University of Southern Queensland

EVALUATION OF VIRTUAL REALITY TECHNOLOGY FOR REDUCING THE RISK OF FALLS AMONG OLDER ADULTS WITH MILD COGNITIVE IMPAIRMENT AND DEMENTIA

A Thesis submitted by

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ABSTRACT

Innovative Virtual Reality (VR) technology shows the proven effectiveness of VR intervention in aged care and rehabilitation services. However, there is yet little evidence to support the usability and acceptance of using new VR technology application in community aged care service. This doctoral study reports on research that aims to address that gap by evaluating the usefulness and acceptance of using an innovative VR Cave Automatic Virtual Environment (CAVE) application among Chinese older adults living with mild cognitive impairment and dementia from Hong Kong during the COVID-19 pandemic. The research is structured around three primary objectives: a pilot randomized control trial comparing full-immersive VR CAVE training with group-based exercise, a single-arm exploratory study gauging participant perceptions of the VR CAVE program, and an outcome study evaluating the adoption of VR CAVE technology for falls prevention. Due to challenges posed by the pandemic, a quasi-experimental quantitative approach was employed.

Regarding the primary outcome of the study, the falls incident in the intervention group (n=2) reported a lesser rate of fall than the control group (n=5) after the study. The hospital admission of participants (n=3) reported in the control group only. There were significant differences in cognition (HK-MoCA, p=.008), executive function (TMT-A, p=.38, TMT-B, p=.006), balance level (BBS, p=.032), and walk speed (6MWT, p=.001) between the two groups across time. However, there had inconsistent results found in executive functions and the fall efficacy between groups. Therefore, the study results indicated that the VR group has been greatly reduced the falls incident and showed improvement in cognitive motor health performances. Participants expressed a high level of acceptance toward VR technology for fall prevention, highlighting the potential of full-immersive VR training as an innovative and meaningful strategy for preventing falls in older adults with mild cognitive impairment. The significant implication of the doctoral study reaffirms that investment in full immersive VR technology application is evidently supported and promising for adoption in aged care and rehabilitation services.

CERTIFICATION OF THESIS

I Wing Keung Ip declare that the PhD Thesis entitled *Evaluation of Virtual Reality Technology for Reducing the Risk of Falls among Older Adults with Mild Cognitive Impairment and Dementia* is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This Thesis is the work of Wing Keung Ip except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the student. The work is original and has not previously been submitted for any other award, except where acknowledged.

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STATEMENT OF CONTRIBUTION

I would like to acknowledge the collaborative effort involved in the research papers associated with this doctoral thesis. While all papers have joint authors, I declare that I made the majority contribution to the research conduct and authorship. I extend my gratitude to all co-authors for their valuable collective input. This doctoral research has produced three research articles submitted in *Q*1 journals. The Articles 1, 2, and 3 are core parts of this thesis and the Article 2 has been accepted for publication.

Article 1 - Chapter 3

Ip, W.K., Soar, J., James, C., Wang, Z. & Fong, N.K, K. (2023), Virtual Reality Activity-based Training for Preventing Falls among Community-dwelling Older Adults with Mild Cognitive Impairment: A Pilot Randomized Control Trial Study. *Submitted to Virtual Reality* ***(Scopus Ranked Q1, Impact Factor:4.697 and SNIP:2.748)***

The overall contributions for this paper are Wing Keung Ip 75%, Jeffrey Soar 10%, Christina James 5%, Zoe Wang 5%, and Kenneth Fong 5%.

Article 2 - Chapter 4

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Article 3 - Chapter 5

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ABBREVIATIONS

AGS/BGS	AMERICAN GERIATRICS/BRISTISH GERIATRICS SOCIETY
BBS	BERG BALANCE SCALE
BMI	BODY MASS INDEX
CAVE	CAVE AUTOMATIC VIRTUAL ENVIRONMENT
COVID-19	CORONAVIRUS DISEASE 2019
CPGS	CLINICAL PRACTICE GUIDELINES
DECC	DISTRICT ELDERLY COMMUNIT CENTRE
EX	EXERCISE
FESI	FALLS EFFIACY SCALE – INTERNATIONAL
FOF	FEAR OF FALLING
HK-MOCA	HONG KONG MONTREAL COGNITIVE ASSSESSMEN
HKSAR	HONG KONG SPECIAL ADMINSTRATIVE REGION
IU	INTENTION TO USE
MCI	MILD COGNITIVE IMPAIRMENT
NGO	NON-GOVERNMENTAL OGRANIZATION
OT	OCCUPATIONAL THERAPY
PE	PERCEIVED ENJOYMENT
PEOU	PERCEIVED EASE OF USE
PU	PERCEIVED USEFULNESS
RCT	RANDOMIZED CONTROL TRIAL
RR	RELATIVE RISK
RO	RESEARCH OBJECTIVE
SN	SOCIAL NORM
TAM	TECHNOLOGY ACCEPTANCE MODEL
TMTA/B	TRAIL MAKING TEEST T/B
TUG	TIME UP AND GO TEST
UE	USER EXPERIENCE
VR	VIRTUAL REALITY
WHO	WORLD HEALTH ORGANIZATION
6MWT	SIX MINUTES WALK TEST

CHAPTER 1: INTRODUCTION

1.1. Background

Managing falls in older persons with cognitive impairment is an international health challenge that continues to attract research interest (Montero-Odasso & Camicioli, 2020). About 30% of persons aged over 65 fall at least once per year, while among those with mild cognitive impairment (MCI) and dementia, about 60-80% of individuals report falls each year (Logan et al., 2010). In Hong Kong, there is an annual reported occurrence of 20-26.4% of community-dwelling older-adults falling (Leung, 2019; Qian et al., 2020). According to Qian et al. (2020) study, amongst 89,100 older adults, about 32% of older adults had a reported fall in the past 90 days. In older fallers, 34% reported repeated falls. Importantly, fall history has been found to be one of the strongest predicators of future falls (Lam, Leung, & Kwok, 2019), a strong indicator of risk of a fall is having previously had a fall. The risks of falls and cognitive impairment are closely related and the incidence of each increases with age. The risks of falls are associated with increasing problems: declining mobility, injuries, depression, fear of falling, institutionalization, and death (Rubenstein & Josephson, 2006). Older fallers with cognitive impairment are five times more likely to be institutionalized than older fallers without cognitive impairment (Myers et al., 1991). Fall-associated problems in ageing place huge burdens on government budgets, impacting the healthcare system and increasing its expenditure (WHO, 2007).

There were reported to be 50 million dementia cases worldwide in 2017, and it is predicted that there will be 65.7 million dementia cases in 2030 and twice that number, 132 million, by 2050 (WHO, 2017). The population with dementia in Hong Kong was estimated to be about 100,000 in 2017 (Hong Kong Mental Health Review Report 2017). By 2040 the projection is that there will be more than 200,000 older adults living with dementia in Hong Kong. Dementia and mild cognitive impairment are interrelated and associated with ageing; together they are causing a rapid increase in the number of falls (Montero-Odasso et al., 2012). The potential exists for falls reduction or prevention through Virtual Reality Technology (VRT) for older adults living with dementia and mild cognitive impairment (MCI); however, there is a little evidence yet to support the research gap in this area (Mirelman, 2016).

Virtual Reality Technology (VRT) intervention is an innovative approach in health-related applications and is growing rapidly in aged care at pandemic (Gao, Lee, & McDonough, 2020). There is few evidence to support its use in fall prevention, as well as reduction in the fall risks among people living with dementia (Shema, 2017; Mazhar et al., 2018). As relevant research evidence is limited, there is a knowledge gap regarding the relationship between VRT and fall risk for people with cognitive impairments.

1.2 Research Questions

The doctoral project seeks to examine this gap by addressing the research questions:

1. What are the differences of intervention effects between a VR CAVE program and an exercise-based program on preventing falls in older adults with mild cognitive impairment and dementia? – *A pilot randomized trial study*
2. What are older adults' perceptions and acceptance toward using VRT in fall prevention? – *A usability and acceptance exploratory study*
3. What are the intervention effects of VR technology (VRT) application on reducing the risk of falls in older adults with mild cognitive impairment? – *An experimental study*

1.3 Research Aims and Objectives

This study adopts a positivist framework which guides the researcher to investigate the potential for the innovative intervention of VRT application to change the fall risk factors in the experimental research. The research aims to evaluate the relationship between the VRT intervention and the risk factors of falling such as cognitive functions, functional balance and mobility, and fear of falling on fall prevention. The following research objectives (ROs) have been developed:

RO1: To pilot a randomized control study on exploring and comparing the intervention effects between VRT application and control group (exercise-based program).

RO2: To understand older adults' perceptions and acceptance toward adopting the VRT application in community aged care service.

RO3: To evaluate the outcomes of VRT (VirCube VR for Rehab Program) on reducing the risk of falls in older adults with mild cognitive impairment.

1.4 Overview of Research Methodology

1.4.1 *Introduction*

This chapter provides an overview of three district areas and the methodology studied in this thesis in evaluating the innovative VRT intervention for falls prevention among older adults with mild cognitive impairment from Hong Kong. Proposed intervention model and new training strategies are of paramount importance to the community support service in Hong Kong and globally where shape a future investment on adoption of health technology focusing on Virtual Reality Technology application. The chosen districts regions are good representation of falls data in a local population from Hong Kong, and the importance is described in each of the chapters. The availability, description of data used, duration and limitations are also discussed. The research findings have been presented in respective chapters, this chapter presents a brief account of the methodology and its challenges countered in the data and methodology.

1.4. 1 *Study Areas*

The recruitment of human research faced numerous difficulties and challenges during the COVID-19 pandemic. The government of the Hong Kong Special Administrative Region (HKSAR) implemented strict COVID-19 infection control precautions, including social distancing measures and public health policies. These measures resulted in restricted face-to-face interactions, suspended community support services, and limited access for visitors or non-service members to non-governmental organization (NGO) facilities and government-funded universities. These policies posed significant obstacles and limitations for subject recruitment and study design in the preparation of this doctoral research.

There are forty-one District Elderly Community Centers (DECC) distributed across eighteen local districts in Hong Kong (HKSAR, 2023). These centers are operated and administered by different non-governmental organizations (NGOs), providing support services funded by the Social Welfare Department of HKSAR. By definition '*District Elderly Community Centre (DECC) is a type of community support services at district level to enable elderly persons to remain in the community and to lead a healthy, respectful, and dignified life. DECCs also collaborate with other service units in the district and cooperate to build a caring community with better use of community resources (*https://www.swd.gov.hk/en/pubsvc/elderly/cat_commsupp/elderly_centres/). Each district has two regional DECCs serving and covering the older population in their community. Unfortunately, many DECCs were temporarily closed down or maintained a minimal daily operation during the pandemic in between 2020 to 2022. Owing to limited resource, data availability, and other considerations e.g. physical distance between selected DECCs and VR CAVE training centre at The Hong Kong Polytechnic University, three nearest local districts including Mongkok, Wan Chai and Causeway Bay were finally chosen for subject recruitment and experimental study. There are approximately 122,576 older adults over 60 living in these districts (https://www.census2021.gov.hk/en/main_tables.html).

The research is fully supported by St. James Settlement and the Salvation Army Hong Kong which are the two largest non-governmental organisations in Hong Kong. Three regional district Elderly District Community Centers (DECCs) have been secured to collaborate with the research project at pandemic period. They operate district-based elderly community centres, day care centres and home care support services for the elderly in their service clusters. Their community aged care services are holistic and one stop service, which are easily accessible for service users in local district regions. The research aims to recruit eligible participants in the district-based elderly community facility through program collaboration e.g. community fall prevention campaign and health promotion program. Each district elderly community centre is serving around 1500 active members. Over 70% of the service users are aged 70-80, and approximately 30% of them are prone to suspected mild cognitive impairment (MCI) or a higher risk of cognitive decline and falls risk ((Lam, Leung, & Kwok, 2019. The research team will co-organise a community fall risk screening assessment for members with a risk of falls and cognitive decline in the chosen DECCs.

To recruit the potential participants in the screening program, a responsible staff member from each DECC would make initial screening based on the proposal clinical practice guideline to recommend the service to users to enrol in a fall risk assessment session. In addition, the research team will collaborate with the organisations to recommend after service for all participants after completing the experimental study. The follow up services would comprise a comprehensive fall assessment report, falls prevention consultation session and introduce a falls prevention referral system and practice guideline for falls prevention in respective DECCs.

1.4. 2 *Methodology*

This doctoral research adopts a quantitative methodology approach and aims for planning a randomized control trial study, i.e. a pilot randomized control trial study (RCT) and an experimental comparison study and investigating the participants' perceptions and acceptance on using new VRT engaging in daily and leisure activities. By addressing the research questions, the cause-effect relationship of VRT technology and fall risk factors will be evaluated, which could contribute to a positive prediction of the effects of VR technology intervention in a targeted population from Hong Kong. The chosen methodology will evaluate and compare how effective the innovative VR CAVE technology could be in reducing fall risks among older adults with mild cognitive impairment (MCI) or potential risk of cognitive decline during pandemic in Hong Kong society. The data of the research is anticipated to be reliable and promising for possible implications in future research. Adding to the data of participants' perceptions and acceptance on VRT application, it is expected to explore and investigate the adopting VRT application in falls prevention for older adults in future aged care and rehabilitation service.

1.4. 3 *Training Program – VirCube VR for Rehab Program*

This VRT intervention program is called **VirCube VR for Rehab program**, locally designed by Motion Force Technology Limited in Hong Kong. VirCube VR is a unique VR & AR platform that allows multi-users to be fully immersive and to interact with VR in a stimulated virtual living environment. In line with objectives of the preliminary study, mainly cognitive-motor training activities have been chosen and modified in the intervention program, some VR games training modules for this study include home safety and cognitive stimulating activities, community shopping practice in daily occupations and walking and balancing programs in leisure engagement. The detailed description of set up and training protocol is documented in Chapter 3 and 5. All the training modules involve dual-task component, the research participant is expected to train up his/her cognitive and motor performances during an 8-week fall intervention program. Eligible participants are required to complete all these training modules in each session, each module takes 15 minutes to complete, therefore, a total of 45 minutes in total for each training session. Each session is administered by a trainer researcher.

1.4. 4 *Data Collection Methods*

The design of data collections involve two timeframes; first phase is a pilot randomized-control trial study (RCT) from July to December 2021 and the second phase is a quantitative experimental study from September 2021 to May 2022. All participants need to meet selection criteria: aged from 65 to 85, able to commute from their homes, had a fall history within two years and a potential risk of cognitive decline or mild cognitive impairment (MCI) tested by a validated test of Hong Kong Montreal Cognitive Assessment (HK-MoCA) which score under 26 out of 30, no severe visual and hearing impairment and stable health conditions. The participants are voluntarily assigned into groups i.e. VR group and control group. The VR CAVE training conducts in a purpose-built VR CAVE centre funded by the Department of Rehabilitation Sciences of The Hong Kong Polytechnic University. The preliminary findings of the pilot RCT data is expected to be valid and to replicate for predicting similar results in the second study (Objective 3).

All responses provided by research participants are measured using validated scales and analysed by SPSS statistical analysis method. The outcome measurements include Fall Efficacy Scale International (FES-I) for assessing fear of falling, Berge Balance Scale (BBS), Timed Up & Go test (TUG), 6-minute walk test (6MW) and Hong Kong Montreal Cognitive Assessment Scale (HK-MoCA) and Trial Marking Test A and Test B (TMTA and TMTB) for measuring the cognitive motor performances. Objectives 1 and 3 are designed to measure three intervals including pretest, post-test and post three-month follow up measurements to evaluate the possible changes in risks factor of falls compared with VR group and control group. Lastly, the Objective 2 adopts a usability and acceptance study on users' perceptions and acceptance on VRT application to explore and investigate the perceptions among VR participants in the doctoral research.

1.4. 5 *Recruitment Method (Data Source)*

Two hundred and three participants (203) had been recruited for screening assessments; they were service members from 3 DECCs in three districts regions. All participants had given informed consent prior to participate in the screening sessions and the research study held from July 2021 to May 2022. About 52.2% participants fell into age range from 70-79 which was similar age range with other DECCs in 18 local districts regions. About 70% participants had a secondary or higher education level, over 60% participants lived with the family (Table 1.1). Among 203 participants, about 84.6% participants had a fall experience before the recruitment and about 22.7% participants had reported fracture due to falls (Table 1.2). Past health conditions related to falls concern were recorded in Table1. 3.

1: Age Group Distribution:				
Age range	Frequency	Percent	Valid Percent	Cumulative Percent
60-65	5	2.5	2.5	2.5
65-69	45	22.2	22.2	24.6
70-79	106	52.2	52.2	76.8
80-85	47	23.2	23.2	100.0
Total	203	100.0	100.0	
2: Education Level				
Years	Frequency	Percent	Valid Percent	Cumulative Percent
0-3yrs	28	13.8	13.8	13.8
4-6yrs	30	14.8	14.8	28.6
7-9yrs	32	15.8	15.8	44.3
10-12yrs	65	32.0	32.0	76.4
>12 years	48	23.6	23.6	100.0
Total	203	100.0	100.0	
3: Living Status				
	Frequency	Percent	Valid Percent	Cumulative Percent
With family	132	65.0	66.3	66.3
Alone	67	33.0	33.7	100.0
Total	199	98.0	100.0	
Missed	4	2.0		
Total	203	100.0		

Table 1. 1 Demographic data including age range, education level and living status.

1: Fall History				
	Frequency	Percent	Valid Percent	Cumulative Percent
Yes (<24 months)	86	42.4	42.8	42.8
Yes (<12 months)	84	41.4	41.8	84.6
None	31	15.3	15.4	100.0
Total	201	99.0	100.0	
Missing	2	1.0		
Total	203	100.0		
2: Fracture after falls				
	Frequency	Percent	Valid Percent	Cumulative Percent
No	157	77.3	77.3	77.3
Yes	46	22.7	22.7	100.0
Total	203	100.0	100.0	

Table 1. 2 Past fall history and frequency of fracture.

1. **Osteoarthritis Knee (OA knee)**				
	Frequency	Percent	Valid Percent	Cumulative Percent
No	111	54.7	54.7	54.7
Yes	92	45.3	45.3	100.0
Total	203	100.0	100.0	

2.Osteoporosis				
	Frequency	Percent	Valid Percent	Cumulative Percent
No	147	72.4	72.4	72.4
Yes	56	27.6	27.6	100.0
Total	203	100.0	100.0	

3.Chronic Pain				
	Frequency	Percent	Valid Percent	Cumulative Percent
No	121	59.6	59.6	59.6
Yes	82	40.4	40.4	100.0
Total	203	100.0	100.0	

4.Cancer (fatigue)				
	Frequency	Percent	Valid Percent	Cumulative Percent
No	189	93.1	93.1	93.1
Yes	14	6.9	6.9	100.0
Total	203	100.0	100.0	

5.Vision problem				
	Frequency	Percent	Valid Percent	Cumulative Percent
Intact	94	46.3	46.3	46.3
Impaired	109	53.7	53.7	100.0
Total	203	100.0	100.0	

5.Hearing problem				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missed	1	.5	.5	.5
Intact	137	67.5	67.5	68.0
Impaired	65	32.0	32.0	100.0
Total	203	100.0	100.0	

Table 1. 3 Past health conditions related to falls concern

1.4. 6 *Data Description*

Three data sources were utilised in evaluating the pilot RCT and experimental study and the VR usability study. Concisely, Table 1.4 describes the data used with respective sources and other relevant details in achieving each objective.

Table 1. 4 Details of all data used in this research.

		Valid Tests/ Parameters	Source- NGOs Hong Kong districts	Study period (dd-mm-yyyy)	Proposed model
OBJECTIVE 1 (STUDY 1)	Paper 1 (Chapter 3)	Tests of Cognition Functions HK-MoCA (30 score) TMTA/TMTB (second) Physical Tests: BBS (total 56 score) TUG (second) 6MWT (meter) Fall Efficacy Test FESI (total 64 score)	Mongkok -Salvation Army (SA) Wanchai- St. James Settlement (SJ)	01-07-2021 to 31-12-2021	*VR CACE Fall Prevention Mode*
OBJECTIVE 2 (STUDY 2)	Paper 2 (Chapter 4)	VR Usability Questionnaire by 5-point scale Perceived Usefulness (PU) Perceived Ease of Use (PEOU) Perceived Enjoyment (PU) Subjective Norms (SNs) User Experience (UE) Intentions to use (IU)	Mongkok (SA) Wanchai (SJ) Causeway Bay (SJ)	01-07-2021 to 31-05-2022	TAM Model
OBJECTIVE 3 (STUDY3)	Paper 3 (Chapter 5)	Same as Objective 1	Mongkok -SA Wanchai- SJ Causeway Bay- SJ	01-09-2021 to 31-05-2022	*VR CAVE Fall Prevention Model*

For Objective 1, the aggregated data from two DECCs chosen from Hong Kong (Mongkok and Wanchai districts) were used to conduct the first pilot RCT study. The sample size was smaller, 18 eligible participants were recruited for a comparison study. The data period was between 01-July-2021 to 31-December-2021. Chapter 4 provided more details regarding data processing and its usage.

For Objective 2, the data from the same source as Objective 1 and Objective 3 were adopted. However, the study focussed on 3 chosen DECCs (Mongkok, Wanchai and Causeway Bay) in Hong Kong and the longer period. Comparatively, the data source from three chosen DECCs were more convenient to commute to the VR training centre at The Hong Kong Polytechnic University. This factor was more favourable and challengeable for the recruitment of doctoral research under COVID-19 pandemic in Hong Kong. The data period was between 01-07–2021 to 31–05–2022. Chapter 5 provided more details of these data.

For Objective 3, the data from three DECCS (Mongkok, Wanchai & Causeway Bay) chosen from Hong Kong were used to conduct the experimental study. Although, the sample size was larger than the pilot RCT study. However, the optimal sample size and the design of RCT study were interrupted and not being achieved due to shifting a convenience sampling method. The data collection period was longer and extended from 01-09-2021 to 31-05-2022. Because the research project was unexpectedly suspended in February 2022 and resumed in May 2022 due to closing all university and public social care services facilities under a special health infection control policy hoisted in this period. A complete list of all variables, including the detail explanations was provided in Chapter 6.

1.5 Ethical Considerations

The research has been complied with all ethical legislation and guidelines under the Australian Code for the Responsible Conduct of Research (2018), the National Statement on Ethical Conduct in Human Research and the framework principles and responsibilities for all University of Southern Queensland (USQ) research workers. The doctoral research has three quantitative experimental design requiring human subjects for participation in the data collection method. Prior to any data collection, an approval from the USQ Human Research Ethics Committee *(application number USQ AEC H21REA071)* has been confirmed, and to give consent to proceed with the data collection for human participations. In addition, the research conducted in Hong Kong, so local subjects to participate in the experimental study using the VR CAVE technology were recruited under the official authorization of the

Rehabilitation Science faculty of the Hong Kong Polytechnic University. The research proposal has been confirmed the ethical approval for data collection from the Human Ethics Committee of The Hong Kong Polytechnic University *(reference number HSEARS20210317007)*. Thus, the doctoral research gains ethical approval from the Human Research Ethics Committee in two respective universities.

The research participants have risk of cognitive decline or early onset dementia, they are volunteer participants who were assigned into experimental and control groups. Informed and written consent must be obtained from each participant before participating in the study. Explanation of the study will be provided to their families for their understanding. All participants must give consent of voluntary participation and agree to being randomly assigned into experimental and control groups. Ethically, all participants' personal information must be kept confidential and restricted to use with authorized permission only. The voluntary consent form must clearly state the purpose and process of the research, any potential risk induced and the right of withdrawal anytime in the experimental period. Governed by the mandatory guidelines of USQ Human Research Ethics Committee, the researcher is strictly following all the rules before and while carrying out the data collection process. During the data collection, only a few participants were accompanied by the family members to the training venue for safety reasons. The research team takes all necessary precautions to compile a health and safety policy and to provide a clean and safe training environment so that participants' personal safety and health can be well-protected.

