of VR participants was incredibly positive and encouraging. They enjoyed the VR activities engagement; the attendance rate was 100%. They reported the VR training provided a stimulating experience and was helpful for improving their physical and balance functions. A similar future study should be considered to investigate the user experience and perceptions toward the use of VR intervention in aged care services.

4.3 Training effects of VR training and exercises-based Training on falls prevention

Our findings supported that VR training was more effective at simulating dual-mode cognitive-motor training than traditional exercise intervention. According to a recent review, people with MCI showed higher risk of falls and poorer stability than healthy adults (Welmer et al. 2017). When compared with traditional exercise group training, the simulated VR CAVE experiences were particularly interesting and stimulating due to the VR game-based engagement. Though the practice of the Baduanjin exercise was healthy and a good balance exercise, it demanded less cognitive challenge for participants with memory impairment to practise and maintain good postural stability. The 8-step Baduanjin exercise was a traditional heathy exercise program, however the movements were repetitive and structured. In contrast, the VR participants showed good attention, engagement, interaction with and good acceptance of VR use. According to results shown in Table 3, the VR participants found greater training effects and significant improvement on the physical performances after the use of VR intervention.

However, the findings did not show any change in executive function and fall efficacy after VR and exercise groups intervention. A recent review indicated that the fall efficacy scale international (FES-I) might not be sufficiently sensitive and not reliable for community-dwelling older adults with cognitive frailty (Uemura et al. 2012). It is likely that the 14-item self-reported questionnaire was too demanding for the participants to understand the level of rating and make an accurate judgment in daily living tasks. For the participants' groups with cognitive decline, the aim of executive functions training was maintaining or slowly improving. The results indicated the executive function (TMTA and TMTB) showed improvement over time within VR group. Further study could support the evidence of the cognitive training on VR intervention.

4.4 Limitations

Compared with similar VR research in a recent review (Chau et al. 2021; Zahabi and Abdul, 2020), the recruitment of the human study had limitations particularly due to COVID-19 restrictions. Firstly, the response rate of study recruitment was very low. Only two community aged care services operators responded and agreed to collaborate with the pilot study from June 2021, as such the sample size of the study was small. Secondly, the convenience sampling method for this pilot randomized control study (RCT) might lead to a volunteer bias and low generalizability of the findings in local population. Thirdly, the RCT study lacked a control group receiving no intervention, which would enhance its reliability. By including such a control group, the study could more accurately assess the impact of various parameters and there is a high risk of the study being underpowered.

Fourthly, the study was a first pilot research project to evaluate the effects between CAVE VR and traditional Chinese Baduanjin exercise training on falls prevention for community-dwelling older adults from Hong Kong. Baduanjin exercise was conducted as part of a group activity-based training, which included discussions on fall prevention. However, VR training was delivered individually, making the two training methods different. The one-on-one VR training might offer certain advantages. In addition, the results lacked sufficient evidence to generalize to other fully immersive VR applications, such as commercial VR apps and devices like Oculus (Meta) Quest and Sony PlayStation VR. Additionally, the new CAVE VR system technology proved costly, requiring inevitable technological support compared to other VR applications. The allocation of labor resources to support and operate the CAVE VR system also posed challenges. In general, the validity and reliability of results might be affected during the pandemic, as the participants were required to wear face masks and follow a social distancing policy. Therefore, the actual performance of participants might be underestimated.

Moreover, the changes of cognitive and executive function tests as repeated measured by MoCA and TMTA/B results could be affected by repeated learning effects (Sarah et al. 2015). Lastly, there was a significant age difference in the study, the VR group was younger than EX-group. Predictably, the VR participants had higher motivation and be physically active to engage with the VR training; the age factor could be considerable as a challenge and contributing to a potential bias effect.

5 Conclusion

Our study confirmed the potential evidence on the effects of Virtual Reality game-based training on preventing falls among community-dwelling older adults with MCI. However, the study did not support the evidence to reduce the fear of falling and executive functions for the participants between two groups. To the best of our knowledge, the study was a first pilot research project to pioneer the VirCube VR for Rehab program in falls prevention and to compare the effects with traditional exercise (Baduanjin) in Chinese older adults in Hong Kong. Prior to adoption of full immersive VR intervention and expanding the use of existing VR applications in aged care and rehabilitation services, adequate technological support for the particular considerations of the VR CAVE application and adaptation for an ageing population would be required. The positive findings indicate the potential benefits of a future replica study, but employing a larger randomized control trial design, to improve the generalisation and provide greater evidence for falls prevention programs adopting a full immersive VR application in community aged care services.

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Data availability The data used to support this study's findings are available from the corresponding author upon request.

Declarations

Competing interests The authors declare no competing interests.

Ethical approval This study was approved by the Human Subjects Ethics Review Committee of The Hong Kong Polytechnic University (reference number HSEARS20210317007) and The University of Southern Queensland (application number USQ AEC H21REA071).

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