1.6 Significance of Research

As VRT has potential to promote physical and cognitive health outcomes in aged care services, the proposed research has the mission to demonstrate the effectiveness of VRT as a fall prevention technology strategy among older adults with cognitive impairments. The potential contributions would be defined at three levels i.e., personal, organisational/professional, and societal. First, the VRT research would promote good quality and safe living for people living with dementia and mild cognitive impairment by reducing the risk of falls. It would reduce the fear of fall, improve postural balance as well as cognitive reserve, consequently the avoidance of fall injury and elimination of loneliness and helplessness for the elderly living in the community. In addition, the VRT training as a cognitive-motor intervention could effectively activate brain activity by means of cognitive and multisensory stimulations to promote cognitive reserve or slow down cognitive decline for people with mild cognitive impairment or at the early stage of dementia.

Second, the VRT research would contribute to healthcare professionals and aged care providers in healthcare system because the research would prove the effectiveness of evidence based VRT practice and recommend a modified VirCube VR for Rehab program for fall technology prevention application in aged care services. It is expected that technology adoption in aged care will become more common, as VRT applications have shown possible benefits in aged care services. Aged care organisations would consider VRT program as one of the best alternative solutions to substitute the conventional fall prevention program particularly in the Covid-19 pandemic. It is more viable option for care providers and healthcare professionals to enrich older adults' social connections and induce less barriers in a virtual stimulated environment by adopting VR technology.

Third, the VRT research is expected to provide substantial evidence and advocate the application of VRT in ageing society. As VRT intervention would be an innovative solution to tackle the challenge and healthcare burden brought along by the problem of falls. Potentially, it would play a significant role as one of the effective fall prevention strategies in the healthcare system. Society should contribute and invest more resources in early intervention of VRT in aged care facilities. In the long run, the VRT research would attract more research attention and help foster allocation of more human resources on this research journey.

1.7 Theis Layout

1.7.1 *Thesis by Publication*

This thesis is presented as a PhD Thesis by Publications, comprising three major experimental studies, and fulfilling requirements of higher degree by research presentation guidelines (USQ) dated 16 March 2023. The thesis covers six chapters including research background and literature review. After three papers chapters, the discussion and conclusion summarise the challenges, findings, limitations and implications and future work in research and age care service.

The thesis schematic and the six chapters are as follows:

Chapter 1 describes the research background, the statement of the research problem and overview of research methodology and outlines the thesis layout.

Chapter 2 reviews the literature and theoretical framework used in this study. This chapter presents a proposal VR CAVE Fall model and Technology Acceptance Model (TAM) adopted in the research, a flow of clinical practice guideline on falls prevention is recommended in community care service in Hong Kong.

Chapter 3 presents as a submitted journal article for under review in Virtual Reality (28 September 2023)

Publication Type: Journal

Scopus Rated: Q1

H-Index: 57

Impact Factor: 4.69

SCImago Journal Rank (*SJR*): 1.081

Chapter 4 presents as a published journal article for publication in Human Behaviour and Emerging Technologies (20 March 2024)

Publication Type: Journal

Scopus Rated: Q1

H-Index: 26

Impact Factor: 10.3

SCImago Journal Rank (*SJR*): 2.126

Chapter 5 presents a submitted journal article for under review in Australian Occupational Therapy Journal (1 June 2023)

Publication Type: Journal

Scopus Rated: Q1

H-Index: 50

Impact Factor: 1.757

SCImago Journal Rank (*SJR*): 0.480

Chapter 6 presents the summary of the thesis with concluding discussion, limitations, and recommendations for future works.

Appendix A: VR CAVE Training Equipment and Set Up

Appendix B: VirCube Training Program and Protocol

Appendix C: VR Usability Questionnaire

1.7.2 *Flow of Chart of Thesis Layout*

The structure of this thesis and clear connections among studies are presented on the flow chart of the thesis in Figure 1.

1.8 SUMMARY

To summarize, this chapter provided the research background context, an overview of the research methodology, and outlined the thesis layout. It described the rationale for data sources and limitations of the research method. The data of three quantitative studies was based on three study areas. This doctoral research follows a Thesis by Publication format, consisting of three papers submitted to Q1 journals. The three research questions are addressed in these studies.

Study 1 is a pilot randomized control trial evaluating and comparing the effects of VR CAVE technology and exercise-based training in fall prevention. Study 2 focuses on users' perception and acceptance of VR technology. The last study, Study 3, is an experimental study with an extended follow-up period, evaluating the effectiveness of the VR CAVE program in fall prevention for older adults with mild cognitive impairment. The thesis layout is visually presented in a diagram (Figure 1.1). The subsequent chapter connects the literature review to the theoretical framework, identifying research gaps that are investigated in the three quantitative studies.

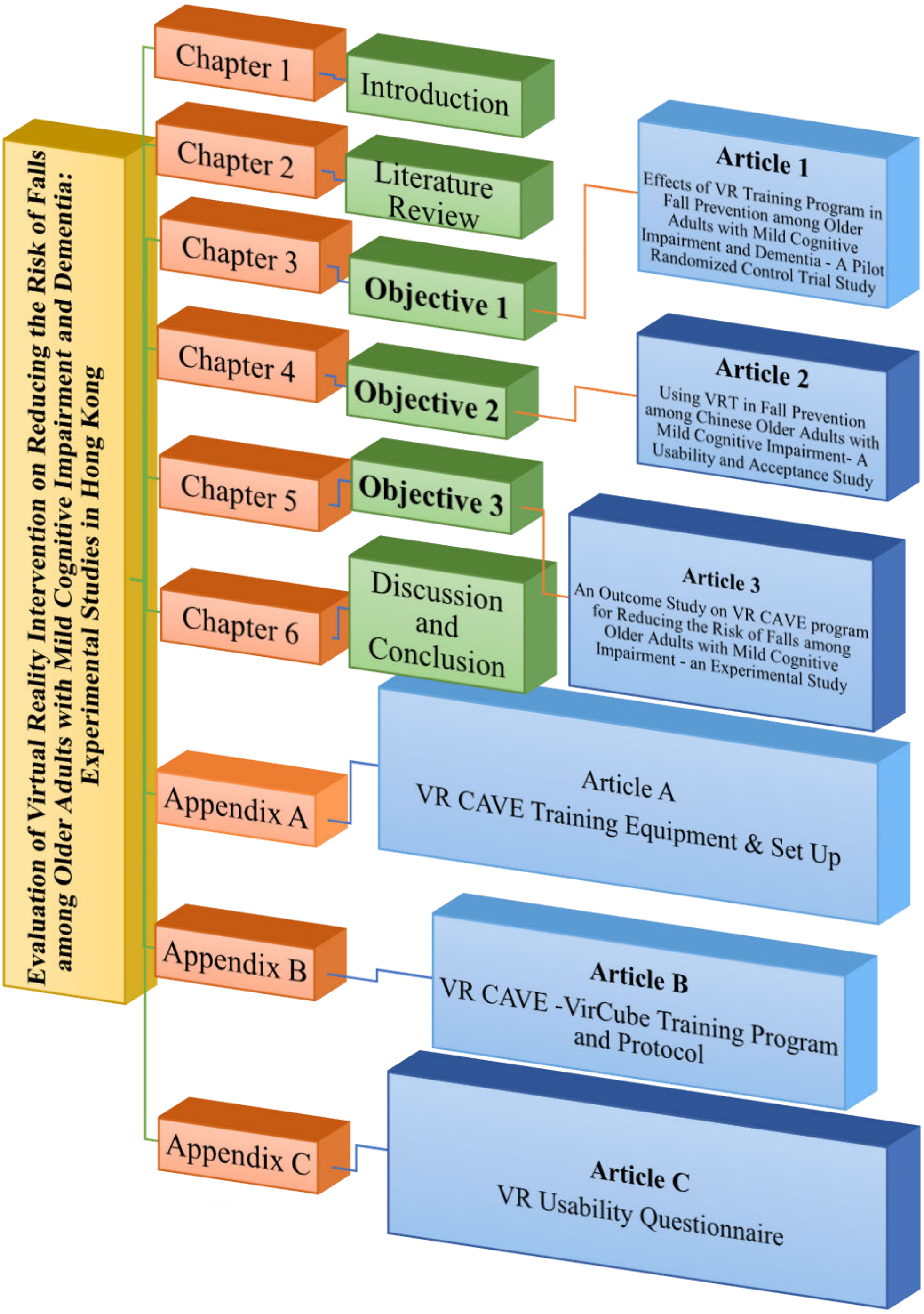


Figure 1. 1 Flow chart of the thesis layout

CHAPTER 2: LITERATURE REVIEW

2.1 Cognition, Gait and Falls in People with Cognitive Impairment

*'Fall is defined as an event which results in a person coming to rest inadvertently on the ground or floor or other lower level. Falls, trips and slips can occur on one level or from a height '(*WHO, 2021). Cognition and gait are interrelated and are fall risk indicators in older persons (Verghese et al., 2008). Walking in the real environment requires paying attention to safety awareness, spatiotemporal orientation, cognitive judgement, and postural stability control to avoid slips and trips. However, cognition is a complex executive brain function; it is a set of cognitive processes which involve inhibitory control, sustained attention, cognitive flexibility and working memory (Yogev-Seligmann, Hausdorff & Giladi, 2008). All factors are essential for normal safe walking (Mirelman et al., 2016). The literature suggests there is a strong relationship between the executive function and falls; executive dysfunction doubles the risk for future falls and increases the risks of fall injury by 40% in older persons living in the community (Muir, Gopaul & Montero-Odasso, 2012). Older adults with mild cognitive impairment have a higher prevalence of gait impairments and higher risk of falling when compared to normal older adults (Verghese et al., 2008). People with mild cognitive impairment and dementia population are at a higher risk of falling (Delbaere et al., 2012). Therefore, there is potential evidence to use cognitive motor training as a fall prevention strategy to reduce fall risks in this population.

This doctoral research modifies the framework adapted by Montero-Odasso et al. (2020) *Figure 1*. Their first published framework, shown in 2012, suggested the emerging view as bi-directional, indicating that low cognition function predicts mobility decline, and consequently falls with fractures, whereas mobility decline (slow gait) predicts cognitive deterioration in older persons, and speeds up the process from cognitive impairment to dementia. As cognition and gait are interrelated, this research adds new views based on their potential therapeutic view. By improving the cognition function, fall incidents e.g. fractures (figure.1 *shown by the red and red dash arrow*) could be reduced. This conceptual framework indicates that cognition is a fall risk factor in the management of falls among older adults with cognitive impairment (Liu-Ambrose et al., 2013). As cognitive impairment can reduce mobility, there exists a potential gap and research interest to evaluate the effect of Virtual Reality Technology in fall prevention. The innovative method adopts a newly designed VR CAVE technology program to increase cognitive motor interaction. The expected result is that falls and fractures in people with MCI and dementia will be reduced (Fig 1.1). Theoretically, cognitive and motor functions should be improved simultaneously after the VRT intervention, and hence the cognitive decline and the clinical onset from MCI to dementia of the participants may slow down (Welmer et al., 2017). It is expected the VRT intervention will assist prevention of falls as well as the promotion of cognitive and physical health outcomes.

There is some evidence showing that cognitive-motor interventions such as virtual reality-based interventions could reduce the risks of falls in older adults with mild cognitive impairment and dementia (Thapa et al., 2020). But there is limited empirical research with MCI and dementia in fall prevention research, with some studies in MCI and dementia population having problems of low response rates, cognitive deterioration, and small sample sizes (Hamm et al., 2016; Miranda-Duro et al., 2021). This intervention has identified a knowledge gap which is to study the evidence of the training effect of cognitive-motor intervention as an alternative fall prevention intervention program in aged care.

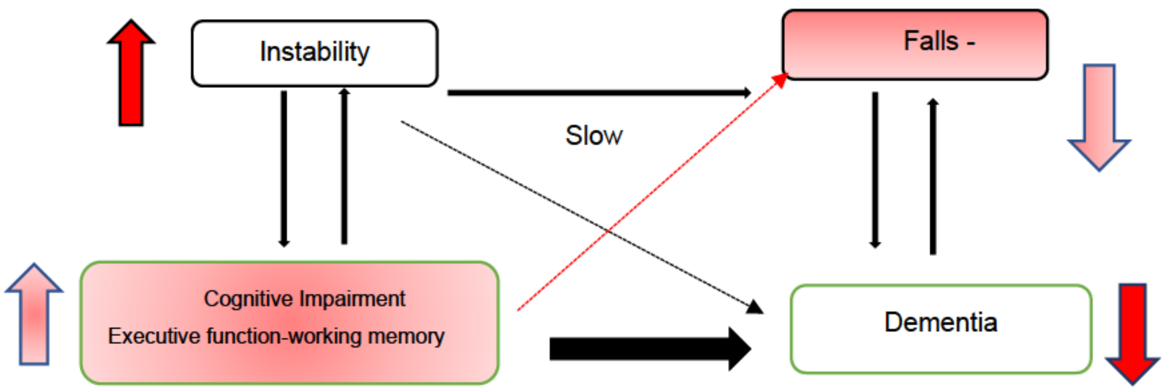


Figure 2. 1 Conceptual framework of cognition and ageing adapted from Montero-Odasso et al. (2020)

2.2 Fear of Falling

This research will focus on a specific fall risk factor - fear of falling, which may impact on the fall risk among older adults with mild cognitive impairment and early dementia. The fear of falling is common among older persons with a prevalence of 20-85% (Scheffer et al., 2008). It is associated with a range of adverse health and psychosocial outcomes, including increased risk of falls, poorer physical functioning, more rapid decline in cognitive function and well-being (Peeters et al., 2018). Not everyone who experiences a fall or balance problem develops a fear of falling, while not everyone with fear of falling has experienced a fall or balance problem (Liu, 2008). This research will extend the conceptual framework for fear of falling adapted by Peeters et al. (2020). As the conceptual framework for fear of falling was originally designed by Hadjistavropoulos et al. (2011) and Peeters et al. (2020) reviews and extends the framework with the aim of understanding the aetiology of fear of falling because the model ignored the component of 'cognitive'. He has discovered that cognitive function and other psychological domains are the inevitable factors contributing to the fear of fall (Fig. 2.2). Difficulty with executive functions can develop into fear of falling and is a predictor of falls (Montero-Odasso & Speechley, 2018). People with mild cognitive impairment are more likely to develop a fear of falls than normal older persons (Uemura et al., 2012).

People have difficulty in recognizing the fear of falling if their cognitive function has worsened due to anosognosia (Borges, Radanovic & Forlenza, 2015). The extended framework does not indicate the importance of motor factors, and mobility decline will also increase the fear of falling. The proposed research will target participants with mild cognitive impairment. The extended framework will explore whether cognitive function and fear of falling are interrelated. There is a knowledge gap exploring whether cognitive motor intervention will reduce the fear of falling as a risk factor of falls in older adults with MCI and dementia.

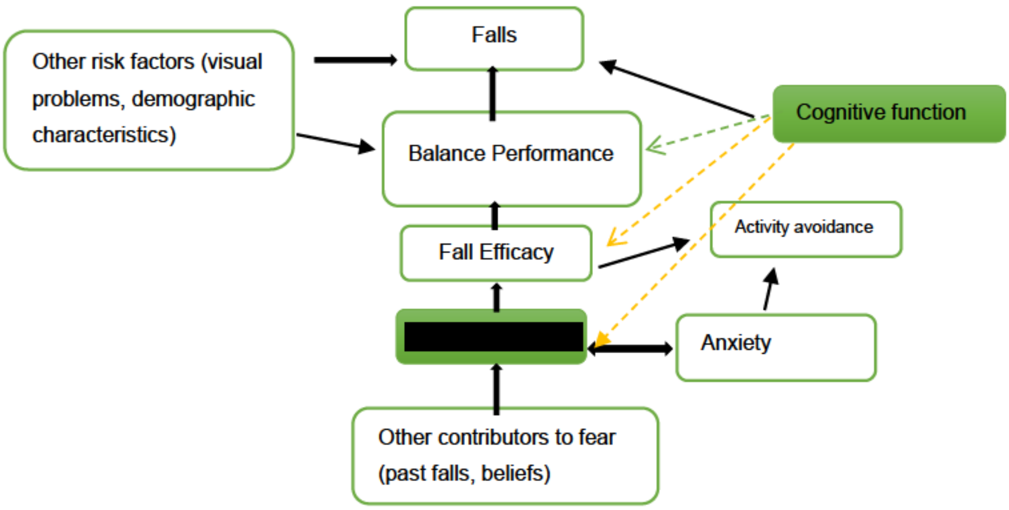


Figure 2. 2 Adapted framework from fear of falling(Peeters et al., 2020)

(orange dot arrows indicate the relationship between cognitive function and fear of fall)

2.3 Falls and Cognitive Impairment

Fall risk factors are normally categorized into intrinsic factors e.g. age, gender, fear of falling, and cognitive and physical functions and extrinsic factors e.g. environmental barriers, and footwear (Hamm, Money, Atwal, & Paraskevopoulos, 2016). Four categories of fall risk factors in older persons are recommended: biological (e.g. age, disease), behavioural (e.g. lack of exercise), socioeconomical (e.g. low education) and environmental (e.g. slippery floors) (WHO 2019). These categories can help the researcher to focus and identify the different prevention strategies for fall management in older adults. This research adopts a dual-task (cognitive and motor) training strategy, for example, improving cognitive and motor function (intrinsic) in a full-immersive virtual simulated environment. The VR CAVE designs a simulated walking environment with obstacles or challenges for walking and balance practice and learning executive function through simulated learning scenarios, for example attention and spatiotemporal judgement in daily walking. Constructively, this research can address different categories of the modified fall risk prevention strategies recommended by the WHO (2019).

Using the information presented in a systematic literature review, the fall risk factors in older persons have been summarized in Table 2.1 (Rubenstein & Josephson, 2002). This research implements the adapted framework proposed by Montero-Odasso and Camicioli (2020), i.e. cognition decline predicts mobility decline (instability) and falls. Cognition and falls have a well-established association and are interrelated. However, the mechanism of such an association among older adults with MCI and dementia is less clear. It may be due to nature of cognitive complexity. The risk factors for fall among people with cognitive impairment have been proposed and generalized (Montero-Odasso & Camicioli, 2020). The dual-task training strategy has resulted in a research gap to better understand the mechanism between falls and cognition association in older people with MCI and dementia.

Risk factors	**Mean RR-OR**
Muscle weakness	4.4
History of falls	3.0
Gait deficits	2.9
Balance deficit	2.9
Use of assistive device	2.6
Visual deficit	2.5
Arthritis	2.4
Impaired activities of daily living	2.3
Depression	2.2
Cognitive impairment	1.8
Age > 80 years	1.7

Relative risk ratios (RR) calculated for prospective studies, odds ratios (OR) calculated for retrospective studies.

Table 2. 1 Risk factors for falls (Montero-Odasso & Camicioli, 2020)

2.4 Research Gap for clinical practice guideline and in fall prevention

Clinical practice guidelines (CPGs) for fall prevention are important and are supported by evidence-based research, giving possible recommendations for researchers to provide consistent and effective interventions to service targets in a specific condition (Montero-Odasso & Speechley, 2018; Montero-Odasso et al., 2022). There are several CPGs for fall prevention for normal older persons. Two of these are the American Geriatrics Society and the British Geriatrics Society (AGS/BGS, 2001). However, none of the CPGs is specifically targeted at providing fall prevention for people living with mild cognitive impairment or dementia, this has led to a knowledge gap of developing specific CPGs in the interest of people with cognitive impairments.

Based on the updated paper of AGS/BGS guidelines (2011), an adapted algorithm (Fig 2.3) has been proposed regarding the fall risk and in association with future fall risks. The algorithm recommends the importance of fall risk screening assessment and makes a good reference point for the accuracy of predictive validity of future falls (Lamb et al., 2005). Fall risk screening is a pathway of clinical practice guidelines to fall prevention because the participants with relatively high risk of falls are the high-risk group for future intervention research studies. Unfortunately, the updated AGS/BGS guidelines are out of date and do not consider the cognitive screening assessment as an important criterion of fall risk screening. And currently there is no fall prevention clinical guideline specifically for people with cognitive impairment. This research adopts new clinical practice guideline for recruiting the potential subjects in three DECCS centers.

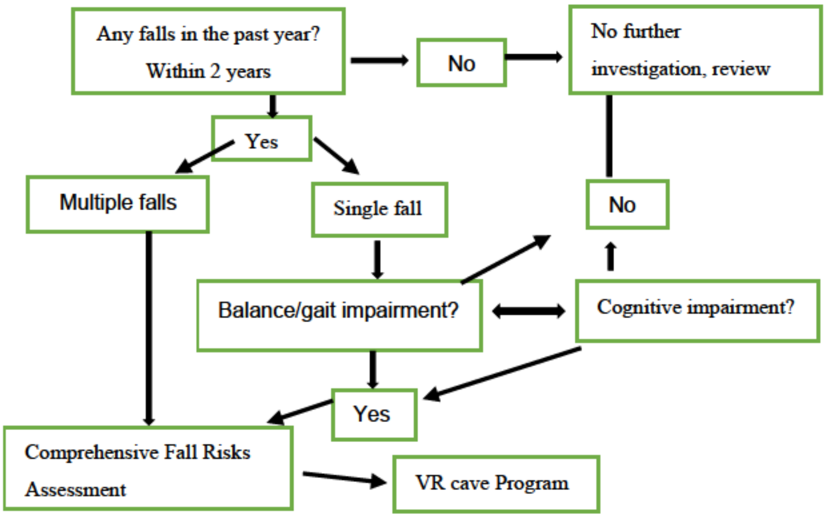


Figure 2. 3 Modified flowchart adapted from ABS/BGS guidelines for fall prevention screening algorithm for fall risk in older adults with recommended interventions (Muir et al., 2012)

2.5 Research Framework

Traditionally, exercise-based intervention is a well-established effective fall intervention strategy for older adults living in the community (Gillespie et al. 2009). However, the single task (motor) intervention may not be adequate nor consistent for older adults with cognitive impairment because the cognitive dysfunction is under-estimated e.g. low attention and exercise motivation and limited social interaction in the exercise training. To understand the possible mechanism of fall reduction, this study modifies the conceptual framework of the "Central Benefit Model" to explain the mechanism of fall reduction in older adults with MCI and dementia (Liu-Ambrose et al., 2013).

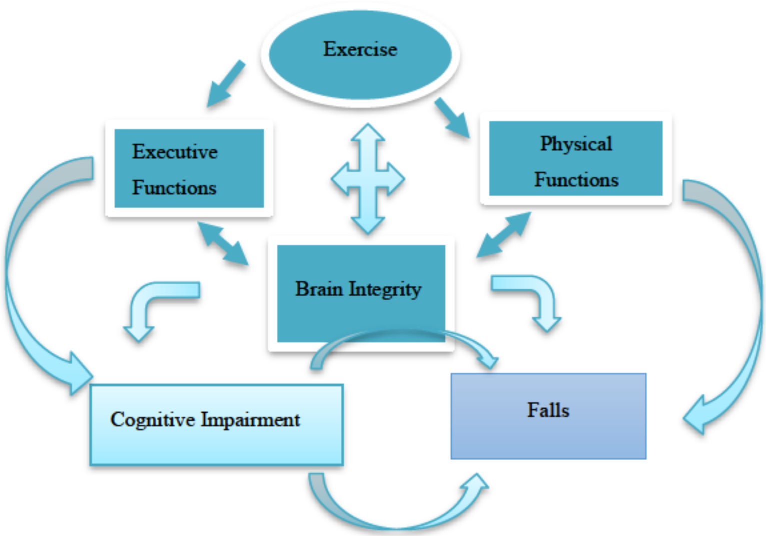


Figure 2. 4. Adapted from Central Benefit Model (Liu-Ambrose et al. 2013)

This model emphasizes that reduced executive and physical functions are associated with increased fall risks and cognitive impairment. Impaired balance and gait, attentional capacity and impaired executive processing of postural response are the possible mechanisms of pathways to inducing the risks of fall (Liu-Ambrose et al., 2013). The exercise-induced framework proposes that exercise can be a good cognitive-motor intervention, which enables the slowing down or stopping of the mechanisms of falls in older persons. This framework supports the belief that cognition and gait can alter brain integrity by effective dual-task intervention. To counter the limitations of an exercise-based program, an innovative Virtual Reality Technology is expected to be a more stimulating cognitive-motor intervention approach to stimulate the participants' attention and interest in a VR CAVE training platform. It is envisaged that the VRT intervention can be effective as a good alternative intervention to target the fall risk factors by improving the cognitive function, postural balance, and fear of falling among older adults with MCI and dementia.

This doctoral research adopts a dual-task (cognitive and motor) training strategy, for example, improving cognitive and motor function (intrinsic) in a virtual simulated environment. The VRT can design a simulated walking environment with obstacles or challenges for walking and balance practice and learning executive function through simulated activity scenarios, for example attention and spatiotemporal judgement. However, the mechanism of such an association among older adults with MCI and dementia is less clear. It may be due to the nature of cognitive complexity. The risk factors for fall among people with cognitive impairment have been proposed and generalized (Montero-Odasso & Camicioli, 2020). The dual-task training strategy has resulted in a research gap to investigate and evaluate the mechanism between falls and cognition association in older adults with MCI and dementia.

Virtual Reality (VR) is defined as a high-end computer interface that involves real time or simulated environment and interactions through multiple sensory channels (Mirelman et al., 2016). VR technology is mainly classified as semi-immersive and fully immersive interfaces. This research uses a full-immersive VR technology named "**C**ave **A**utomatic **V**irtual **E**nvironment" "(**CAVE**)". The VR CAVE technology asks the participants to wear stereoscopic glasses which enable them to see 3D graphics and images so that they can walk all the way around the objects in a simulated scenario and get a full view and a proper understanding of exactly how those objects would look in the real time environment, although it is virtual.

From a systematic literature review, evidence has shown that the immersive VR technology provided a simulated real-life environment and scenarios, which engaged the users with the sensation of physical existence (Baus & Bouchard, 2014 & Moreno et al., 2019). It is expected that VRT intervention could improve mobility and cognitive functions among older persons (Tsang & Fu, 2015; Mazhar, Shi & Laura, 2018; Nath et al., 2019). This intervention may support the physical activity of people living with dementia (Shema, 2017; Mazhar et al., 2018).

Traditionally, the fall prevention intervention strategy uses a human-guided exercise with trained professionals leading the fall prevention program to make a positive impact on overall health conditions (Ohman, Savikko & Strandberg, 2016). During the Covid-19 pandemic, human-guided practice was severely impacted and therefore changed to an online simulated platform. The VR technology becomes more accessible and affordable to operate as compared with therapist-lead exercise, indicating potential to develop it as an interactive (alternative) approach to fall prevention strategy and other engagement in community aged care service.

Although, there have been some arguments that the wearing of a head-mounted device may possibly induce discomfort and agitation associated with wearing the technology in older people (Bourrelier & Ryard, 2016). To minimize the impact of motion sickness or dizziness when using VR technology applications, the VR CAVE technology is designed to be more user-friendly as 3D stereoscopic glasses are more convenient and comfortable for older adults.

2.5.1 *VR CAVE Fall Prevention Model (Study 1 and Study 3)*

Based on the literature review, there exists a major gap that no current research has been done on VR CAVE technology for preventing falls in older persons (Zahabi & Abdul Razak, 2020). In addition, there is no unified research framework which describes the essential components and mechanisms of VRT intervention in fall prevention. Therefore, this research serves as a pioneering attempt to make a potential contribution to developing VR CAVE research and advocating VRT-based activity training in aged care services. As substantial evidence indicates that risk factors of falls are interrelated and associated with each other such as gait and balance, fear of falling and cognitive factors (Peeters et al., 2018), the research proposes an alternative training model named as **VR CAVE Fall Prevention model** (Figure 2.5).

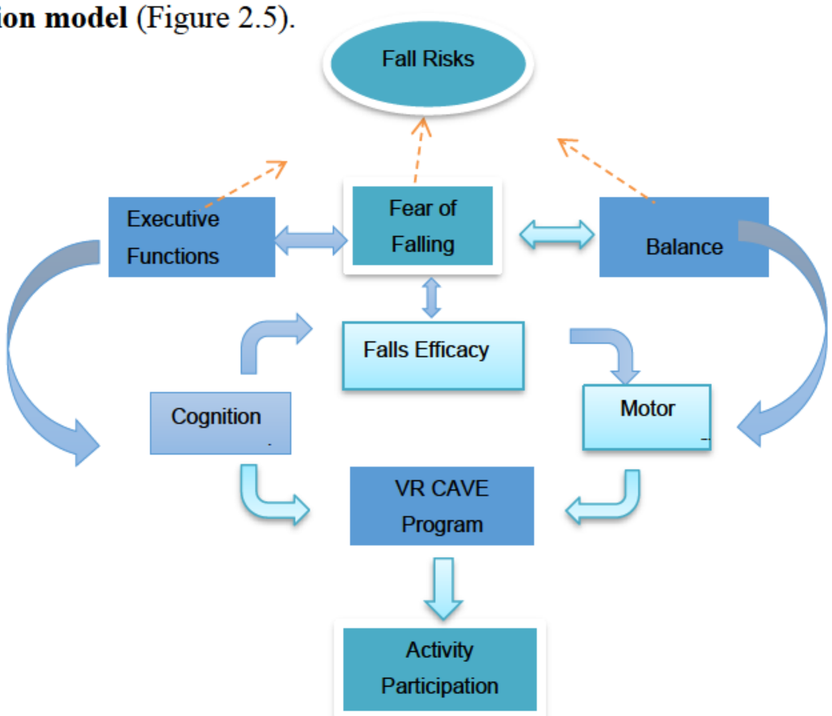


Figure 2. 5 VR CAVE Fall Prevention Model

The proposed model builds on and integrates the concepts of the two models mentioned i.e. Fear of Falling (FoF) and Central Benefit models into a human centred technology approach. It indicates the risk of falls in older persons with mild cognitive impairment is expected to be lowered by improving the cognition and motor functions via a virtual learning platform. The VRT human interface attracts the old adults' interest and motivation in a multisensory stimulation and reminiscence experience. It is expected to draw their cognitive attention to recall pleasant memory experiences, and to stay active and meaningful by engaging in a virtual simulated learning environment e.g., shopping in an old market and walking in a beautiful scene. By participating in virtual cognitive motor activities, the participant is expected to increase cognitive functions and other balance domains. Consequently, the doctoral research has great potential contributions by providing promising evidence of the intervention effects of VRT on reducing the risk of falls and the older adults' acceptance to use VRT as an alternative fall prevention training and meaningful engagement in community aged care service.

2.5.2 *Technology Acceptance Model (Study 2)*

The framework of Technology Acceptance Model (TAM) is applied in Study 2 for investigation of participants' acceptance of a new technology in VR CAVE application. Technology acceptance model is a well-known model for predicting technological acceptance (Davis, 1989; Kamal et al., 2020). It helps to anticipate and explain users' behaviours. In addition, it suggests a theoretical groundwork to understand the relationships between various variables, user perception, and benefits of technology application (Hsiao and Yang, 2011). The Study 2 applies a TAM scale including perceived usefulness (PU), perceived ease of use (PEOU), and intention to use (IU). The perceived usefulness (PU) and perceived ease of use (PEOU) are defined as the degree to which the older adults perceived that using VR would increase their daily activities and be free of effort (Venkatesh et al., 2003). Predictably, PU and PEOU are one of predictive factors in the acceptance of a technology in our study (Venkatesh, 2000).

VR usability questionnaire (HK-version) also includes social norms (SNs) and perceived enjoyment (PE) to indicate the participants' perception and acceptance on using VR technology application (Syed-Abdul, 2019). Commonly, SNs are defined as older adults' perception to consider whether they should use VR. The perceived enjoyment (PE) is defined as older adults perceived using the technology as fun, stimulating, and interactive. All factors are counted as the predictive factors to influence the acceptance and intention to use VR in older adults. According to previous research, user experience (UE) indicates a strong effect on usage intentions and the older adults' behaviour during and after using VR technology intervention (Kim and Ning, 2012). In view of TAM model and reviewed literature, the study adopts to use the VR usability questionnaire (HK-version) as an instrument to compare the changes of these variables across the time intervals. This study serves the purpose to examine and review the questionnaire internal validity and reliability using for older adults from Hong Kong.

CHAPTER 3: PAPER 1 –VIRTUAL REALITY ACTIVITY-BASED TRAINING FOR PREVENTING FALLS AMONG COMMUNITY-DWELLING OLDER ADULTS WITH MILD COGNITIVE IMPAIRMENT: A PILOT RANDOMIZED CONTROL TRIAL STUDY

1.5 Introduction

This was a first pilot research study employing VR activity-based training (VR CAVE) to prevent falls among community-dwelling older adults with mild cognitive impairment in Hong Kong. Implemented during the COVID-19 pandemic, the study encountered numerous challenges and limitations related to sampling methods and data collection. The VirCube VR for Rehab program utilized VR CAVE technology, providing a full-immersive virtual learning environment for multi-service users. The VR program encompassed various modules, including sport exercises, community living simulations, memory games, leisure activities, and more, all tailored for fall prevention training in older adults. The project team underwent comprehensive training in operating VR CAVE facilities and the application of the VR CAVE program, with technological support and maintenance services monitored and provided by the product owner at The Hong Kong Polytechnic University.

Commencing with a pilot randomized control trial study, a small group of subjects was identified and recruited for a six-month study. Study 1 aimed to investigate and compare the training effects between the VR group and the exercise-based group in fall prevention training. The insights gained from this pilot experience in Study 1 were crucial for planning the subsequent studies in Chapter 4 and 5.

Submitted Paper

VIRTUAL REALITY ACTIVITY-BASED TRAINING FOR PREVENTING FALLS AMONG COMMUNITY-DWELLING OLDER ADULTS WITH MILD COGNITIVE IMPAIRMENT: A PILOT RANDOMIZED CONTROL TRIAL STUDY

***Wing Keung Ip[1,2], Jeffrey Soar[2], Christina James[2], Zoe Wang[3], and Kenneth N. K. Fong[4]**

Abstract

Using a Virtual Reality (VR) games-based application as an innovative falls prevention technology in an aged care service. The study explored and evaluated the effects of VR activity-based training on falls prevention among community-dwelling older adults with mild cognitive impairment. A pilot randomized control trial study was applied to compare the effects on falls prevention between participants who experienced a full-immersive VR training and group-based exercise (Baduanjin) training. Eighteen participants were recruited using convenience sampling and were randomly assigned into the VR group and the exercise group (non-VR). The participants in both groups attended 16 falls prevention training sessions over eight weeks. Eligible participants identified with a higher risk of mild cognitive impairment and early dementia undertook three measurements. The primary outcomes assessed included changes in physical risks factor of falls, and the secondary outcomes assessed included changes in cognition and fall efficacy. The results showed VR group had significantly greater improvement than the exercise group on measures of cognitive-motor performance, such as cognition (HK-MoCA), functional mobility (TUG), balance (BBS) and walk speed (6MWT) across time occasion. There were, however, no significant differences in executive functions (TMTA and TMTB) and the fall efficacy (FES-I) between the two groups. In conclusion, the study provides promising evidence on possible effects of VR training for preventing falls among community dwelling older adults with mild cognitive impairment. But the study does not support the evidence to reduce the fear of falling and executive functions between two groups.

KEYWORDS

Full-immersive Virtual reality (VR); cognitive-motor training; community-dwelling older adults; mild cognitive impairment (MCI); dementia; falls prevention.

Introduction

In Hong Kong, there is an annual reported occurrence of 20-26.4% of community-dwelling older-adults falling (Leung 2019; Qian et al. 2020). According to a previous study, amongst 89,100 older adults, about 32% older adults fell in the past 90 days (Qian et al. 2020). Dementia and mild cognitive impairment are interrelated and associated with aging; together they are associated with a rapid increase in the number of falls. Cognition and gait are interrelated and are fall risk indicators in older adults (Verghese et al. 2008). Walking in the real environment requires paying attention to safety awareness, spatiotemporal orientation, cognitive judgement, and postural stability control to avoid slips and trips. However, cognition is a complex brain executive function; it is a set of cognitive processes which involve inhibitory control, sustained attention, cognitive flexibility and working memory (Yogev-Seligmann 2008). All these factors are essential for normal safe walking (Mirelman 2016). The literature suggests there is a strong relationship between the executive function and falls; executive dysfunction doubles the risk for future falls and increases the risks of fall injury by 40% in community-dwelling older adults (Muir 2012). Older adults with mild cognitive impairment have a higher prevalence of gait impairments and higher risk of falling when compared to healthy ageing (Verghese 2008).

The pilot study applies and modifies the framework adapted by Montero-Odasso et al. (2020). Their first published framework shown in 2012, suggested the emerging view as bi-directional, indicating that low cognition function predicts mobility decline, and consequently falls with fractures, whereas mobility decline (slow gait) predicts cognitive deterioration in older adults, and speeds up the process from cognitive impairment to dementia (Montero-Odasso 2012). As cognition and gait are closely interrelated, this research suggests new views based on their potential therapeutic view. By alternating the cognition function, fall incidents e.g., fractures and injuries (Figure 1 *shown by the red and red dash arrow*) could be reduced. The conceptual framework indicates that cognition is 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 exists potential evidence to support using VR technology-based Intervention on falls prevention. The comparison methods involve using an innovative designed VR Cave Automatic Virtual Environment (CAVE) technology and traditional exercise training to enhance cognitive-motor interaction. The expected result is that falls and fractures in people with MCI and dementia may be reduced (*Figure 1)*. Theoretically, cognitive and motor functions should be improved simultaneously after the VR intervention, and hence the cognitive decline and the clinical onset from MCI to dementia of the participants may slow down (Welmer 2017). It is expected the VR CAVE intervention will assist prevention of falls as well as the promotion of cognitive health outcomes.

There is some evidence showing that cognitive-motor interventions such as virtual reality interventions could reduce the risks of falls in older adults with mild cognitive impairment and dementia (Thapa 2020). However, there is little empirical research with MCI in falls prevention intervention research, with few studies in MCI and dementia population all having problems of low response rates, cognitive decline, and small sample sizes. This intervention has identified another knowledge gap to provide an alternative falls prevention intervention program in aged care.

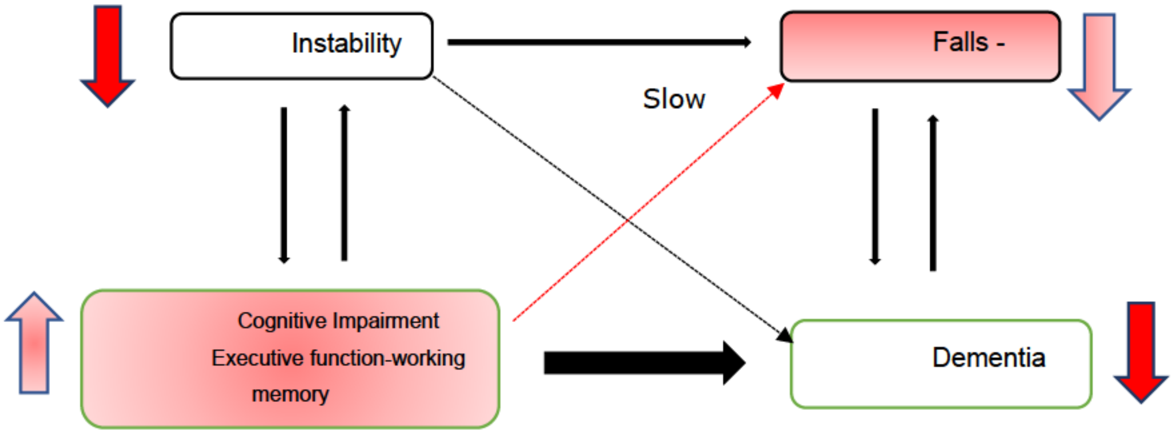


Figure 1. Modified framework adapted from Montero-Odasso et al. (2020)

Traditionally, exercise-based intervention is a well-established effective fall intervention strategy for older persons living in the community (Gillespie 2009; Ohman 2016; Montero-Odasso 2022). However, the single task (motor) intervention may not be adequate nor consistent for older adults with cognitive impairment because the executive dysfunction is under-estimated e.g., low attention and exercise motivation and low cognitive learning capacity in the exercise-based training. To counter the limitations of an exercise-based program, an innovate full-immersive VR intervention is expected to be an alternative falls prevention strategy to stimulate the participants' attention and slow down a cognitive decline in a new virtual reality simulation. It is envisaged that new VR games-based intervention can be effective as a good alternative intervention to reduce the fall risk factors by improving the cognitive function, postural balance and fall efficacy among older adults with cognitive impairment (Ge 2018).

Due to the Covid-19 outbreak between 2020-2022, the human-guided fall prevention program had been severely restricted or reduced in community aged care service (Gao 2020). This could lead to an adverse effect on older persons' physical activity and cognitive functioning, but also induced loneliness and social isolation. The new development of VRT based training can be an alternative training platform to provide a virtual simulated environment for the older adults at post-pandemic. The use of VR intervention will become more affordable and attractive to develop equally important with other professional-led exercise on falls prevention strategies. It offers good potential as a user friendly and interactive (alternative) approach to falls prevention in adoption of new VR technology. Therefore, the objective of the study is to pilot a VR games-based training program on falls prevention among community-dwelling older adults in aged care services from Hong Kong.

Methods

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). Under Covid-19 restrictions between 2020 and 2022, the recruitment method for community-dwelling older adults from Hong Kong faced challenges and limitations. Older adults participating in public services including community aged care services were limited and restricted; potential participants and other collaborative parties were more hesitant to participate in the research study. Therefore, the study required additional safety procedures and fulfilled infection control health policies to meet the requirements of human ethics application from research institutions.

With permission and approval from all stakeholders, all falls prevention training sessions, measurements, and clinical observations were taken either in the VR research centre at the Hong Kong Polytechnic university or at either of two community aged care centres in Hong Kong.

Participants

Fifty-five participants were recruited from two community aged care centres in Hong Kong using convenience sampling. 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 of a pilot falls prevention research program held between June 2021 and September 2021. Initially, the participants gave consent to enrol in the recruitment sessions and indicated interest and needs to attend fall risk assessment and 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. Finally, eighteen participants were volunteers who met the selection criteria and were provided with an informed consent form (Figure 2.).

Inclusion Criteria

The target population included the service members from two aged care settings in Hong Kong community. The inclusion criteria were (1) aged 65 years to 85 years inclusive; (2) had a history of a fall within the past 2 years; (3) community-dwelling older adults; (4) at a higher risk of mild cognitive impairment and dementia, assessed by a validated screening tool of Hong Kong Montreal Cognitive assessment test (HK-MoCA score ≤22); (5) walk independently e.g. able to access publicly - VR research centre or local community aged care facilities. These criteria were pre-set and chosen for a pilot randomized control study design.

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 illness. These exclusions were for participants' safety to meet the set requirements governed by the university ethics approval committee and mutual agreement from all stakeholders.

Intervention

The comparison groups involved VR activity-based and exercise-based (Baduanjin) falls prevention groups. The VR training was used **VirCube VR for Rehab program** locally designed from Hong Kong. The ownership of the VR program was wholly managed by the Department of Rehabilitation Sciences of The Hong Kong Polytechnic university. All research logistics and communications and operational management were fully supported by the research team of 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 stimulated cave automated virtual environment (CAVE) platform. This program was eligible for different service users. 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 fire drill, 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 minutes to complete with a short break before the next module. Therefore, each training session lasted approximately 45 minutes. 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 community aged care centres. The exercise group used a traditional Chinese Qigong Baduanjin exercise incorporating a fall prevention education strategy. Based on reviewed literature, the Baduanjin exercise had evidence support on improving the balance function and positive effects on reducing the fall risks for older adults (Zhang 2022; Xia 2021; Cheng2023). The participants learned and practiced Qigong exercise for 20 minutes per session to train up the balance function, breathing exercise and body coordination. In addition, they learned some practical tips for preventing falls and understanding of possible falls scenarios to improve the problem-solving skills and provide cognitive stimulation training. Therefore, every session lasted for about 45 minutes and the exercise group was led by a trained research staff member. After completion of the exercise group training, the group participants were taken the post-test and follow up measurements in respective centres. All repeated measurements were administered by a principal investigator and two research occupational therapists.

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. All participants had signed the consent form and given permission for the research team to conduct the pilot study. 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 practice qigong exercise group training. Photo A to F display the training activities of exercise group (additional file 3).

Data Collection Methods

All participants were assessed and provided information including demographic and health information on 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 concern (Scheffer 2008; Yardley 2005).

Physical Measures

The study measured the physical risk factors and determinants of falls risk level by assessing the postural balance, walking speed and functional mobility in 3-intervals (T1, T2 and T3). We included three validated assessment tools such as Berg Balance Scale (BBS), 6-minute walk test (6MWT) and Time Up and Go test (TUG) to predict the fall risk and measure changes in physical health outcomes across three assessment time points in two intervention groups (Bandara et al. 2020).

The Berg Balance Scale (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 the individuals with a greater risk of falling. A score below 51 with history of falls indicated a predictive risk of fall (Muir et al. 2008).

Another validated fall risk assessment tool was measured by the Time Up and Go test (TUG). The participants were asked to get up from a chair, walk 3 meters, turn around, walk back to the chair, and sit down, and the time taken was recorded (Bischoff et al. 2003). The older adults aged between 65 to 85 living in the community were expected to be able to perform the TUG test within 12 seconds, which indicated a reduced risk of fall. Shorter walking time for participants indicated lesser fall risk. The six-minute walk test (6MWT) measured a longer walking distance with better physical health condition.

Cognitive Measures

Cognitive function was measured using the Hong Kong Montreal Cognitive Assessment (HK-MoCA version). This validated 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 had a good validity in detecting older adult with mild cognitive impairment and dementia (Yeung et al. 2020). For a cutoff point, a score of 22 or below indicated a higher risk of cognitive impairment and dementia. In addition, the study assessed the executive function for the participants by Trail Making Tests (TMT-A and TMT-B) to measure the changes of executive functions in two intervention groups (Lei and Erin 2000).

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 divided into three levels, a score 16-19 indicating low concern of falling, a score 20-27 indicating moderate concern and a score 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.

Statistical Analysis

The primary outcome measured the changes of physical risk factors, and secondary outcomes measured the changes in cognitive performances and fall efficacy at assessments time points. The statistical outcomes were analysed using SPSS version 27 and a p significance value set $\leq .05$. 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 fall 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.

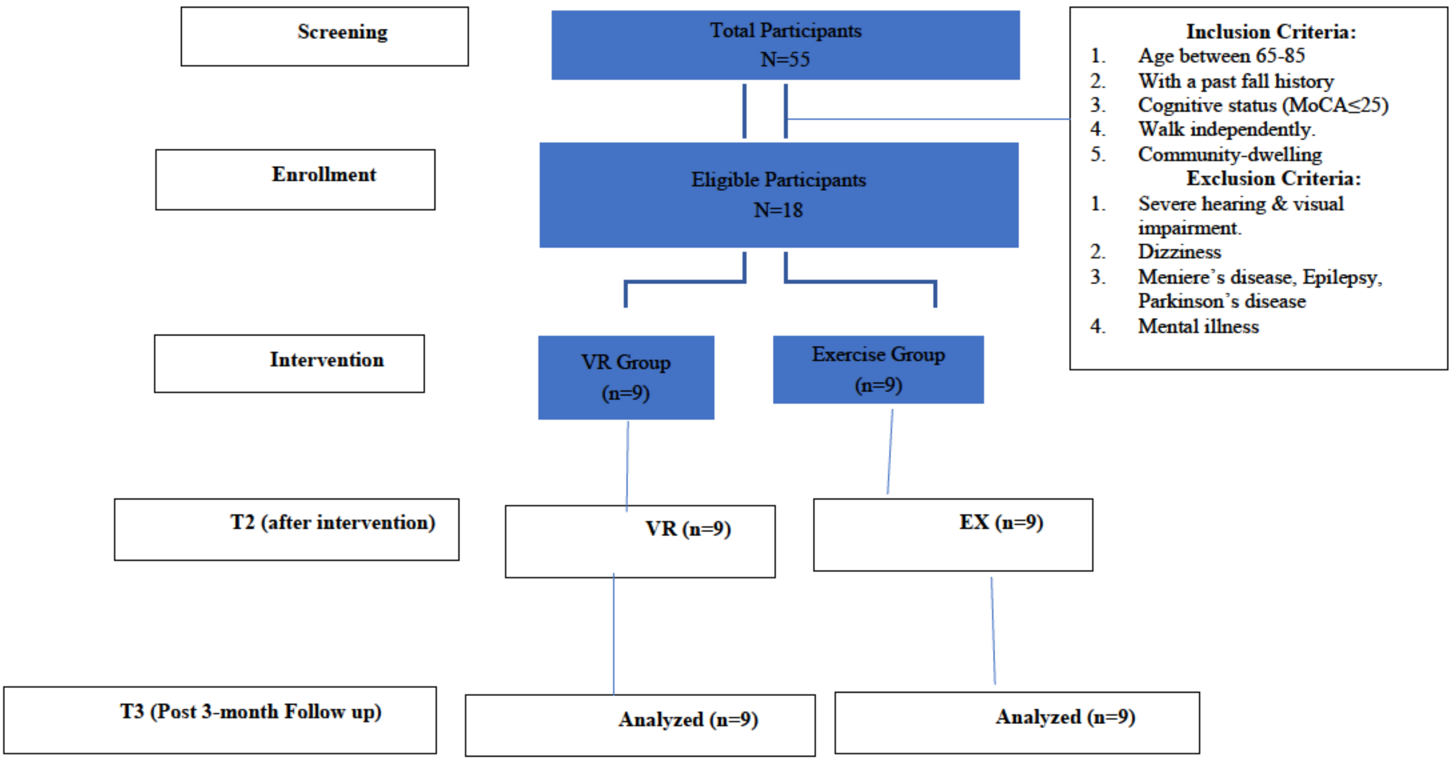
Results

Characteristics of the Participants

Eighteen participants were randomly assigned into groups and were given an informed consent to enrol in the study (Figure 2). All participants successfully completed all measurements, 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 classified as a higher risk of mild cognitive impairment or dementia (mean score HK-MoCA= 18.28 below cutoff score 21/22), and with the history of fall within 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.

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



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 chosen in the VR group, only 2 participants were male in the EX- group. Comparatively, VR group had a higher education level with secondary level but higher incident rate of history of fall (<12 months), fracture and OA knee than the EX-group. Two groups showed a higher incident rate of overweight (VR=44.4%, EX=33.3%) and chronic pain (VR=44.4%, EX=56.6%) at the baseline measurements.

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)	.023*
Gender n (%)			.150
Male	0	2(22.2%)	
Female	9(100%)	7(77.8%)	
Education Level (years),			.461
n (%)	5(55.6%)	7(77.8%)	
Primary or below	4(44.4%)	2(22.2%)	
Secondary or above			
Living Status, n (%)			.372
Live alone	3(33.3%)	5(55.6%)	
With family/carer	6(66.7%)	4(44.4%)	
History of Fall, n (%)			.661
< 12 months	8(88.9%)	5(55.6%)	
> 12 months	1(11.1%)	4(44.4%)	
Number of Chronic Illness			.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)			.141
Normal	5(55.6%)	6(66.7%)	
Overweight	4(44.4%)	3(33.3%)	
History of Chronic Pain,			.661
n (%)	4(44.4%)	5(55.6%)	
Yes	5(55.6%)	4(44.4%)	
No			
History of Fracture, n (%)			.128
Yes	4(44.4%)	1(11.1%)	
No	5(55.6%)	8(88.9%)	
History of Osteoporosis, n (%)			.555
Yes	1(88.9%)	2(22.2%)	
No.	8(11.1%)	7(77.8%)	
History of OA knee, n (%)			.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. * $p < .05$

Baseline Data

As shown in Table 2, there were no significant differences (p>.05) between two groups in all outcome measurements. The HK-MoCA mean score =18.28 of 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 21/22, 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) showed the participants in two groups indicated 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 (6MWT) measurements used for baseline comparison, there were no specific standardized cutoff score and interpretation applied for community dwelling older adults with cognitive impairment.

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<.05
Cognition: HK-MoCA[c]	18.28(3.611)	19.89(1.616)	16.67(4.387)	.055
Executive Function				
Trail Making Test A (TMT-A)	82.096(42.461)	79.194(50.291)	84.998(35.820)	.782
Trail Making Test B (TMT-B)	159.371(94.716)	147.362(102.920)	171.380(90.258)	.606
Time Up and Go Test (TUG)	12.472(2.420)	12.165(2.825)	12.780(2.062)	.605
Berg Balance Scale (BBS)	50.39(4.217)	50.89(4.755)	49.89(3.822)	.630
6-minute walk test (6MWT)	306.766(49.247)	301.833(57.231)	311.700(42.703)	.684
Fall Efficacy Scale International (FES-I)	40.39(11.030)	43.67(5.635)	37.11(14.234)	.217

M[a]: Mean. SD[b]: Standard Deviation. HK-MoCA[c]: Hong Kong- Montreal Cognitive Assessment.

Primary Outcomes

The outcomes of the study are illustrated in the table of multivariate and univariate of dependent variables between groups and time effects (Table 3 and table 4). The primary outcomes including functional mobility ($p=.002$) and balance ($p=.01$) 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 VR group showed significant improvement across three time points. Therefore, the results of physical outcomes showed better improvement and lesser predictive fall risks by VR intervention.

Table 3. Comparison of outcomes measures between groups at post-test and follow up.

Variables	Intervention VR & EX	Post (T2) P value<.05	Follow up (T3) P value<.05
Cognition: HK-MoCA		.013	.021
Executive Function			
Trail Making Test A (TMT-A)		.084	.023
Trail Making Test B (TMT-B)		.280	.033
Time Up and Go Test (TUG)		.013	.075
Berg Balance Scale (BBS)		.021	.193
6-minute walk test (6MWT)		.372	.103
Fall Efficacy Scale International (FES-I)		.691	.788

HK-MoCA: Hong Kong Montreal Cognitive Assessment.

Table 4. Comparison of outcome measures between and within groups (VR n=9, EX n=9)

Outcome measures	Group	Pre-test + SD	Post-test	Follow up	Multivariate	Univariate Within group	P<.05 Between group
Cognition (HK-MoCA)	R	19.88 (1.616)	23.78(3.930)	3.89(4.457)	.010*	.335	.002**
	X	16.67 (4.387)	18.44(4.216)	8.33(4.717)			
Executive Function TMT-A	R	79.19 (50.291)	62.23(22.670)	8.80(19.714)	.110	.103	.227
	X	84.99 (35.820)	95.32(48.893)	9.37(44.374)			
TMT-B	R	147.36(102.920)	112.12(74.661)	9.05(32.0263)	.131	.310	.585
	X	171.38(90.258)	160.75(106.897)	91.34(92.879)			
Balance Level BBS	R	50.89 (4.755)	52.22(4.577)	3.00(3.240)	.130	.027*	.010*
	X	49.89 (3.822)	47.44(3.245)	1.00(3.000)			
Walk Speed 6MWT	R	301.83(57.231)	347.89(71.416)	57.26(60.773)	.352	.128	.061
	X	311.70(42.703)	322.05(44.923)	12.82(47.396)			
Functional Mobility TUG	R	12.16 (2.825)	9.48(2.729)	.14(1.839)	.074	.131	.002**
	X	12.78 (2.062)	12.60(3.215)	1.16(2.587)			
Fear of Fall (FES-I)	R	43.67 (5.635)	41.89(11.230)	4.11(12.534)	.339	.728	.063
	X	37.11 (14.234)	39.78(10.883)	2.56(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 <.05 level of significance.

***P* <.005

Secondary outcomes

There was significant difference in cognition (HK-MoCA, p=.010) between the two groups and times interactions (Table 4.). The mean scores (HK-MoCA) of VR group at post-test (23.78) and follow up (23.89) were above the cutoff point >22 indicating a greater improvement on cognition than the EX-group. In contrast, the result of executive functions showed no significant difference between two groups, but VR group showed greater improvement than 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 concern of falling (FES-I>28) after intervention (FES-I p=.691) and follow up (FES-I p=.788). The results indicated VR group had better improvement on cognition, but no evidence supported the changes of executive functions and fall efficacy in the two groups.

Discussion

Overview

The pilot study showed promising effects on falls prevention using VR activity-based application (VR CAVE program) for the participants from Hong Kong. The results supported the full-immersive VR intervention had better training outcomes than traditional Chinese Baduanjin exercise training. It supported the VR CAVE pilot program was useful and a potential falls prevention training program applicable for older adults with mild cognitive impairment in Hong Kong aged care services (Kim et al. 2019; Kwan et al. 2021).

Full Immersive VR CAVE Training on Falls Prevention

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

With similar findings on literature review, 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 minutes, 16 training sessions in total (Law et al. 2014; Yang et al. 2020). Because the study allowed flexibility for participants to complete 16-session longer than 8 weeks because of the unexpected occasion during pandemic in Hong Kong. The VR participants reported that a wearable 3D stereoscopic was handy and much more comfortable than head-mounted headset, so the new headset largely eliminated VR simulator sickness during VR CAVE training. Throughout the intervention period, the feedback of VR participants was very 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 very helpful for improving their physical and balance functions. A similar future study should be considered to investigate the user experience and perception toward the use of VR intervention in aged care services.

Training Effects of VR Training and Exercises-based Training on falls prevention

Our research findings supported that VR training was more effective at simulating dual-mode cognitive-motor training than traditional exercise intervention (Irazoki et al. 2020). According to a recent review, people with mild cognitive impairment showed higher risk of falls and poorer instability than healthy adults (Welmer et al. 2017). When compared with traditional exercise group training, the simulated VR CAVE experiences were so interesting and stimulating for VR activity-based engagement. Though, the practice of Baduanjin exercise was healthy and a good balance exercise, relatively it demanded more cognitive challenge for participants with memory decline to follow and memorize every single step. Therefore, the 8-step Baduanjin exercise was a routine repetitive training and less cognitive stimulation for the participants with cognitive impairment. In contrast, the VR participants showed good attention, engaging, interactive and good acceptance of VR use. According to results shown in table 3 and table 4, the VR participants found greater training effects and significantly 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 sensitive and not reliable for community-dwelling older adults with cognitive frailty (Uemura et al. 2012). Likely, 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 showed no significant improvement between groups but the mean scores of TMTA and TMTB in VR group were decreasing and EX-group remained no change across time occasions. Unexpectedly, the VR group showed significantly longer improvement on executive function at follow up. Further study is recommended to investigate the effect of cognitive training on VR intervention.

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 might lead to a volunteer bias and low generalizability of the findings in local population. However, the study was a pilot research project to evaluate the effects between VR and exercise-based training on falls prevention for community-dwelling older adults from Hong Kong. The small sample size was justified to start a pilot randomized control trial study. Thirdly, the validity and reliability of results might be affected because the participants were required to wear face masks and follow social distancing policy during the falls prevention training. Therefore, the actual performance of participants might be limited and restricted.

Fourthly, 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 seemed to have 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.

Conclusion

Our study supported the promising evidence on the effects of Virtual Reality activity-based training on preventing falls among community-dwelling older adults with mild cognitive impairment. 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 my 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 aged care services from Hong Kong. Prior to adoption of full immersive VR intervention and expanding the use of existing VR applications in aged care and rehabilitation services, the special considerations of VR CAVE application are technological support and adaptation for ageing population. A future study should be replicated 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 aged care service.

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References

Bandara, K. M. T., Ranawaka, U. K., & Pathmeswaran, A. (2020). Usefulness of Timed Up and Go test, Berg Balance Scale and Six Minute Walk Test as fall risk predictors in post stroke adults attending Rehabilitation Hospital Ragama. 13th International Research Conference, General Sir John Kotelawala Defence University. http://ir.kdu.ac.lk/handle/345/2958

Bischoff, H. A., Stähelin, H. B., Monsch, A. U., Iversen, M. D., Weyh, A., Von Dechend, M., & Theiler, R. (2003). Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women. *Age and ageing*, *32*(3), 315-320. https://doi.org/10.1093/ageing/32.3.315

Chau, P. H., Kwok, Y. Y. J., Chan, M. K. M., Kwan, K. Y. D., Wong, K. L., Tang, Y. H., & Leung, M. K. (2021). Feasibility, Acceptability, and Efficacy of Virtual Reality Training for Older Adults and People With Disabilities: Single-Arm Pre-Post Study. *J Med Internet Res, 23*(5), e27640. https://doi.org/10.2196/27640

Cheng M, Wang Y, Wang S, Cao W, Wang X. Network meta-analysis of the efficacy of four traditional Chinese physical exercise therapies on the prevention of falls in the elderly. Front Public Health. 2023 Jan 4;10:1096599. doi: 10.3389/fpubh.2022.1096599. PMID: 36684937; PMCID: PMC9846771. https://doi: 10.3389/fpubh.2022.1096599.eCollection 2022

Gao, Z., Lee, J., & McDonough, D. (2020). Virtual Reality Exercise a Coping Strategy for Health and Wellness Promotion in Older Adults during the COVID-19 Pandemic. *Journal of Clinical Medicine. 9*,1986; https://doi.org/10.3390/jcm9061986

Ge, S., Zhu, Z., Wu, B., & McConnell, E. S. (2018). Technology-based cognitive training and rehabilitation interventions for individuals with mild cognitive impairment: a systematic review. *BMC Geriatric, 18*(1), 213. https://doi.org/10.1186/s12877-018-0893-1

Gillespie, L. D., Robertson, M. C., Gillespie, W. J., Lamb, S. E., Gates, S., & Cumming, R. G. (2009). Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev. 2*:CD007146. https://doi.org/10.1002/14651858.CD007146.pub3

Irazoki, E., Contreras-Somoza, L. M., Toribio-Guzman, J. M., Jenaro-Rio, C., van der Roest, H., & Franco-Martin, M. A. (2020). Technologies for Cognitive Training and Cognitive Rehabilitation for People With Mild Cognitive Impairment and Dementia. A Systematic Review. *Front Psychol, 11*, 648. https://doi:10.3389/fpsyg.2020.00648

Kim, O., Pang, Y., & Kim, J. H. (2019). The effectiveness of virtual reality for people with mild cognitive impairment or dementia: a meta-analysis. *BMC psychiatry*, *19*(1), 1-10. https://doi.org/10.1186/s12888-019-2180-x

Kwan, R. Y. C., Liu, J. Y. W., Fong, K. N. K., Qin, J., Leung, P. K., Sin, O. S. K., & Lai, C. K. (2021). Feasibility and Effects of Virtual Reality Motor-Cognitive Training in Community-Dwelling Older People With Cognitive Frailty: Pilot Randomized Controlled Trial. *JMIR Serious Games, 9*(3), e28400. https://doi:10.2196/28400

Law, L.L., Barnett, F., Yau, M.K., & Gray, M.A. (2014). Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: a systematic review. *Ageing Res Rev*. 2014; 15:61–75. https://doi.org/10.1016/j.arr.2014.02.008

Lei. L., & Erin, D. B. (2000). Performance on Original and a Chinese Version of Trail Making Test Part B: A Normative Bilingual Sample, *Applied Neuropsychology*, 7:4, 243-246, https://doi.org/10.1207/S15324826AN0704_6

Leung, D. D. M. (2019). Influence of functional, psychological, and environmental factors on falls among community-dwelling older adults in Hong Kong. *Psychogeriatrics, 19*(3), 228-235. https://doi:10.1111/psyg.12386

Liu-Ambrose, T., Nagamatsu, L. S., Hsu, C. L., & Bolandzadeh, N. (2013). Emerging concept: "Central benefit model" of exercise in falls prevention. *Br J Sports Med. 47*(13):856. http://dx.doi.org/10.1136/bjsports-2011-090725

Mirelman, A, Rochester, L., & Maidan, I (2016). Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomized controlled trial. *Lancet. 388*(10050):1170–82. https://doi.org/10.1016/S0140-6736(16)31325-3

Mirelman, A., Maidan, I., Shiratzky, S.S., Hausdorff, J.M. (2020). Virtual Reality Training as an Intervention to Reduce Falls. In: Montero-Odasso, M., Camicioli, R. (eds) Falls and Cognition in Older Persons. Springer, Cham. https://doi.org/10.1007/978-3-030-24233-6_18

Montero-Odasso, M. M., Verghese, J., Beauchet, O., & Hausdorff, J. M. (2012). Gait and cognition: a complementary approach to understanding brain function and the risk of falling. *Journal of American Geriatric Society, 60*, 2121-36. https://doi.org/10.1111/j.1532-5415.2012.04209.x

Montero-Odasso, M., van der Velde, N., Martin, F. C., Petrovic, M., Tan, M. P., Ryg, J., & Masud, T. (2022). World guidelines for falls prevention and management for older adults: a global initiative. *Age and ageing*,*51*(9), afac205. https://doi.org/10.1093/ageing/afac205

Muir, S. W., Berg, K., Chesworth, B., & Speechley, M. (2008). Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study. *Physical therapy, 88*(4), 449-459. https://doi.org/10.2522/ptj.20070251

Muir, S. W., Berg, K., Chesworth, B., & Speechley, M. (2008). Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study. *Physical therapy, 88*(4), 449-459. https://doi.org/10.2522/ptj.20070251

Muir, S. W., Gopaul, K., & Montero-Odasso, M. M. (2012). The role of cognitive impairment in fall risk among older adults: a systematic review and meta-analysis. *Age Ageing. 41*(3):299–308. https://doi.org/10.1093/ageing/afs012

Ohman, H., Savikko, N., & Strandberg, T. E. (2016). Effects of exercise on cognition: the Finnish Alzheimer disease exercise trial: a randomized, controlled trial. *Journal of American Geriatric Society: 64*:731-38. https://doi.org/10.1111/jgs.14059

Qian, X. X., Chau, P. H., Kwan, C. W., Lou, V. W., Leung, A. Y. M., Ho, M., Chi, I. (2020). Seasonal pattern of single falls and recurrent falls amongst community-dwelling older adults first applying for long-term care services in Hong Kong. *Age Ageing, 49*(1), 125-129. https://doi:10.1093/ageing/afz139

Sarah, A. C., Jodi, M. H., Jacob, D., Bolzenius, L.E., Salminen, L. M., Baker, S. S., & Robert, H. P. (2015). Longitudinal Change in Performance on the Montreal Cognitive Assessment in Older Adults, *The Clinical Neuropsychologist*,29:6,824-835, https:/doi.org/10.1080/13854046.2015.1087596

Scheffer, A. C., Schuurmans, M. J., van Dijk, N., van der Hooft, T., & de Rooij, S. E. (2008). Fear of falling: Measurement strategy, prevalence, risk factors and consequences among older persons. *Age and Ageing*, 37,19–24. https://doi.org/10.1093/ageing/afm169

Stanmore, E.K., Mavroeidi, A., de Jong, L.D. et al. (2019). The effectiveness and cost-effectiveness of strength and balance Exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: a multi-center, cluster randomized controlled trial. *BMC Med* 17, 49. https://doi.org/10.1186/s12916-019-1278-9

Thapa, N., Park, H. J., Yang, J., Son, H., Lee, M. J., Kang, S. W., Park, K. W., & Park, H. (2020). The Effect of a Virtual Reality-Based Intervention Program on Cognitive in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial. *Journal of Clinical Medicine 9*,1283. https://doi.org/10.3390/jcm9051283

Uemura, K., Shimada, H., Makizako, H., Yoshida, D., Doi, T., & Tsutsumimoto, K. (2012). A lower prevalence of self-reported fear of falling is associated with memory decline among older adults. *Gerontology. 58*(5),413–8. https://doi.org/10.1159/000336988

Verghese, J., Robbins, M., & Holtzer, R. (2008). Gait dysfunction in mild cognitive impairment syndromes *Am Geriatric Soc.;56*(7),1244. https://doi.org/10.1111/j.1532-5415.2008.01758.x

Welmer, A. K., Rizzuto, D., Laukka, E. J., Johnell, K., & Fratiglioni, L. (2017). Cognitive and physical function in relation to the risk of injurious falls in older adults: a population-based study. *Journal Gerontology a Biological Science Medicine Society. 2*(5),669–75. https://doi.org/10.1093/gerona/glw141

World Health Organization. (2008). WHO global report on falls prevention in older age. World Health Organization. https://apps.who.int/iris/handle/10665/43811

Xiao, Y., Luo, Q., Yu, Y., Cao, B., Wu, M., Luo, Y., ... & Zhou, J. (2021). Effect of baduanjin on the fall and balance function in middle-aged and elderly people: A protocol for systematic review and meta-analysis. *Medicine*, *100*(37), e27250. https://doi:10.1097/MD.0000000000027250

Yang, C.M., Chen Hsieh, J.S., Chen, Y.CV., Yang, S.Y., & Lin, H.C.K. (2020). Effects of Kinect exergames on balance training among community older adults: A randomized controlled trial. *Medicine* (Baltimore).:99(28): e21228. https://doi.org/10.1097/ MD.000000000002122822

Yardley, L., Beyer, N., Hauer, K., Kempen, G., Piot-Ziegler, C., & Todd, C. (2005). Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and ageing, 34*(6), 614-619. https://doi.org/10.1093/ageing/afi196

Yeung, P. Y., Wong, L. L., Chan, C. C., Yung, C. Y., Leung, L. J., Tam, Y. Y., & Lau, M. L. (2020). Montreal cognitive assessment—single cutoff achieves screening purpose. *Neuropsychiatric Disease and Treatment*, 2681-2687. https://doi.org/10.2147/NDT.S269243

Yogev-Seligmann, G., Hausdorff, J. M. & Giladi, N. (2008). The role of executive function and attention in gait. *Mov Disorder. 23(3),*329–42. https://doi.org/10.1002/mds.21720

Zahabi, M., & Abdul Razak, A. M. (2020). Adaptive virtual reality-based training: a systematic literature review and framework. *Virtual Reality, 24*(4), 725-752. https://doi:10.1007/s10055-020-00434-w

Zhang Y, Wu J, Wang X, Zheng G. Baduanjin exercise for balance function in community-dwelling older adults with cognitive frailty: a randomized controlled trial protocol. *BMC Complement Med Ther.* 2022 Nov 17;22(1):295. doi: 10.1186/s12906-022-03764-1. PMID: 36397018; PMCID: PMC9670484. https://doi: 10.1186/s12906-022-03764-1

1.6 Links and Implications

The findings of this study supported that VR CAVE training had significant training effects in the VR groups, demonstrating greater improvement than the exercise-based group in physical and cognitive health outcomes. However, the fear of falling and executive function did not show improvement between the two groups. Furthermore, the data collected from the VR group were utilized for the analysis in Study 2. Similarly, all three quantitative studies employed similar research methods and shared data sources. Study 1 examined the feasibility of the VR CAVE fall prevention framework and provided predictive results for reference in the next study.

CHAPTER 4: PAPER 2 –INNOVATIVE VIRTUAL REALITY (VR) APPLICATION FOR PREVENTING OF FALLS AMONG CHINESE OLDER ADULTS: A USABILITY AND ACCEPTANCE EXPLORATORY STUDY

4.1 Introduction

This paper was a first exploratory study to investigate the user' perception and acceptance on using VR CAVE application for older adults in Hong Kong. The data collected from study 1 and study 3 were shared and utilized for analysis in this chapter. This study was a single-arm exploratory study, VR participants were recruited who completed the full VR CAVE training sessions in respective studies. The data collection period was taken longer between July 2021 and May 2022. Based on TAM and the review literature, a usability questionnaire was employed to investigate the participants' results in measuring the change of different perceived factors on using VR technology in fall prevention and leisure engagement at pandemic. The findings supported the usefulness and acceptance of using full-immersive VR training on fall prevention among Chinese older adults.

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Accepted Paper

Innovative Virtual Reality (VR) Application for Preventing of Falls among Chinese Older Adults: A Usability and Acceptance Exploratory Study

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Abstract

Objective: Full immersive Virtual Reality (VR) technology shows potential for reducing the risks of falls in older adults. There is yet little evidence to support the usability and acceptance on using VR technology application in community aged care service. The study reports on research that aims to address that gap by evaluating the usefulness and acceptance of using an innovative VR application among Chinese older adults from Hong Kong.

Methods: A single-arm exploratory study was conducted to evaluate how the participants experienced the use of a fully immersive Cave Automatic Virtual Environment (CAVE) VR program on fall prevention. Thirty-one participants were recruited by convenience sampling based on their fall concerns and potential risk of falls. The participants completed 16 training sessions over eight weeks using VR CAVE application. They were asked to complete a VR usability questionnaire (HK-version) based on the Technology Acceptance Model and previous research, and they took fall risk assessments at pretest, post-test and follow up.

Results: The participants' group significantly showed improvements on reducing the risk factor of falls including balance, functional mobility, walking speed and fear of falling after VR intervention. Perceived usefulness (PU), perceived enjoyment (PE), user experience (UE) and intention to use (IU) had an overall significant change at different time points. These are important factors to influence the participants' acceptance of use of VR technology application. Perceived ease of use (PEOU) and social norms (SNs) had an inconsistent result, and some items were low validity. The findings indicated a positive training effect on fall prevention and high acceptance of adoption of the VR technology application.

Conclusion: This study supports the growing evidence on the usefulness and acceptance of using full-immersive VR training on fall prevention among Chinese older adults. They perceived that VR CAVE application was useful and innovative as an effective fall prevention training. Technically, the application of VR CAVE technology faced many challenges and not easily manageable under Covid-19 restrictions and the limitation on technological adaptation for older adults. However, investment in full immersive VR technology application is supported for future adoption in aged care and rehabilitation services.

KEYWORDS

Full immersive virtual reality (VR); cave automatic virtual environment (CAVE); technology acceptance model (TAM); ageing; fall risk; usefulness and acceptance.

Introduction

Falls in older adults is a global health challenge causing severe impacts on individuals and a financial burden on the public healthcare system [1]. A worldwide multidisciplinary group of experts and all stakeholders proposed a global new initiative on guidelines for fall prevention and management in older adults [2]. New worldwide guidelines recommended healthcare professionals and aged care operators provide advice and support on falls prevention with evidence-driven fall prevention strategies for all older adults. About 30% of older adults aged over 65 fall at least once per year, while among those with mild cognitive impairment (MCI) and dementia, about 60-80% of individuals report falls each year [3]. In Hong Kong, there was an annual reported occurrence of 20-26.4% of community-dwelling older-adults falling [4,5]. In [5], amongst 89,100 older adults, about 32% older adults fell in the past 90 days. Importantly, a history of falls is found to be one of the predicators of future falls [6]; the risks of falls and cognitive impairment are closely interrelated, and the incidence of falls increases with health decline in ageing. The risks of falls are associated with life-changing impacts: fear of falling, fall injuries, mobility decline, depression, loneliness, and premature death [7,8].

Virtual Reality Technology (VRT) intervention attracts more research attention in health-related applications and is growing rapidly in recent years in aged care fields [9,10]. There is evidence to support its use in fall prevention, as well as reduction in the fall risks among older adults living with cognitive impairment [11,12,13]. There is a research gap in exploration of the usability and acceptance of use of VRT application in older adults.

Based on a literature review, the fall risk factors in older adults have been summarized. Four categories of fall risk factors in older adults include: biological (e.g., age, disease), behavioural (e.g., lack of exercise), socioeconomical (e.g., low education) and environmental (e.g., slippery floors) [14]. VRT intervention adopts a dual-task (cognitive and motor) training strategy, for example, improving cognitive-motor function in a virtual simulated environment. VRT application can design a simulated walking environment with obstacles or challenges for walking and balance practice and learning executive function through simulated activity scenarios, for example attention and spatiotemporal judgement. To reduce the physical risk factors in older adults, a novel intervention of Virtual Reality Technology is proposed to be an innovative cognitive-motor intervention approach to stimulate the participants' attention and interest in a virtual reality simulation. VRT intervention can be effective as a good alternative intervention to target the fall risk factors but the perceptions and attitudes towards using VR technologies among older adults are still under-investigated [15]. Therefore, the study applies the method of the Technology Acceptance Model (TAM) to evaluate perceived factors on acceptance using VRT application in older adults from Hong Kong [16].

Materials and Methods

This exploratory study involved a single-arm design and used a convenience sampling method to measure the changes on physical health outcomes at fall risk measurements and perceived factors based on VR usability questionnaire (HK-version) at pretest (T1), post-test (T2) and the follow up (T3). As the study was carried out during the COVID pandemic in Hong Kong between 2020-2022, the recruitment of participants was very challenging, and randomization was no longer feasible. Mostly, potential participants and other stakeholders such as aged care operators were hesitant about face-to-face training both in community aged care centres and the VR CAVE research centre at the Hong Kong Polytechnic University. Despite restrictions of Covid-19 regulations, the requirements from the human ethics committee application and importantly the participants' availability, thirty-one eligible participants were successfully recruited according to their needs, potential to use VR and other selection criteria set in our study.

The TAM model was applied in the study for understanding of participants' acceptance of a new technology in VR CAVE application. It helped us to anticipate and explain users' behaviours. In addition, it suggested a theoretical groundwork to understand the relationships between various variables, user perception, and benefits of technology application [16,17]. The study applied a TAM scale including perceived usefulness (PU), perceived ease of use (PEOU), and intention to use (IU). The perceived usefulness (PU) and perceived ease of use (PEOU) were defined as the degree to which the older adults perceived that using VR would augment their daily activities and be free of effort [18]. Evidently, PU and PEOU were one of predictive factors in the acceptance of a technology in our study [19].

The VR usability questionnaire (HK-version) also included social norms (SNs) and perceived enjoyment (PE) to indicate the participants' perception and acceptance on using VR technology application. Commonly, SNs were defined as older adults' perception to consider whether they should use VR. The perceived enjoyment (PE) was defined as older adults perceived using the technology as fun, stimulating, and interactive. These factors were counted as the predictive factors to influence the acceptance and intention to use VR in older adults. According to previous research [20-22], user experience (UE) indicated a strong effect on usage intentions and the older adults' behaviour during and after using VR technology intervention. In view of TAM model and reviewed literature, the study adopted to use the VR usability questionnaire (HK-version) as an instrument to compare the changes of these variables across the time intervals.

Fall risk measurements:

The fall risk measurements focused on physical performances relating to intrinsic risk factors of falls [8]. The study measured the risk factors of falls by assessing the postural balance, walking speed and functional mobility in 3-time intervals (T1, T2 and T3). Three validated assessment tools for older adults were used such as Berg Balance Scale (BBS), 6-minute walk test (6MWT) and Time Up and Go test (TUG) to assess the change in falls risk using the VRT intervention [23].

Participants

Thirty-seven participants were recruited from three community aged care centres in Hong Kong (Figure 1). All participants gave consent to enrol in the screening sessions and indicated interest and willingness to participate in the fall risk assessment and VR study. Thirty-one participants (83.78%) were analysed after successfully completing 16 VR trainings between June 2021 and May 2022. Volunteer participants met the selection criteria and provided their permission with informed consent.

Inclusion Criteria

The inclusion criteria were (1) aged 65 years to 85 years; (2) had a history of falls within 2 years; (3) no experience of VR; (4) able to walk independently and to be able to access the VR research centre; (5) HK-MoCA < 26

Exclusion Criteria

Participants were excluded if they had a medical diagnosis of unstable health conditions such as dizziness, epilepsy, Parkinson's disease, and severe sensory and motor impairments. These exclusions were for participants' safety and to fulfill the requirements of the University Ethics Approval Committee.

Intervention

A new VRT application called **VirCube VR** for Rehab program was used in the VR training. The VR CAVE program was set up for research purpose, fully managed by the Department of Rehabilitation Sciences at 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 virtual living environment. The VR training modules included fire emergency handling, walking exercise, balancing game activities and community daily practices. The participants received 2 sessions per week, 16 training sessions in total. Each training session lasted 45 minutes. VR training sessions were standardized and supervised by a trained researcher.

Procedure

Eligible participants signed the consent form and gave permission for the research team to provide the VR training. The participants were required to arrange public transportation to attend the VR training sessions. At the onset of the COVID pandemic, all participants were required to apply for a special permission permit to access the VR research centre at The Hong Kong Polytechnic University and meet the requirements of the health declaration. 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 physical discomfort or complaint. To meet an additional safety requirement by the human ethics committee of the Hong Kong Polytechnic University, the study had provided full insurance coverage for all participants.

For each session, all participants were kept under close supervision and supported by a trained researcher. They were allowed to take a rest or stop at any time if necessary or before the next VR module training. The VR research centre was considered a safe environment and comfortable for all participants. The participants in the waiting area could observe the other participants playing VR game activities. After the VR training session, the researcher asked the participants' feedback on experiencing full immersive VR game activities, and checked and cleaned all VR wearing devices before the next session.

One specific full immersive VR game activity for preventing falls is displayed with a detail description. The other similar VR games activities are displayed and documented in additional file 1.

VR Game: **Jogging and balancing exercise**

Purpose: Physical balance and safe walking training

Grading: 3 levels (Level 1-by hand trackers; Level 2- by hand trackers & obstacle; Level 3- by hand/foot trackers & obstacles)

Device: 3D stereoscopic eyewear, hand, and foot trackers

<table>
<tr>
<td>Jogging in the park


</td>
<td>Sequencing & Grading:
1. Participant uses hand trackers & selects a level of activity
2. Participant runs with arms movement and keeps on a running path (upper limb balance)
3. Participant runs with upper and lower limbs trackers and follows a running path (whole body balance & physical training)
4. Participant runs and avoids hitting any obstacle on a running path (advanced physical balance and coordination skill)
5. Participant runs faster and overcomes more obstacles (physical and cognitive training)
  
VR trial (video samples)
physical.mp4 balancetraining.mp4</td>
</tr>
</table>

Data Collection

All participants provided information including demographic and other health information in the screening session. The basic information included age, gender, living status, education level, falls history, cognitive status, and other medical history (Table 1.). Risks assessment was undertaken, and the participants completed a VR acceptance questionnaire before and after VR training; there was a post 3-month follow up for statistical analysis.

VR Usability - Outcome Measure

Participants were asked to fill in a VR usability questionnaire (appendix 1) at pretest (Time 1), posttest (Time 2) and 3-month follow up (Time 3). The HK-version questionnaire was based on TAM scale and Venkatesh studies (appendix 1: VR Questionnaire). The self-rating questionnaire was used to collect the participants' perceptions about the usefulness and user experience of VR by six sets of questions (PU, PEOU, SNs, PE, UE & IU). A 5-point Likert scale was used to assess a level of perception and experience on using CAVE VR technology, scoring from (1) strongly disagree, (2) disagree, (3) neutral, (4) agree to (5) strongly agree. The higher the score indicated greater user perception and acceptance of VR.

Health Outcome Measures

The study measured the risk factors of falls by assessing the postural balance, walking speed and functional mobility. The Berg Balance Scale (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 persons aged 65 or above. The cut off score below 45 indicated the individuals with a greater risk of falling. A score below 51 with history of falls indicated a predictive risk of fall [24].

Another validated fall risk assessment tool was measured by the Time Up and Go test (TUG). The participants were asked to get up from chair, walk 3 meters, turn around, walk back to chair, and sit down, and the time taken was recorded [25]. The older persons with ages between 65 to 85 living in the community were expected to be able to perform the TUG test within 12 seconds which indicated a reduced risk of fall. Shorter walking time for participants indicated better balance performance and lesser fall risk. The six-minute walk test (6MWT) measured a longer walking distance with better physical condition.

Psychological consideration

Fear of falling is associated with a range of adverse health and psychosocial outcomes, including increased risk of falls, poorer physical functioning, more rapid decline in cognitive function and well-being [26]. The Fall Efficacy International Scale (FES-I) was a validated assessment tool to compare the level of fall concerns for the participant's group. 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 cut off score of older persons living in community divided into three levels, a score 16-19 indicating low concern of falling, a score 20-27 indicating moderate concern and a score 28-64 indicating high concern [27].

Statistical Methods

The statistical outcomes were analysed using SPSS version 27. All eligible participants' information was summarised using descriptive statistics (Table 1). The baseline demographic characteristics of participants included age, gender, educational level, living and cognitive status, body mass index, history of falls and other health history such as chronic pain and disease, and history of fracture.

To compare the outcomes measures within subjects in the same group from pre-test, post-test and follow up, one-way repeated measures ANOVA was used in SPSS analysis. The time factor was used as the independent variable, the dependent variables including each subset of VR acceptance questionnaire, physical and psychological factors of falls. The reliability and validity of items on the VR usability questionnaire (HK-version) were analysed by Cronbach's alpha and Pearson's product moment correlation method.

Results

Characteristics of the Participants

Table 1 shows the 31 participants (30 female, and 1 male) who were recruited into the study. The mean age of the participants was 72.23 years old, education level was secondary (64.5%), had a fall history within 12 months (54.8%), a history of fracture (38.7%) and chronic pain (45.2%). The body mass index (BMI) was 23.03 kg/m^2 (WHO Asian BMI= 23–27.5 kg/m^2(overweight). The average number of chronic diseases per participant was 3.12 chronic, most commonly in older adults such as knee osteoarthritis (OA), osteoporosis, chronic pain, and hypertension etc. In addition, the study assessed the participants' cognition by a Hong Kong version of Montreal Cognitive test (HK-MoCA), the mean score (HK-MoCA =23.48) was above the cut-off point (HK-MoCA = 21/22) indicating a lesser risk of cognitive decline [28].

Table 2 shows the validity test of VR usability questionnaire, it indicated PU ($p<.005$), PE ($p <.001$), UE ($p <.005$) and IU ($p<.001$) items were tested as high validity (*p* value ≤.05 and Pearson product moment coefficient > .361 [29]. However, three items only such as PEOU1 ($p =.075$), PEOU3 ($p=.123$) and SN2 ($p=.061$) were tested as not significant (*p* value >.05 and $r_{xy} < 0.361$). Predictably, the VR acceptance questionnaire (HK-version) was a good validity test in the study.

Table 3 shows summary statistics and frequency distributions of variables in the VR usability questionnaire. The mean (M) value was ranging from 3.03-4.45 and the standard deviation (SD) was ≤ 1.3292 in Time 1 (T1). The mean (M) value was ranging from 3.48-4.68 and the standard deviation (SD) was ≤ 0.922 in Time 2 (T2). Whereas the mean (M) value was ranging from 3.191-4.81 and the standard deviation (SD) was ≤ 1.078 in Time 3 (T3). The trend of each subset of variables (mean values) were increasing at different time assessment points.

Table 4 shows the internal consistency and reliability of the dependent variables, Cronbach's α ranged from 0.532 - 0.833. PU, PEOU, PE, and UE showed higher internal consistency and reliability, however, SNs ($\alpha=.532$) and IU ($\alpha=.642$) indicated a lesser internal consistency and reliability. Cronbach's α reliability analysis indicates an acceptable reliability when $\alpha > 0.700$.

Results on VR usability in older adults

Table 5 shows there was an overall significant difference (increase) between the means at different time points from pretest, post-test and follow up in perceived usefulness **(PU)** $F(1.975, 59.250)=4.685$, $p<.05$), perceived enjoyment **(PE)** $F(1.690, 50.703)=4.852$, $p<.05$), user experience **(UE)** $F(1.745, 52.353)=3.289$, $p<.05$) and intention to use **(IU)** $F(1.976, 59.286)=6.716$, $p<.005$). In particular, the participants' group indicated a significance difference (p=.011) on user experience **(UE)** after VR training. Besides, **PU** (p=.018), **PE** (p=.017) and **IU** (p=.005) were found significantly differences when comparing from T3 (at follow up) with T1. However, there was no significant difference in perceived ease of use (PEOU) and social norms (SNs) among the three assessment points. The overall means scores of all perceived factors were increasing over time effects.

Results on health outcomes (risk factors of falls)

The research found an overall significant difference between the means difference at different time points in all health outcomes shown in Table 5 (6MWT, TUG and FES-I $p<.001$; BBS $p<.05$). By comparison, walk speed (6WMT), functional mobility (TUG) and fear of falling (FES-I) were found to have significant differences ($p<.001$) when comparing T3 with T1. Significantly, the physical performance such as walk speed (6MWT) and functional mobility (TUG) showed greater improvement ($p<.001$) after VR training (T2). The overall health outcomes showed greater improvement indicating a lesser risk of predictive fall after the study.

Discussion

This exploratory study found improvements in usability and acceptance on use of VRT application for preventing falls among Chinese older adults. The participants' group significantly showed improvement on health outcomes and the perceived factors toward accepting the use of VRT application. To a certain extent, learning to use new VRT was innovative but a new challenge for older adults, promisingly the direct engagement of VR CAVE technology was effective and supported by evidence from previous research. To maintain a smooth study continuity, the operation of VR session was closely monitored, and tailor made for the participants.

The study confirmed the evidence to adopt the use of VR acceptance questionnaire (HK-version) based on TAM scale and reviewed literature to assess the perceived factors on influence the users' experience and behaviour in Hong Kong [30] The used questionnaire was valid and reliable ($r> 0.361$; p value < 0.05) in different perceived factors except items PEOU1, PEOU3 and SN2. Responses to the question regarding the influence of friends and acquaintances (SN2) might have been misinterpreted from the participants under the impact of pandemic in Hong Kong because they had limited social connection and face-to-face interaction in community. They became less socially active and not often meeting peers as usual in daily living. Predictably, the peer influence and seeking friends support to trial new VR application might be minimized and overlooked. Based on the participants' behaviour and the observation from the research team, the new VR CAVE application was not easy for participants to manage at the beginning of the study. The technological support of VR CAVE technology was critical for an inexperienced user and the research support team, for example difficult to operate hand controller accurately and position the limbs sensor properly in different users. Though the new VR CAVE technology encountered some technical limitations, it indicated a great potential to develop and invest the high-tech application in future in the aged care field. Similarly, our study indicated that the participants encountered difficulty using VR CAVE, and they required additional help and supervision to engage with VR game activities in the training period. Practically, the participants might experience differently or be less skilful using the VR CAVE application without prior VR experience. More particularly, the self-rated score was lower in perceived ease of use (PEOU) than other perceived factors. Tables 2 and 3 indicate the low internal validity and reliability of PEOU items.

Based on the findings, PU, PE, UE, and IU were the most important factors to attract and influence the usability, users' behaviours, and perceptions to use a new VRT. The perceived factors were significant increases at three assessment time points. Although the PEOU and SNS were not a significant difference in the study, the overall means showed a small increase across time occasions. Constantly, the feedback of participants was positive, and they were willing to learn and fully engage with all VR sessions. Partly, the negative results might be reflective of the limitation on VR CAVE technology and the social impact during Covid-19 restrictions in Hong Kong. Therefore, the overall results of VR usability in older adults showed promising evidence on the usefulness and acceptance to use new VRT application in falls prevention training.

Tabe 1 shows the participants' group had a high risk of falls at T1 e.g., 54.8% of the participants had falls within 12 months. They reported to have biological and behavioural risk factors such as overweight, three chronic diseases per each participant and lack of physical activity. These health problems might limit physical activity and influence the factor of fear of falling, because they were worried about falling and experienced falls in the past. Based on their personal needs and falls concerns, they showed good intention to participate the CAVE VR study. Possibly, it could induce a sampling bias and might influence the results of the study.

On the other hand, our results were consistent with recent reviews and supported the usefulness of an innovative VR intervention in falls prevention, showed greater effects on reducing the risk factors of fall (Law et al., 2014; Stanmore et al., 2019). In particular, the physical and psychological outcomes were significantly improved or reduced, indicating the lesser risk of fall in the VR study. The fear of falling indicated a significant decrease after the VR training (T2) and the follow up (T3), but the participants maintained a high fall concern (FES-I ranging from 42.0 to 32.90), indicating a high fear of falling. Therefore, the training effect of VR CAVE training on fear of falling was unmet and not enough to reduce the fall concern from high to moderate level (FES-I =20-27). The consequence of the high fear of falling in older community-dwelling adults may be associated with decreased physical activity and cognitive decline [31].

Regarding physical health performances, the study showed a significant result and positive outcome on functional mobility (TUG), walk speed (6MWT) and balance (BBS). The predictive risk of an unexpected fall could be minimized. In particular, the functional mobility (TUG=11.25) was borderline before the VR training. After the VR intervention, the participants could walk faster and safer, and had a better physical condition. They became more physically active and showed intention to accept and use VR in future.

In general, the participants enjoyed and fully engaged with simulated VR games redesigned for people with old age [32,33]. Importantly, that VR simulator sickness was largely eliminated by a newly designed headset (3D stereoscopic eyewear) in the VR CAVE technology application [34]. Besides, the researcher provided adjustment and modification for the older adults using new 3D handy eyewear, sensor devices and spacious CAVE setting. Therefore, the VR CAVE design in the VR session could increase participants' engagement and stimulate better user experience. In conclusion, the study supported that the VR CAVE application was a useful and innovative falls prevention training application, the older adults perceived usefulness and enjoyment in the use of new technology in aged care services.

Limitations

Considering the challenges of recruitment and adopting VR technology in recent reviews [35-37], our study had some limitations. Firstly, the sample size was small due to low recruitment rate under Covid-19 restrictions in Hong Kong. As the study was implemented in a university CAVE VR research centre instead of community aged care centres, the older adults showed more resistance and difficulty to participate in the study. Secondly, the study was not a randomized control trial design, it might create a sampling bias due to a convenience sampling method and no control group comparison. The validity and reliability of the results were minimized and overestimated. Thirdly, the intervention method focused on a pilot VR program through CAVE system design to assess usability and acceptance on the use of VR among the older population. Fourthly, the study reported primarily on quantitative findings, more investigations such as a participant-observational or ethnographic study would be recommended in a follow-up study.

To the best of my knowledge, this was the first experimental research using a pilot VR CAVE application for older adults on fall prevention in Hong Kong. The supporting evidence and similar research were limited, the findings might not be expanded and generalized to other full immersive VR technology applications [38]. In addition, the new CAVE VR system technology was costly and heavily reliant on governmental funding support in Hong Kong, the technological support was inevitable compared with other VR apps and devices (Oculus (Meta) Quest & Sony PlayStation VR), and the manpower resources to support and operate the CAVE were also challenging. Thus, attracting similar research employing CAVE VR technology would be challenging and becoming a new trend in future healthcare services.

Conclusions

The study reaffirms the promising evidence on the usefulness and acceptance of using full immersive VR technology among Chinese older persons from Hong Kong [30,39-40]. They perceived the VR CAVE application on preventing of falls was useful and innovative. The study also shows positive perceptions and users' experiences adopting new VR CAVE technology in older adults. To attract similar research interests using full-immersive VR CAVE technology, a user-friendly accessible design of CAVE VR technology is recommended to invest in future. For future development, similar studies should be replicated by comparing different VR applications with a larger sample and a randomized control trial study design, to generalize greater evidence on usability and acceptance of adopting new VR technology in rehabilitation and aged care services.

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 Human Ethics Committee (H21REA071). Informed consent was obtained from all participants. To ensure safety and suitability, the participants were provided with a VR trial before the first VR training session. All participation was voluntary.

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Authors' declaration of authorship contribution

All authors contributed to conceptualizing the study, data analysis, and reviewing the current version. They have read and agreed to the published version of the manuscript.

Conflicts of interest

None declared.

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References

1. M. Montero-Odasso, R. Camicioli, editors. Falls and cognition in older persons: fundamentals, assessment and therapeutic options. Springer Nature; 2019 Oct 4.
2. M. Montero-Odasso, N. van der Velde, F.C. Martin, M. Petrovic, M.P. Tan, J. Ryg, S. Aguilar-Navarro, N.B. Alexander, C. Becker, H. Blain, I.D. Cameron, World guidelines for falls prevention and management for older adults: a global initiative (vol 51, afac205, 2022). Age And Ageing. 2023 Oct 2;52(10).
3. P.A. Logan, C.A. Coupland, J.R. Gladman, O. Sahota, V. Stoner-Hobbs, K. Robertson, V. Tomlinson, M. Ward, T. Sach, A.J. Avery. Community falls prevention for people who call an emergency ambulance after a fall: randomized controlled trial. Bmj. 2010 May 11;340.
4. D.D. Leung, Influence of functional, psychological, and environmental factors on falls among community-dwelling older adults in Hong Kong. Psychogeriatrics, 2019; 19(3), 228-235.
5. X.X. Qian, P.H. Chau, C.W. Kwan, V.W. Lou, A.Y. Leung, M. Ho, M.I. Chi, Seasonal pattern of single falls and recurrent falls amongst community-dwelling older adults first applying for long-term care services in Hong Kong. Age Ageing, 2019; 49(1), 125-129.
6. F.M. Lam, J.C. Leung, T.C. Kwok, The clinical potential of frailty indicators on identifying recurrent fallers in the community: The Mr. OS and Ms. OS Cohort Study in Hong Kong. Journal of the American Medical Directors Association, 2019,20(12), 1605-1610.
7. L.Z. Rubenstein, K.R. Josephson, Falls and their prevention in elderly people: what does the evidence show? Medical Clinics. 2006 Sep 1;90(5):807-24.
8. World Health Organization. Ageing, Life Course Unit. WHO global report on falls prevention in older age. World Health Organization; 2008.
9. Z. Gao, J. Lee, D. McDonough, Virtual reality exercise a coping strategy for health and wellness promotion in older adults during the COVID-19 Pandemic. Journal of Clinical Medicine.2020; 9,1986.
10. S. Ge, Z. Zhu, B. Wu, E.S. McConnell, Technology-based cognitive training and rehabilitation interventions for individuals with mild cognitive impairment: a systematic review. BMC Geriatric, 2018; 18(1), 213.
11. S.R. Shema, P. Bezalel, Z. Sberlo, N. Giladi, J. Hausdorff, A. Mirelman, Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training. Journal of Alternative Medicine Research. 2017 Apr 1;9(2):171-5.
12. E. Mahzar, C. Shi, D. Laura, Virtual reality exergames for people living with dementia based on exercise therapy best practices. Proceedings of the Human Factors & Ergonomics Society 2018; Annual Meeting.
13. N. Thapa, H.J. Park, J. Yang, H. Son, M.J. Lee, S.W. Kang, K.W. Park, H. Park, The effect of a virtual reality-based intervention program on cognitive in older adults with mild cognitive impairment: A Randomized Control Trial. Journal of Clinical Medicine 2020; 9,1283.
14. World Health Organization. Falls Prevention in Older Persons. 2019; https://www.who.int/ageing/projects/falls/prevention/older/age/en/.
15. K.J. Miller, B.S. Adair, A.J. Pearce, C.M. Said, E. Ozanne, M.M. Morris, Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: a systematic review. Age Ageing.2014; 43(2):188–95.
16. F.D. Davis, R.P. Bagozzi, P.R. Warshaw, User acceptance of computer technology: A comparison of two theoretical models. Management Science. 1989;35(8):982–1003.
17. C.H. Hsiao, C. Yang, The intellectual development of the technology acceptance model: a co-citation analysis. International Journal of Information Management. 2011; 31(2):128–36.
18. V. Venkatesh, M.G. Morris, G.B. Davis, F.D. Davis, User acceptance of information technology: toward a unified view. MIS quarterly. 2003; 27(3):425–78.
19. V. Venkatesh, Determinants of perceived ease of use: integrating control, intrinsic motivation, and emotion into the technology acceptance model. Information Systems Research. 2000; 11(4):342–65.
20. S.Y. Park, An analysis of the technology acceptance model in understanding university students' behavioral intention to use e-learning. Educational technology & society. 2009; 12(3):150–62.
21. P. Legris, J. Ingham, P. Collerette, Why do people use information technology? A critical review of the technology acceptance model. Information & management. 2003; 40(3):191–204.
22. X. Ning, Ki-Su. Kim, An empirical study of user experience (UX) factors affecting continued usage intention of smartphone. The Journal of Eurasian Studies, 2012, 9(4):91–118.
23. K.M.T. Bandara, U. K. Ranawaka, A. Pathmeswaran, Usefulness of Timed Up and Go Test, Berg Balance Scale and Six Minute Walk Test as fall risk predictors in post stroke adults attending Rehabilitation Hospital Ragama. (2020).
24. S.W. Muir, K. Berg, B. Chesworth, M. Speechley, Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study. Physical therapy, 2008, 88(4), 449-459.
25. H. A. Bischoff, H.B. Stähelin, A.U. Monsch, M.D. Iversen, A. Weyh, M. Von Dechend, R. Theiler, identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women. *Age and ageing*, 2003, *32*(3), 315-320.

26. G. Peeters, N.M. Van Schoor, R. Cooper, L. Tooth, R.A. Kenny, Should prevention of falls start earlier? Co-ordinated analyses of harmonised data on falls in middle-aged adults across four population-based cohort studies. PLoS One, 2018, 13(8), e0201989.
27. L. Yardley, N. Beyer, K. Hauer, K., G. Kempen, C. Piot-Ziegler, C. Todd, Development and initial validation of the Falls Efficacy Scale-International (FES-I). Age and ageing,2005, 34(6), 614-619.
28. A.C. Sarah, M.H. Jodi, D. Jacob, L.E. Bolzenius, L.M. Salminen, S.S. Baker, H.P. Robert, Longitudinal Change in Performance on the Montreal Cognitive Assessment in Older Adults, The Clinical Neuropsychologist,2015; 29:6,824-835.
29. V. Bewick, L. Cheek, J. Ball, Statistics review 7: correlation and regression. Critical Care.2003; 7(6):451.
30. S. Syed-Abdul, S. Malwade, A.A. Nursetyo, M. Sood, M. Bhatia, D. Barsasella, M.F. Liu, C.C. Chang, K. Srinivasan, Y.C. Li, Virtual reality among the elderly: a usefulness and acceptance study from Taiwan. BMC geriatrics. 2019 Dec;19(1):1-0.
31. K. Uemura, H. Shimada, H. Makizako, D. Yoshida, T. Doi, K. Tsutsumimoto, A lower prevalence of self-reported fear of falling is associated with memory decline among older adults. Gerontology. 2012, 58(5),413–8.
32. L. Law, F. Barnett, M.K. Yau, M.A. Gray, Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: a systematic review. Ageing Research Revision. 2014; 15:61–75.
33. E.K. Stanmore, A. Mavroeidi, L.D. de Jong, D.A. Skelton, C.J. Sutton, V. Benedetto, L.A. Munford, W. Meekes, V. Bell, C. Todd, The effectiveness and cost-effectiveness of strength and balance Exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: a multi-center, cluster randomized controlled trial. BMC medicine. 2019 Dec; 17:1-4.
34. N. Mascret, L. Delbes, A. Voron, J.J. Temprado, G. Montagne, Acceptance of a virtual reality headset designed for fall prevention in older adults: questionnaire study. Journal of Medical Internet Research. 2020 Dec 14;22(12): e20691.
35. P.H. Chau, Y.Y.J. Kwok, M.K. Chan, K.Y.D. Kwan, K.L. Wong, Y.H. Tang, M.K. Leung, Feasibility, acceptability, and efficacy of virtual reality training for older adults and people with disabilities: single-arm pre-post study. Journal of Medical Internet Research, 2021; 23(5).
36. Y.L. Ng, F. Ma, F.K. Ho, P. Ip, K.W. FU, Effectiveness of virtual and augmented reality-enhanced exercise on physical activity, psychological outcomes, and physical performance: A systematic review and meta-analysis of randomized controlled trials. Computers in Human Behavior Oct 2019; 99:278-291.
37. M. Zahabi, A.M. Abdul Razak, Adaptive virtual reality-based training: a systematic literature review and framework. Virtual Reality, 24(4), 2020; 725-752.
38. A. Wojciechowski, A. Wiśniewska, A. Pyszora, M. Liberacka-Dwojak, K. Juszczyk, Virtual reality immersive environments for motor and cognitive training of elderly people–a scoping review. Human Technology. 2021 Oct 31;17(2):145-63.
39. R. Kwan, J. Liu, K. Fong, J. Qin, P.S.O. Leung, P. Hon, L. Suen, M. Tse, C. Lai, Feasibility and effects of virtual reality motor-cognitive training in community-dwelling older people with cognitive frailty: pilot randomized controlled trial. JMIR Serious Games 2021;9(3): e28400URL.
40. R. Qiu, Y. Gu, C. Xie, Y. Wang, Y. Sheng, J. Zhu, Y. Yue, J. Cao, Virtual reality-based targeted cognitive training program for Chinese older adults: A feasibility study. Geriatric Nursing. 2022 Sep 1; 47:35-41.

Figure 1. Flow chart of study

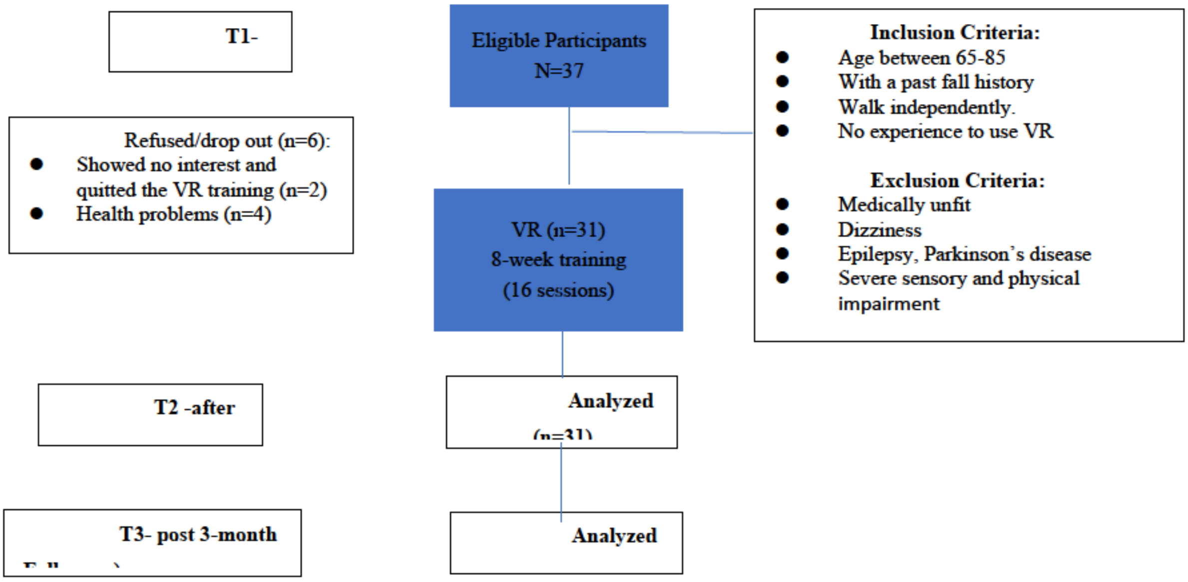

Table 1. Baseline characteristics of the participants (n=31)

Characteristics	VR Use (n=31)
Age (years), M (SD)	72.23 (5.162)
Gender n (%)	
Male	1 (3.2%)
Female	30 (96.8%)
Education Level (years), (%)	
Primary or below	35.5%
Secondary or above	64.5%
Living Status, (%)	
Alone	22.6%
With family	77.4%
History of Fall, (%)	
≤ 12 months	54.8%
> 12 months	45.2%
Body Mass Index (BMI Kg/M^2)	23.03
Cognitive Status (HK-MoCA) M (SD)	23.48 (.631)
No. of Chronic Disease, mean (SD)	3.129 (1.995)
History of Fracture, (%)	
Yes	38.7%
No	61.3%
History of Chronic Pain, (%)	
Yes	45.2%
No.	54.8%

Table 2. Criterion validity test of VR usability questionnaire (HK-version) with Pearson's product-moment correlations.

Items	Rxy	P value
Perceived usefulness (PU)		.
VR is useful to me for entertainment. (PU1)	.774	001
VR improves engagement and motivates daily activities. (PU2)	.537	.002
VR is an efficient tool to raise my mood. (PU3)	.800	.001
Perceived ease of use (PEOU)		
It is easy for me to become skilful at using VR. (PEOU1)	.324	.075
Learning to operate VR was easy for me. (PEOU2)	.378	.036
Overall, I find it easy to use VR. (PEOU3)	.283	.123
Perceived enjoyment (PU)	.	.
I find VR very attractive to use. (PE1)	873	001
I enjoy using VR. (PE2)	.809	.001
I have fun when I use VR. (PE3)	.656	.001
Social norms (SNs)		
My family members think I should use VR. (SN1)	.696	.001
People who are friends and acquaintance have influence on my intention to use VR. (SN2)	.341	.061
People who take care of me encourage me to use VR. (SN3)	.473	.001
User experience (UE)		
VR will give me new experience. (UE1)	.670	.001
VR was comfortable to use. (UE2)	.694	.001
Overall, I had a positive experience when using VR. (UE3)	.576	.001
Intention to use (IU)		
In the future, I intend to use the device for mental relaxation. (IU1)	.661	.001
In the future, VR will help keep my mind sharp and alert. (IU2)	.770	.001

Table 3. Summary statistics and frequency distributions of variables in the VR usability questionnaire (HK-version)

Variable description	T1 M(SD)	T2 M(SD)	T3 M(SD)
Perceived usefulness (PU)			
PU1	4.39 (.615)	4.61 (.558)	4.65 (.486)
PU2	4.23(.669)	4.35 (.608)	4.55 (.624)
PU3	4.35 (.669)	4.42 (.564)	4.58 (.564)
Perceived ease of use (PEOU)			
PEOU1	3.65 (.985)	3.90 (.539)	3.87 (.806)
PEOU2	3.90 (.870)	3.87 (.922)	4.19 (.792)
PEOU3	3.97 (.651)	4.19 (.654)	4.26 (.631)
Perceived enjoyment (PU)			
PE1	4.32 (.702(	4.48 (.626)	4.58 (.620)
PE2	4.35 (.709)	4.52 (.508)	4.65 (.608)
PE3	4.42 (.564)	4.68 (.475)	4.81 (.402)
Social norms (SNs)			
SN1	3.77 (.884)	3.97 (.706)	4.13 (.670)
SN2	3.03 (1.329)	3.48 (1.061)	3.191 (1.078)
SN3	4.10 (.908)	4.16 (.735)	4.29 (.643)
User experience (UE)			
UE1	4.45 (.568)	4.61 (.495)	4.61 (.558)
UE2	4.13 (.718)	4.39 (.558)	4.32 (.599)
UE3	4.42 (.502)	4.61 (.495)	4.52 (.570)
Intention to use (IU)			
IU1	3.90 (.790)	4.23 (.617)	4.52 (.570)
IU2	4.29 (.588)	4.48 (.570)	4.52 (.626)

T1: before VR training, T2: after VR training, T2: Post 3 months follow up.

Table 4. Cronbach's α values before VR training (T1)

Items	**T1** **Cronbach's α**
Perceived usefulness (PU)	.781
Perceived ease of use (PEOU)	.730
Perceived enjoyment (PE)	.833
Social norms (SNs)	.532
User experience (UE)	.778
Intention to use (IU)	.642

Table 5. Summary statistics and frequency distributions of variables in the VR usability questionnaire (HK-version)

Variable description	T1 M(SD)	T2 M(SD)	T3 M(SD)
Perceived usefulness (PU)			
PU1	4.39 (.615)	4.61 (.558)	4.65 (.486)
PU2	4.23(.669)	4.35 (.608)	4.55 (.624)
PU3	4.35 (,669)	4.42 (.564)	4.58 (.564)
Perceived ease of use (PEOU)			
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PEOU3	3.97 (.651)	4.19 (.654)	4.26 (.631)
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PE1	4.32 (.702(	4.48 (.626)	4.58 (.620)
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SN3	4.10 (,908)	4.16 (.735)	4.29 (.643)
User experience (UE)			
UE1	4.45 (.568)	4.61 (.495)	4.61 (.558)
UE2	4.13 (.718)	4.39 (.558)	4.32 (.599)
UE3	4.42 (.502)	4.61 (.495)	4.52 (.570)
Intention to use (IU)			
IU1	3.90 (.790)	4.23 (.617)	4.52 (.570)
IU2	4.29 (.588)	4.48 (.570)	4.52 (.626)

T1: before VR training, T2: after VR training, T2: Post 3 months follow up.

Additional file 3:

Baduanjin Exercise Group

Part A: **Traditional Chinese Qigong - Baduanjin**

Photo A: English version

Picture B: Chinese version

Photo C: Practice session 1

Photo D: Practice session 2

Part B: **Fall prevention strategies.**

Photo E: Practice tips for preventing falls

Photo F: Group sharing

4.2 Links and Implications

Perceived usefulness (PU), perceived enjoyment (PE), user experience (UE), and intention to use (IU) demonstrated significant changes at different time points. These factors play a crucial role in influencing participants' acceptance of the use of VR technology applications. Interestingly, perceived ease of use (PEOU) and social norms (SNs) yielded inconsistent results, with some items showing low validity. Predictively, the operation of VR CAVE technology and the technological demand posed challenges for older users and the researchers. This paper supported theoretical frameworks, including TAM, and the proposed VR CAVE FALL PREVENTION MODEL. Unlike other studies, participants in the VR group exhibited a significant reduction in the risk of falls, including the fear of falling.

CHAPTER 5: PAPER 3- VIRTUAL REALITY TECHNOLOGY-BASED TRAINING FOR REDUCING THE RISKS OF FALLS AMONG OLDER PERSONS WITH MILD COGNITIVE IMPAIRMENT: AN EXPERIMENTAL STUDY

5.1 Introduction

This paper aimed to evaluate the effectiveness of VR CAVE program for reducing the risks of falls among older adults with mild cognitive impairment. The sampling size was larger than the pilot RCT study, but this paper employed a quasi-experimental study instead due to challenges and limitations faced on voluntary participation and full loading for utilisation of VR technology at university research centre. This research applied the similar research method and data analysis from paper 1 and paper 2. The data sources and operational procedures were shared, good research experience was learned from previous studies. This study faced much more difficulties and restrictions than previous studies because the data collection had been suspended for three months and increased dropout rate owing to unfavourable research environment at pandemic between Jan and May 2022 in Hong Kong. At last, the findings showed promising evidence on the effectiveness of VR CAVE technology-based training for reducing the risks of fall in community aged care services from Hong Kong.

Submitted Paper

Virtual Reality Technology-based Training for Reducing the Risks of Falls among Older Persons with Mild Cognitive Impairment: An Experimental Study

Key Points for Occupational Therapy

- Virtual Reality (VR) technology application has positive training effects on fall prevention for older persons.
- Occupational Therapy assisted by VR can play a significant role on prevention of falls for older persons with mild cognitive impairment and dementia.
- Occupational Therapists can support the creation, inclusion, and adoption of accessible health technologies in future occupational therapy practice.

Abstract

Introduction: Virtual Reality (VR) technology has potential for reducing the risks of falls of older persons. There are indications of a positive training effect of a cognitive-motor intervention method to improve the postural balance and cognition for safer walking. There is little evidence, however, supporting the long-term effect of VR application or the existence of a research-based falls prevention training protocol using VR among older persons with mild cognitive impairment. This study focused on evaluating the outcomes of deploying VR technology-based applications for preventing falls of older persons with mild cognitive impairment.

Methods: A quasi-experimental design was applied to investigate how the participants experienced a full-immersive Cave Automatic Virtual Environment (CAVE) VR intervention program. Volunteer participants were recruited from three community aged care facilities in Hong Kong. Fifty-five participants were successfully recruited by convenience sampling and randomly assigned into the VR intervention group (n=25) or the control group (n=30). The experimental group participants attended 16 VR falls prevention training sessions over eight weeks using a VR CAVE technology application. The control group participants received no VR falls prevention program, only the regular service from respective centres. All participants identified with a risk of mild cognitive impairment undertook three falls risk assessments, one each in screening session (T1), after intervention (T2) and three months (T3) follow up. The primary outcome assessed any falls after the study, the secondary outcomes assessed included changes in cognition and executive function, walk speed and balance performances, and the psychological factor such as fear of falling relating to the risk factors of fall.

Results: The VR intervention group showed significant greater improvement ($p<0.05$) than the control group on measures of cognitive-motor performance, such as cognitive level (HK-MoCA), executive function (TMT-A and TMT-B), balance (BBS) and walk speed (6MWT) across group and time interaction. There were, however, no significant differences on level of functional mobility (TUG *p*=.938) and the fear of falling (FES-I *p*=.148) between the two groups.

Conclusion: This study provides promising evidence on the effectiveness of VR CAVE technology-based training for reducing the risks of fall among older persons with mild cognitive impairment in aged care services from Hong Kong. The remarkable results support less recurrent falls and risks of fall in the VR intervention group. VR technology-based application supports evidence-based practice and it is considered to be an emerging area in future occupational therapy practice.

KEYWORDS

Virtual reality (VR); cognitive-motor training; older persons; mild cognitive impairment (MCI); fall risks; fall prevention; full-immersive: Cave Automatic Virtual Environment (CAVE) VR

Introduction

Managing falls in older persons with cognitive impairment is a public health challenge that continues to attract research interest (Montero-Odasso & Camicioli, 2020). *Fall is defined as an event which results in a person coming to rest inadvertently on the ground or floor or other lower level. Falls, trips and slips can occur on one level or from a height* (WHO, 2021). Significantly, older fallers with cognitive impairment are five times more likely to be institutionalized than older fallers without cognitive impairment (Myers et al., 1991). The literature suggests there is a strong relationship between executive function and falls; executive dysfunction doubles the risk for future falls and increases the risks of fall injury by 40% in older persons living in the community (Muir, Gopaul & Montero-Odasso, 2012). There is some evidence showing that cognitive-motor interventions such as virtual reality-based interventions could reduce the risks of falls in older persons with mild cognitive impairment and dementia (Thapa et al., 2020). However, the empirical research using VR technology intervention on the occupational therapy area is very limited (Miranda-Dura et al., 2021). The study aims to investigate the effects of Virtual Reality Technology (VRT) based training as a meaningful occupation and an alternative cognitive-motor training to reduce the intrinsic risk factors of falls by altering the cognition, postural balance, and fear of falling among older persons with mild cognitive impairment.

Virtual Reality (VR) is a high-end computer interface that involves real-time simulated environment and interactions through multiple sensory channels (Mirelman et al., 2016). VRT can be either semi-immersive or fully immersive. This research used a fully immersive VR technology named Cave Automatic Virtual Environment (CAVE). The CAVE technology asks the participants to wear stereoscopic glasses which enable them to see 3D graphics and images so that they can walk all the way around the objects in a simulated scenario and get a full view and a better understanding of exactly how those objects would look and what the real time environment is like. The adoption of VRT can be an innovation for the occupational therapy (OT) profession. OT researchers could advocate to pilot use an innovative training tool for preventing falls in older persons at the pandemic. OT is increasingly using assistive technology and Kinect motor sensor technology for older persons on home modifications, safe footwear device e.g., fall sensor, Kinect with Xbox or Nintendo Wii and tele-rehab educational program for falls prevention (Elliot et. al, 2018). This study becomes a pilot and pioneer research project using commercially VR CAVE application on fall prevention for older persons with cognitive impairment. The study explored an emerging area for adoption of accessible technology in future occupational therapy service (Liddle, 2023).

VRT intervention is an innovative approach in health-related applications, growing rapidly especially in rehabilitation and aged care (Gao, Lee, & McDonough, 2020, Miranda-Duro et al., 2021). The immersive VRT provided simulated real-life environment and scenarios, which engaged the users with the sensation of physical existence (Baus, & Bouchard, 2014; Moreno et al., 2019). VRT may be a useful adjunct to falls prevention approaches in health-related applications. Similarly with previous European projects such as the iStoppFalls, Farseeing and PreventIT project, this research explored using technology to improve older persons' physical health and functioning (Boulton et al., 2019). For instance, iStoppFalls project used exergames to reduce falls in older adults. These projects provided an essential background and supporting evidence to fall prevention by adoption of technology. Exercise programs and interprofessional fall prevention programs are recommended as a useful fall prevention intervention strategy, clinicians such as physiotherapists and occupational therapists can use a professional-led fall prevention program in aged care services (Ohman, Savikko, & Strandberg, 2016, Miranda-Duro et. al., 2021, Montero-Odasso et al, 2022). Due to the Covid-19 outbreak between 2020-2022, the human-guided fall prevention program had been severely restricted or reduced in community aged care service. This could lead to an adverse effect on older persons' physical activity and cognitive functioning, but also induced loneliness, boredom, and social isolation. The new development of VRT exercise-based training can be an alternative training platform to provide a virtual simulated training environment for the older persons in a post-pandemic. The use of VRT is becoming more affordable and can be easy to operate as compared with therapist-lead exercise. It offers potential as a safe and interactive (alternative) approach to fall prevention strategy in adoption of future healthcare application.

There have been reports that wearing a head-mounted device may induce discomfort and agitation in older people (Bourrelier, & Ryard, 2016). To minimize the impact of motion sickness or dizziness when using VR technology applications, the VR CAVE technology is designed to be more user-friendly as 3D stereoscopic glasses are more convenient and comfortable for older persons than the headsets. There exists a knowledge gap in developing useful clinical practice application for fall prevention by using VR technology to reduce the fall risks among older persons with cognitive impairment (Hamm et al., 2016). The objective of the study is to investigate the effects of VRT exercise-based training among older persons with mild cognitive impairment. The OT profession may consider the adoption of accessible VR CAVE technology in future occupational therapy practice.

Methods

This experimental study involved a parallel group design with 3-interval measurements from pre-test, post-test and post 3 months follow up. Originally, the study plan was to conduct a pilot randomized controlled trial study. Unfortunately, Hong Kong had a social distancing policy and other public health policies enacted in 2020 and 2022 due to the COVID19 pandemic. Older persons travelling to public areas was not recommended during the pandemic, and participants and other collaborative parties were more hesitant to participate in the research study under COVID-19 restrictions. The study adopted a convenience sampling method as a feasible alternative. The study was required to request additional safety requirements and procedures for protection of participants to fulfil the extra requirements of human ethics application.

The operators of community aged care facilities offered two service modes including online telecare and limited center-based social support services. With special permission and approval from all stakeholders, all VR training, measurements, and clinical observations were taken either in the VR research centre at the Hong Kong Polytechnic university or three community aged care centers in Hong Kong.

Participants

Two hundred and three participants were recruited from three community aged care centres in Hong Kong. They were invited for screening sessions of fall risks assessments co-organized by the research team and three operators of aged care facilities. All participants received an invitation directly from center staff or through a promotion leaflet of the VR technology-based fall prevention research program held between June 2021 and March 2022. Initially, the participants gave consent to enrol in the screening sessions and indicated interest and willingness to participate in the fall risk assessment and VR intervention study. Mostly, they were worried about falling and had experienced falls because of general health decline in ageing. The research team provided detailed explanations of the research purpose for the participants prior to the screening assessments. Eligible participants were volunteers who met the selection criteria and were provided with an informed consent form.

Inclusion Criteria

The target population included the service members from three service settings in Hong Kong. The inclusion criteria were (1) aged 65 years to 85 years inclusive; (2) had a history of a fall within the past two years; (3) living in a non-residential age housing; (4) at risk of mild cognitive impairment, assessed by a validated screening tool of Hong Kong Montreal Cognitive assessment test (HK-MoCA score ≤25), indicating a risk of mild cognitive impairment or early dementia; (5) walk independently e.g. able to access VR research center or community aged care facilities freely. These criteria must be satisfied prior to enrolment procedure taken in community aged care facilities.

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, visual impairments, or mental disorder. These exclusions were for participants' safety and to meet the set requirements governed by the university ethics approval committee and formal approval from all stakeholders.

Intervention

The intervention program was called the **VirCube VR for Rehab program**, commercially designed by Motion Force Technology Limited in Hong Kong. The VR company had responsibility to provide the continuous technical and maintenance services covered in a warranty period. The ownership of the program was wholly managed by the Department of Rehabilitation Sciences of The Hong Kong Polytechnic university. The researcher of the study declared no conflict of interest with the VR company;

all research logistics, communication, and operations were restricted to VR research office of the university.

The VR research center set up the **VirCube** VR for Rehab program for different research purposes under the Department of Rehabilitation Sciences. It was a VR & AR (Augmented Reality) platform that allowed participants to fully immerse and interact with VR in a stimulated virtual living environment. To match with the aims of the experimental study, cognitive-motor training programs were chosen for the intervention program. The VR training modules for this study included fire emergency handling, outdoor walking, balancing game activities and community daily practices. The training modules involved dual task components; the participant was expected to train up his/her cognitive motor performances in an intensive VR technology-based training 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 minutes to complete with a short break before the next module. Each training session lasted approximately 45 minutes. VR training sessions were standardized and supervised by the same research team. The application of the **VirCube** VR program was guided by the VR game instruction and training protocol (additional file 2).

The control group participants did not receive any VR intervention in community aged care centres. They received limited center-based social care service in community aged care centres as most regular services were provided online or cancelled during Covid-19 restrictions. Some services were resumed - regular online zoom social meetings, center-based health check service and social support services in June 2021. The control group participants were invited by staff of respective DECCs to take pretest, post-test and follow up measurements in same period of VR group (T1, T2 and T3 intervals) in respective centres. All outcome measurements were administered by same research team in the study. The research team involved a principal investigator and two occupational therapists.

Procedure

The **VirCube VR** for Rehab program and all VR CAVE facilities were built-in on a VR research centre at the Department of Rehabilitation Sciences of the Hong Kong Polytechnic University. Eligible participants had signed the consent form and given permission for the research team to provide the VR training. The participants were required to arrange public transportation to attend the VR training sessions. If a participant needed special assistance to access the VR laboratory, 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 headset and motion trackers. At the onset of the COVID pandemic, all participants were required to apply for a special permission permit to access the VR research centre at The Hong Kong Polytechnic university and meet the requirements of the health declaration. 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 physical discomfort or complaint.

For each session, all participants were kept under close supervision and supported by a trained researcher. They were allowed to take a rest or stop at any time if necessary or before the next VR module training. The VR research centre was considered a safe environment and comfortable for all participants. The participants in the waiting area could observe the other participants playing VR game activities. After the VR training session, the researcher asked the participants' feedback on experiencing full immersive VR game activities and checked and cleaned all VR wearing devices before the next session. Pictures A to G display the VR wearing devices, VR CAVE physical set up and cognitive-motor VR games (additional file 1). The VR game instruction and training protocol is documented in additional file 2.

Data Collection and Outcome Measures

All participants were assessed and provided information including demographic and health information on the screening assessment at three respective centres. The basic information included age, gender, living status, education level, falls history and the reason, cognitive status, and medical history (e.g., fracture, multiple pain, and other health conditions). Primarily, the staff of community aged care centers recruited their members according to inclusion criteria set in the study, particularly those with a past fall history and showing interest to take part on the fall risk assessment by research team. The fall risk measurements focused on cognitive and motor performances relating to intrinsic risk factors of falls (WHO, 2008). The psychological factor of risk included fall efficacy indicating the fear of falling (Scheffer et al., 2008; Yardley et al., 2005).

Cognitive Measures

Cognitive function was measured using the Hong Kong Montreal Cognitive Assessment (HK-MoCA full version). This validated 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 had a good validity in detecting people with mild cognitive impairment (Yeung et al., 2020). A score of 25 or below indicated a higher risk of cognitive impairment or decline. Testing executive function of research participants was one of the indicators to detect the change of cognitive level after VR intervention. The study chose the executive function test: The Trail Making Tests (TMT-A and TMT-B) for measuring the changes of cognitive performance (Lei, & Erin, 2000).

Physical Measures

The study measured the risk factors of falls by assessing the postural balance, walking speed and functional mobility in 3-intervals (T1, T2 and T3). We used three validated assessment tools for older persons such as Berg Balance Scale (BBS), 6-minute walk test (6MWT) and Time Up and Go test (TUG) to assess the change in health outcomes using the VR technology-based intervention (Bandara et al., 2020).

The Berg Balance Scale (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 persons aged 65 or above. The cut-off score below 45 indicated the individuals with a greater risk of falling. A score below 51 with history of falls indicated a predictive risk of fall (Muir et al., 2008).

Another validated fall risk assessment tool was measured by the Time Up and Go test (TUG). The participants were asked to get up from chair, walk 3 meters, turn around, walk back to chair, and sit down, and the time taken was recorded (Bischaff et al., 2003). The older persons with age between 65 to 85 living in the community were expected to be able to perform the TUG test within 12 seconds which indicated a reduced risk of fall. Shorter walking time for participants indicated better balance performance and lesser fall risk. The six-minute walk test (6MWT) measured a longer walking distance with better physical condition.

Psychological consideration

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 cut off score of older persons living in community divided into three levels, a score 16-19 indicating low concern of falling, a score 20-27 indicating moderate concern and a score 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 intervention group and the control group.

Statistical Analysis

The primary outcome recorded the number of falls, and secondary outcomes recorded the change in cognitive motor performances and fall efficacy after intervention and follow up. The statistical outcomes were analysed using SPSS version 27 and a p value set $\leq .05$. All 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 fall 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, executive, and physical functions. When any variable between two groups found a significant difference at baseline measurement, the comparison of covariance was applied. There was missing data found in the study, an intention-to-treat analysis was performed according to a last observation carried forward method.

Ethical Approval

This study was approved by the Human Subjects Ethics Review Committee of research institutions (reference number XXXXXXXXX and XXXXXXXX- removed for peer review). Informed consent was obtained from all participants. To ensure safety and suitability, the participants were provided with a VR trial before the first VR training session. All participation was voluntary, and participants were allowed to quit the VR intervention and terminate the study any time.

Results

Characteristics of the Participants

Sixty-five participants were considered eligible and were given a formal consent to enrol in the study (Figure 1). Fifty-five participants were completed all measurements, a mean age of 74.84, 89.1% of the participants were female, 52.5% of the participants had an education level of secondary or above, and 32.7% of the participants were living alone in community (non-residential aged care facility). They were classified as a higher risk of mild cognitive impairment or dementia (mean score HK-MoCA= 21.22), and with the history of fall within 12 months (50.9%). There was 38.2% had been reported chronic pain and 29.1% had a history of fracture due to a fall.

Some of the sixty-five eligible enrolled participants dropped out unexpectedly due to medical reasons (n=3) and loss of interest (n=2) in the VR group, some (n=5) in the control refused to continue due to anxiety of Covid spreading. In total 10 participants dropped out throughout the study; relatively the refusal rate in the VR group (n=2) was lesser than the control group (n=5). Finally, 84.62% (n=55) participants were analysed for investigating the relationship between Virtual Reality technology-based training and the risk factors of fall.

As shown in Table 1, there were no significant differences between two groups in any of the demographic information. All participants were female in the intervention group, they had a higher education level (60% with secondary level) than the control group (46.7%). The intervention group had higher incident rate (53.3%) of fall history (<12 months), the history of fracture (40%) and chronic pain (44%). The control group had a higher incident rate (50%) of history of Osteoporosis than the intervention group (35.3%).

Health Outcomes

Baseline Data

As shown in Table 2, there were no significant differences (p>.05) between two groups in executive function (TMT-A and TMT-B), balance (BBS) and 6-minute walk (6MWT) tests. Three other outcome measures included cognition (HK-MoCA), functional status (TUG) and fall efficacy (FESI) showed significant different ($p<.05$) at baseline measurement. The HK-MoCA mean score (VR M=22.68; control M=20.00) of cognitive status in the two groups indicated a higher risk of cognitive decline such as mild cognitive impairment or dementia. The cut-off score of HK-MoCA screening tool was 22, indicating a higher risk of cognitive impairment, recommended for further medical investigation (Sarah et al., 2015, Yeung et al., 2020). The functional mobility (TUG, mean score=15.01) of the control group indicated a higher risk of fall. Regarding the fall efficacy international scale (FES-I), the two groups indicated a high concern of falling (high concern of fall when FES-I >28). Some variables in two groups were not totally identical at the baseline measurement.

Regarding the primary outcome of the study, the falls incident in the intervention group (n=2) reported a lesser rate of fall than the control group (n=5) after the study. The hospital admission of participants (n=3) reported in the control group only.

The secondary outcomes of the study were illustrated on the table of multivariate and univariate of dependent variables between groups and time effects (Table 3). There were significant differences in cognition (HK-MoCA, p=.008), executive function (TMT-A, p=.38, TMT-B, p=.006), balance level (BBS, p=.032), and walk speed (6MWT, p=.001) between the two groups at pre-test, post-test and follow up. These outcomes indicated greater improvement effects between groups and times in the intervention group. However, there were no significant differences in functional mobility (TUG, p=.938) and fall efficacy level (FES-I, p=.148) between groups and times occasions. The effect of executive function (TMT-B, p=.172) had an inconsistent result within group in the follow up. The intervention group (TMT-B, mean difference=-10.28s) showed faster time than the control group (TMT-B, mean difference= +30.18s). For the balance outcome measure, the mean score (BBS, at post-test=52.84 and follow up =53.21) indicated less predictive risk of falls (BBS score > 51) in the intervention group. The mean score of Time Up and Go Test (TUG) of the intervention group at post-test (9.27s) and follow up (8.46s) below 12s indicated a lessor risk of falls compared with the control group. The HK-MoCA means scores of the intervention group at post-test (25.72) and follow up (25.96) were above the cut-off point >22 indicating a lessor risk of mild cognitive impairment or decline than the control group. Although the fall efficacy showed no significant difference between the two groups, the intervention group showed greater improvement in the mean scores of FES-I (mean score=39.00 at post-test and mean score=33.48 at follow up), but the mean score indicated no significant decrease in fear concern of falling (FES-I>28) after intervention. Figure 2 to Figure 8 showed the changes of different variables over time between groups (additional file 3)

Discussion

Overview

The evaluation study showed significant improvement on reducing the risks of falls among older persons with mild cognitive impairment by deploying the Virtual Reality technology-based applications

(VirCube VR). The results supported the greater improvement of health outcomes using technology-based cognitive motor training. Alternatively, the VR CAVE technology application was recommended as an effective training method on falls prevention program for older persons with mild cognitive impairment (Kim, & Pang, 2019; Kwan et al., 2021; Ng et al., 2019).

Full Immersive VR Training on Falls Prevention – VR CAVE Application

To the best of our knowledge, this was the first pilot study using the new application of **VirCube** VR program focusing on the risks of falls among older persons with mild cognitive impairment in Hong Kong. The **VirCube** in Rehab program designed VR simultaneous cognitive-motor games for service users. The researcher selected simulated VR games relating to the aims of the research project, designing, and modifying a stimulated falls prevention program for the participants in the intervention group. Our results were consistent with recent reviews and found that the VR participants' results supported the usefulness of VR intervention in falls prevention, showed greater improvement on health outcomes and fully engaged with simulated VR games redesigned for people with old age (Law et al., 2014; Stanmore et al., 2019). However, the study design encountered shortcomings in invested manpower resources in addition to the VR system and facilities accessibility during COVID pandemic in Hong Kong.

With similar findings on literature review, the study supported a falls prevention training protocol using VR CAVE technology as 2-day per week for 8 weeks, each VR session within 45 minutes, 16 training sessions in total (Kim & Pang, 2019; Law et al., 2014; Yang et al., 2020). For the VR CAVE technology program, each participant was suggested to take a break to avoid mental fatigue in between every VR game. The feedback of VR participants was positive and encouraging. Totally, five participants (16% drop out rate) were reported to terminate the VR training due to health and personal reasons. The study supported that VR simulator sickness was eliminated by a newly designed headset (3D stereoscopic eyewear) in the CAVE VR technology application. The study allowed flexibility for participants to complete 16-session longer than 8 weeks because of the unexpected occasion during pandemic in Hong Kong. In the end, a high completion rate (100%) of the participants was achieved in the study. The participants also reported good satisfaction on improving their health outcomes using VR CAVE technology training program. However, this study did not cover qualitative data to support the participants' subjective feedback. It could a good idea to conduct a focus group or participants' survey on their perceptions and acceptance to use technology in the follow up e study.

Effects of VR technology-based Training on Reducing the Risk of falls of VR Participants

Our research findings confirmed the evidence that VR technology-based training was effective at stimulating cognitive motor training for the participants (Irazoki et al., 2020; Kim, & Pang, 2019). It further supported the evidence on effects of the VR technology intervention for reducing the risk factors of falls among older persons with mild cognitive impairment. According to a literature review, the cognitive function was associated with a risk of falling and poor postural balance indicated a higher risk of falls (Delbaere et al., 2012; Montero-Odasso, & Speechley, 2019; Fu et al., 2015). People with mild cognitive impairment showed higher risk of falls than community-dwelling older people (Welmer et al., 2017). Our findings also provided promising effect in follow up. Beyond that, the VR CAVE training experience was so interactive and stimulating among VR participants. The participants showed good motivation, cohesiveness, and training compliance on VR falls prevention training program. Positively, they showed good learning effects and greater improvement on health outcomes after VR technology intervention.

However, the findings did not show significant improvement in functional mobility and fear concern of falling between two groups. At the baseline measurement (T1), the functional mobility and the fear concern of falling between two groups showed significant difference. VR participants showed higher functional mobility level and fear concern of falling. The intervention effect of VRT was not significant due to a selection bias. Statistically, the mean score of the fear concern of falling between two groups showed similar after the VRT intervention. To certain extent, the VR group had shown greater improvement than the control group on the fear concern of falling. But two groups remained the higher fear level of falling (FES-I>28). On the other hand, the original design of VR CAVE program focused on cognitive motor intervention (dual-task component) which might be missing the training component to address the fear of falling. The 16-item fall efficacy international scale (FES-I) was a subjective assessment scale and targeted for general ageing population, these items focused on daily living tasks. Participants with cognitive impairments found it difficult to interpret and understand each questions particularly many restrictions for community living during the pandemic period in Hong Kong. The FES-I international scale might not be the best standardized assessment tool to assess the fear of falling specifically for older persons with cognitive impairment. Overall, the results might be impacted by selection bias, the assessment tool and other environmental limitations. The intervention was conducted in the VR research centre at The Hong Kong Polytechnic University. The participants spent a long time travelling and it was physical demanding to undertake all the training sessions. Comparatively, those participants with fair physical condition and higher risk of falls would become reluctant to opt for the intervention group. The VR participants showed better functional mobility (TUG) in the intervention group than the control group at baseline measurement.

Challenges and Limitations

Compared with similar VR research (Chau et al., 2021; Ng et al., 2019; Zahabi, & Abdul, 2020), the recruitment of participants for this study was challenging. The sample size of the study was small, but the dropout rate (15.38%) seemed comparatively low. Convenience sampling can lead to a volunteer bias and affect the generalizability of the findings in local ageing population (Nikolopoulou, 2022). The intervention group achieved a 100% attendance rate of VR training. The participants actively engaged with the training with a positive perception towards the application of VR technology. The other benefits of study showed good social and peer support, enjoyment on learning VR technology in the study. Certainly, the positive effect of face-to-face interaction and interactive learning could promote being mentally and physically active and eliminate social isolation and boredom during the pandemic (Gao, Lee, & McDonough, 2020; Ng et al., 2019). These observations were identical with the findings indicating the VR CAVE training was effective with a positive training effect. Future study is recommended to investigate the participants' acceptance of and perception towards using full immersive VR technology intervention.

However, the study has some limitations. Firstly, the study was a non-randomized control trial design, affecting the validity of the findings due to sampling bias. The researcher admitted the predictive limitation because the study had encountered many restrictions to implement a face-to-face experimental study in Hong Kong. Secondly, the improvement of cognitive and executive function tests as repeated measured by MoCA and TMTA/B results could be affected by repeated learning (Sarah, 2015). Thirdly, the group size between the intervention group and control group was different, the VR participants showed higher motivation and engagement to take part in the research, these factors could be contributing to a potential bias effect. Fourthly, the VR CAVE intervention had limited functions and focused on intrinsic factors of fall risks reduction because it was tailor-made a dual-task virtual simulated training program. According to the World Health Organization (WHO), falls prevention was complex to manage and a multifactorial program was used to reduce the multiple risks of falls because of their complexity (WHO, 2004; Morello et al., 2019)

Finally, the challenges and demands for participants in the intervention group were greater than the control group. The research team consumed manpower resources and faced difficulties to tackle the research logistics including the participants' accessibility, VR CAVE facility arrangement and other technical issues. The data collection of follow up was heavily suspended owing to a Hong Kong lock down between January 2022 to May 2022. The Hong Kong Polytechnic university and the community social service centres suspended all research projects and daily services in Hong Kong. The 3-month follow up measurement in the two groups was delayed. It might have upset the dropout rate because some participants refused to continue the study during this period. As an alternative, the research team adopted a special arrangement to maintain contact with the participants by telephone call and other social mean e.g., WhatsApp group. Thus, the research adopted the intention-to-treat method for data analysis.

Conclusion

The pilot study supported the promising evidence on the effects of Virtual Reality technology-based training on reducing the risk of falls among older persons with mild cognitive impairment by deploying VR CAVE application. Its application was proved to be effective technology-based in preventing falls and had a positive cognitive-motor training effect. VirCube VR for Rehab program in falls prevention was supported with evidence as a potential VR technology-based application in aged care and rehabilitation services. The case of using VR technology-based intervention was strengthened, as an innovative occupation and alternative treatment approach on future occupational therapy practice. Occupational therapists can expand the scope and make use of VR technology-based applications in different rehabilitation services. However, the demand of technological support using VR applications is high and crucial particularly for ageing population. To the end, similar studies should be replicated by employing a larger sample and randomized control trial design to generalize the greater evidence on VR technology-based application in future occupational therapy practice.

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Authors' declaration of authorship contribution

All authors contributed to conceptualizing the study, data analysis, and reviewing the current version. They have read and agreed to the published version of the manuscript.

Conflicts of interest

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References

Bandara, K. M. T., Ranawaka, U. K., & Pathmeswaran, A. (2020). Usefulness of Timed Up and Go test, Berg Balance Scale and Six Minute Walk Test as fall risk predictors in post stroke adults attending Rehabilitation Hospital Ragama. http://ir.kdu.ac.lk/handle/345/2958

Baus, O., & Bouchard, S. (2014). Moving from virtual reality exposure-based therapy to augmented reality exposure-based therapy: a review. *Frontiers in human neuroscience*, *8*, 112. https://doi.org/10.3389/fnhum.2014.00112

Bischoff, H. A., Stähelin, H. B., Monsch, A. U., Iversen, M. D., Weyh, A., Von Dechend, M., & Theiler, R. (2003). Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women. *Age and ageing*, *32*(3), 315-320. https://doi.org/10.1093/ageing/32.3.315

Boulton, E., Hawley-Hague, H., Vereijken, B., Clifford, A., Guldemond, N., Pfeiffer, K., ... & Todd, C. (2016). Developing the FARSEEING Taxonomy of Technologies: Classification and description of technology use (including ICT) in falls prevention studies. *Journal of biomedical informatics*, *61*, 132-140. https://doi.org/10.1016/j.jbi.2016.03.017

Boulton, E., Hawley-Hague, H., French, D. P., Mellone, S., Zacchi, A., Clemson, L., ... & Todd, C. (2019). Implementing behaviour change theory and techniques to increase physical activity and prevent functional decline among adults aged 61–70: The PreventIT project. *Progress in cardiovascular diseases*, *62*(2), 147-156. https://doi.org/10.1016/j.pcad.2019.01.003

Bourrelier, J., & Ryard, J. (2016). Use of a virtual environment to engage motor and postural abilities in elderly subjects with and without mild cognitive impairment (MAAMI Project*). IRBM*. *37*(2),75-80. https://doi.org/10.1016/j.irbm.2016.02.007

Chau, P. H., Kwok, Y. Y. J., Chan, M. K. M., Kwan, K. Y. D., Wong, K. L., Tang, Y. H., ... & Leung, M. K. (2021). Feasibility, acceptability, and efficacy of virtual reality training for older adults and people with disabilities: single-arm pre-post study. *Journal of Medical Internet Research*, *23*(5), e27640. https://doi.org/10.2196/27640

Coyle, H., Traynor, V., & Solowij, N. (2015). Computerized and virtual reality cognitive training for individuals at high risk of cognitive decline: systematic review of the literature. *The American Journal of Geriatric Psychiatry*, *23*(4), 335-359. https://doi.org/10.1016/j.jagp.2014.04.009

Delbaere, K., Kochan, N. A., Close, J. C., Menant, J. C., Sturnieks, D. L., Brodaty, H., & Lord, S. R. (2012). Mild cognitive impairment as a predictor of falls in community-dwelling older people. *The American Journal of Geriatric Psychiatry*, *20*(10), 845-853. https://doi.org/10.1097/JGP.0b013e31824afbc4

Elliott, S., & Leland, N. E. (2018). Occupational therapy falls prevention interventions for community-dwelling older adults: A systematic review. *The American Journal of Occupational Therapy*, *72*(4), 7204190040p1-7204190040p11. https://doi.org/10.5014/ajot.2018.030494

Fu, A. S., Gao, K. L., Tung, A. K., Tsang, W. W., & Kwan, M. M. (2015). Effectiveness of exergaming training in reducing risk and incidence of falls in frail older adults with a history of falls. *Archives of physical medicine and rehabilitation*, *96*(12), 2096-2102. https://doi.org/10.1016/j.apmr.2015.08.427

Gao, Z., Lee, J., & McDonough, D. (2020). Virtual Reality Exercise a Coping Strategy for Health and Wellness Promotion in Older Adults during the COVID-19 Pandemic. *Journal of Clinical Medicine. 9*,1986; https://doi.org/10.3390/jcm9061986

Ge, S., Zhu, Z., Wu, B., & McConnell, E. S. (2018). Technology-based cognitive training and rehabilitation interventions for individuals with mild cognitive impairment: a systematic review. *BMC Geriatric, 18*(1), 213. https://doi.org/10.1186/s12877-018-0893-1

Hamm, J., Money, A. G., Atwal, A., & Paraskevopoulos, I. (2016). Fall prevention intervention technologies: A conceptual framework and survey of the state of the art. *Journal of Biomedical Informatics, 59*, 319-345. https://doi:10.1016/j.jbi.2015.12.013

Iakovidis, P., Lytras, D., Fetlis, A., Kasimis, K., Ntinou, S. R., & Chatzikonstantinou, P. (2023). The efficacy of exergames on balance and reducing falls in older adults: A narrative review. *International Journal of Orthopaedics Sciences, 9*(1), 221-225. https://doi:10.22271/ortho.2023.v9.i1d.3299

Irazoki, E., Contreras-Somoza, L. M., Toribio-Guzman, J. M., Jenaro-Rio, C., van der Roest, H., & Franco-Martin, M. A. (2020). Technologies for Cognitive Training and Cognitive Rehabilitation for People With Mild Cognitive Impairment and Dementia. A Systematic Review. *Front Psychol, 11*, 648. https://doi:10.3389/fpsyg.2020.00648

Kim, O., Pang, Y., & Kim, J. H. (2019). The effectiveness of virtual reality for people with mild cognitive impairment or dementia: a meta-analysis. *BMC psychiatry*, *19*(1), 1-10. https://doi.org/10.1186/s12888-019-2180-x

Kwan, R. Y. C., Liu, J. Y. W., Fong, K. N. K., Qin, J., Leung, P. K., Sin, O. S. K., & Lai, C. K. (2021). Feasibility and Effects of Virtual Reality Motor-Cognitive Training in Community-Dwelling Older People With Cognitive Frailty: Pilot Randomized Controlled Trial. *JMIR Serious Games, 9*(3), e28400. https://doi:10.2196/28400

Law, L.L., Barnett, F., Yau, M.K., & Gray, M.A. (2014). Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: a systematic review. Ageing Res Rev. 2014; 15:61–75. https://doi.org/10.1016/j.arr.2014.02.008

Lei. L., & Erin, D. B. (2000). Performance on Original and a Chinese Version of Trail Making Test Part B: A Normative Bilingual Sample, Applied Neuropsychology, 7:4, 243-246, https://doi.org/10.1207/S15324826AN0704_6

Liddle, J. (2023), Considering inclusion in digital technology: An occupational therapy role and responsibility. Aust Occup Ther J, 70: 157-158. https://doi.org/10.1111/1440-1630.12867

Miranda-Duro, M. D. C., Nieto-Riveiro, L., Concheiro-Moscoso, P., Groba, B., Pousada, T., Canosa, N., & Pereira, J. (2021). Occupational therapy and the use of technology on older adult fall prevention: a scoping review. *International journal of environmental research and public health*, *18*(2), 702. https://doi.org/10.3390/ijerph18020702

Mirelman, A., Rochester, L., Maidan, I., Del Din, S., Alcock, L., Nieuwhof, F., & Hausdorff, J. M. (2016). Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomised controlled trial. *The Lancet*, *388*(10050), 1170-1182.https://doi.org/10.1016/S0140-6736(16)31325-3

Mirelman, A., Maidan, I., Shiratzky, S.S., Hausdorff, J.M. (2020). Virtual Reality Training as an Intervention to Reduce Falls. In: Montero-Odasso, M., Camicioli, R. (eds) Falls and Cognition in Older Persons. Springer, Cham. https://doi.org/10.1007/978-3-030-24233-6_18

Montero-Odasso, M., & Speechley, M. (2018). Falls in cognitively impaired older adults: implications for risk assessment and prevention. *Journal of the American Geriatrics Society*, *66*(2), 367-375.https://doi.org/10.1111/jgs.15219

Montero-Odasso, M., & Camicioli, R. (Eds.). (2019). *Falls and cognition in older persons: fundamentals, assessment and therapeutic options*. Springer Nature.

Montero-Odasso, M., Van Der Velde, N., Martin, F. C., Petrovic, M., Tan, M. P., Ryg, J., ... & Masud, T. (2022). World guidelines for falls prevention and management for older adults: a global initiative. *Age and ageing*, *51*(9), afac205. https://doi.org/10.2522/ptj.20070251

Morello, R. T., Soh, S. E., Behm, K., Egan, A., Ayton, D., Hill, K., ... & Barker, A. L. (2019). Multifactorial falls prevention programmes for older adults presenting to the emergency department with a fall: systematic review and meta-analysis. *Injury prevention*, *25*(6), 557-564.https://doi.org/10.1136/injuryprev-2019-043214

Myers, A. H., Baker, S. P., Van Natta, M. L., Abbey, H., & Robinson, E. G. (1991). Risk factors associated with falls and injuries among elderly institutionalized persons. *American journal of epidemiology*, *133*(11), 1179-1190.https://doi.org/10.1093/oxfordjournals.aje.a115830

Ng, Y. L., Ma, F., Ho, F. K., Ip, P., & Fu, K. W. (2019). Effectiveness of virtual and augmented reality-enhanced exercise on physical activity, psychological outcomes, and physical performance: A systematic review and meta-analysis of randomized controlled trials. *Computers in Human Behavior*, *99*, 278-291. https://doi.org/10.1016/j.chb.2019.05.026

Nikolopoulou, K. (2022). What Is Convenience Sampling? | Definition & Examples. Scribbr. https://www.scribbr.com/methodology/convenience-sampling/

Ohman, H., Savikko, N., & Strandberg, T. E. (2016). Effects of exercise on cognition: the Finnish Alzheimer disease exercise trial: a randomized, controlled trial. *Journal of American Geriatric Society: 64*:731-38. https://doi.org/10.1111/jgs.14059

Podsiadlo, D., & Richardson, S. (1991). Journal of American Geriatric Society: Mar;39(2):142-148. https://doi.org/ 10.1111/j.1532-5415. 1991.tb01616.x

Sarah, A. C., Jodi, M. H., Jacob, D., Bolzenius, L.E., Salminen, L. M., Baker, S. S., & Robert, H. P. (2015). Longitudinal Change in Performance on the Montreal Cognitive Assessment in Older Adults,The Clinical Neuropsychologist,29:6,824-835. https:/doi.org/10.1080/13854046.2015.1087596

Scheffer, A. C., Schuurmans, M. J., van Dijk, N., van der Hooft, T., & de Rooij, S. E. (2008). Fear of falling: Measurement strategy, prevalence, risk factors and consequences among older persons. Age and Ageing, 37,19–24. https://doi.org/10.1093/ageing/afm169

Shema, S. R., Bezalel, P., Sberlo, Z., Giladi, N., Hausdorff, J., & Mirelman, A. (2017). Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training. *Journal of Alternative Medicine Research*, *9*(2), 171-175.

Stanmore, E. K., Mavroeidi, A., de Jong, L. D., Skelton, D. A., Sutton, C. J., Benedetto, V., ... & Todd, C. (2019). The effectiveness and cost-effectiveness of strength and balance Exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: a multi-centre, cluster randomised controlled trial. *BMC medicine*, *17*, 1-14. https://doi.org/10.1186/s12916-019-1278-9

Thapa, N., Park, H. J., Yang, J., Son, H., Lee, M. J., Kang, S. W., Park, K. W., & Park, H. (2020). The Effect of a Virtual Reality-Based Intervention Program on Cognitive in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial. *Journal of Clinical Medicine 9*,1283; https//doi:10.3390.

Todd, C., & Skelton, D. (2004). *What are the main risk factors for falls amongst older people and what are the most effective interventions to prevent these falls?* World Health Organization. Regional Office for Europe. https://iris.who.int/handle/10665/363812

Welmer, A. K., Rizzuto, D., Laukka, E. J., Johnell, K., & Fratiglioni, L. (2017). Cognitive and physical function in relation to the risk of injurious falls in older adults: a population-based study. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *72*(5), 669-675. https://doi.org/10.1093/gerona/glw141

World Health Organization. (2008). WHO global report on falls prevention in older age. World Health Organization. https://apps.who.int/iris/handle/10665/43811

World Health Organization. (2021). Step safely: strategies for preventing and managing falls across the life-course.

Yang, C. M., Hsieh, J. S. C., Chen, Y. C., Yang, S. Y., & Lin, H. C. K. (2020). Effects of Kinect exergames on balance training among community older adults: A randomized controlled trial. *Medicine*, *99*(28). https://doi.org/10.1097/ MD.0000000000021228.

Yardley, L., Beyer, N., Hauer, K., Kempen, G., Piot-Ziegler, C., & Todd, C. (2005). Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and ageing*, *34*(6), 614-619. https://doi.org/10.1093/ageing/afi196

Yeung, P. Y., Wong, L. L., Chan, C. C., Yung, C. Y., Leung, L. J., Tam, Y. Y., & Lau, M. L. (2020). Montreal cognitive assessment—single cutoff achieves screening purpose. *Neuropsychiatric Disease and Treatment*, 2681-2687. https://doi.org/10.2147/NDT.S269243

Zahabi, M., & Abdul Razak, A. M. (2020). Adaptive virtual reality-based training: a systematic literature review and framework. *Virtual Reality*, *24*, 725-752. https://doi:10.1007/s10055-020-00434-w

Figure 1. Flow chart of the study. VR: Virtual Reality

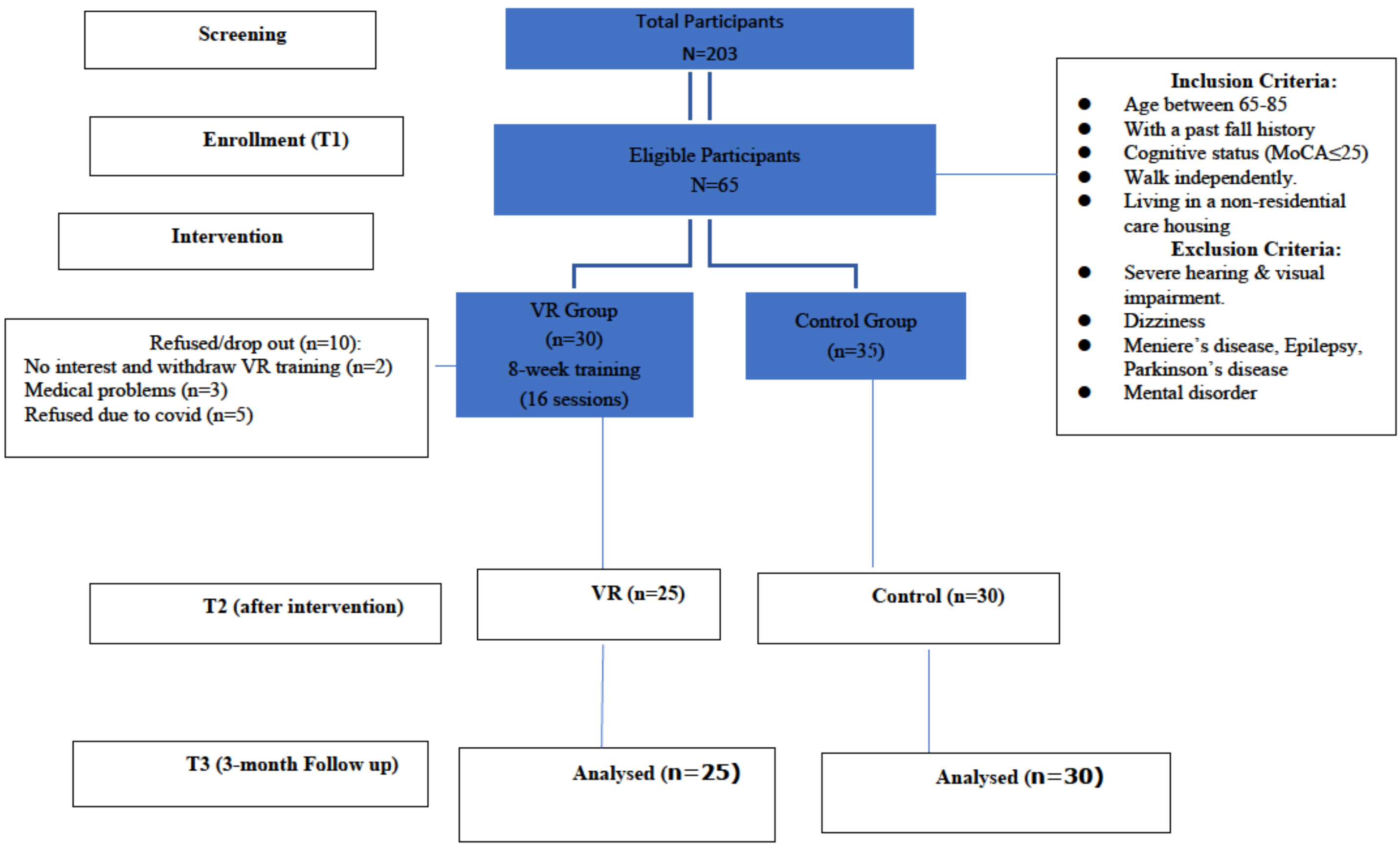


Table 1. Baseline characteristics of the participants (n=55)

	Characteristic	**Intervention (n=25)**	**Control (n=30)**	***P value***
	Age (years), M (SD)	71.96(5.11)	77.23(4.59)	.067
	Gender n (%)			.180
	Male		20%	
	Female	100%	80%	
	Education Level (years), n			.179
(%)		40%	53.3%	
	Primary or below	60%	46.7%	
	Secondary or above			
	Living Status, n (%)			.208
	Alone	24%	40%	
	With family	76%	60%	
	History of Fall, n (%)			.218
	< 12 months	53.6%	33%	
	> 12 months	46.4%	67%	
	History of Chronic Pain, n			.418
(%)		44%	33%	
	Yes	56%	67%	
	No			
	History of Fracture, n (%)			.104
	Yes	40%	20%	
	No	60%	80%	
	History of Osteoporosis, n			.311
(%)				
	Yes	35.3%	50%	
	No.	64.7%	50%	

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

Table 2. Baseline outcome measures of participants (n=55)

Outcomes, M[a] + SD[b]

Variables	All (N=55)	Intervention (n=25)	Control (n=30)	P value<.05
Cognition: HK-MoCA[c]	21.22	22.68(.69)	20.00(.63)	.006
Executive Function				
Trail Making Test A (TMT-A)	67.91	65.84(8.45)	69.63(7.71)	.742
Trail Making Test B (TMT-B)	112.64	104.28(75.44)	119.61(69.60)	.421
Time Up and Go Test (TUG)	13.41	11.48(.93)	15.01(.85)	.007
Berg Balance Scale (BBS)	50.71	50.71(.98)	50.70(.90)	.988
6-minute walk test (6MWT)	310.51	318.52(12.18)	303.84(12.03)	.415
Fall Efficacy Scale International (FES-I)	40.11	43.04(2.31)	37.16(2.10)	.043

M[a]: Mean. SD[b]: Standard Deviation. HK-MoCA[c]: Hong Kong- Montreal Cognitive Assessment.

Table 3. Comparison of outcome measures between and within groups (intervention group n=25, control group n=30)

Outcome measures	Group	Pre-test	M + SD Post-test	Follow up	Multivariate	Univariat Within group	*P<.05 Between group
Cognition							
(HK-MoCA)	VR	22.68(.69)	25.72(.79)	25.96(.81)	.008**	.000**	.000**
	Control	20.00(.63)	20.97(.72)	21.2(.74)			
Executive Function	VR	65.85(8.45)	47.29(6.93)	42.94(6.24)			
TMT-A	Control	69.63(7.14)	61.68(6.32)	64.52(6.07)	.038*	.000**	.038*
TMT-B	VR	104.28(13.96)	83.16(14.49)	72.88(15.41)			
	Control	119.61(12.74)	109.83(13.22)	140.01(14.66)	.006**	.172	.041*
Balance Level							
BBS	VR	50.72(.98)	52.84(1.65)	53.21(1.16)	.032*	.311	.047*
	Control	50.70(.90)	47.33(1.15)	50.13(1.05)			
Walk Speed							
6MWT	VR	318.51(13.18)	365.10(12.82)	373.68(13.02)	.001**	.002**	.002**
	Control	303.84(12.03)	298.42(11.07)	305.19(11.89)			
Functional Mobility	VR	11.48(.93)	9.27(.56)	8.46(.71)			
TUG	Control	15.01(.85)	12.61(.51)	12.07(.66)	.938	.000**	.000**
Fear of Fall	VR	43.64(2.31)	39.00(2.35)	33.48(2.01)			.299
	Control	37.16(2.10)	38.80(2.15)	33.53(1.84)	.148	.001**	
(FES-I)							

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 <.05 level of significance.

***P* <.005

Figure 2. Change in cognitive function (HK-MoCA), a higher score indicates better cognitive function. VR group showed greater improvement than control group in the study (P value <.005).

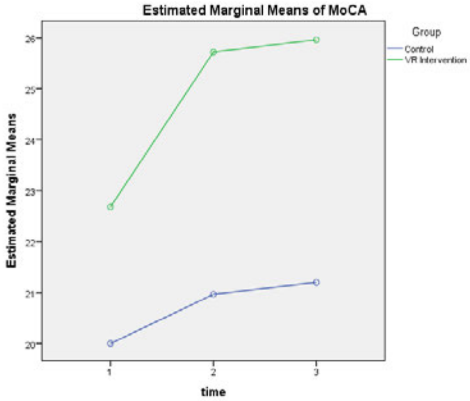


Figure 3. Change in postural balance (Berg Balance Test), a higher score indicates better balance level. VR group showed greater improvement than control group in the study (p value<.05).

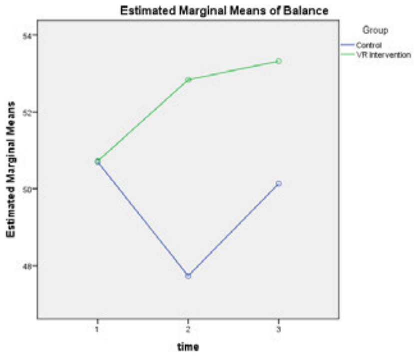


Figure 4. Change in walk speed (6-minute walk test), a longer distance indicates faster walking speed. VR group showed greater improvement than control group (p value <.005).

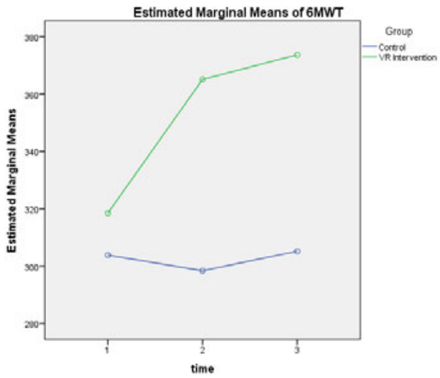


Figure 5. Change in functional mobility (Time Up and Go Test), a shorter time (<12s) indicates better functional level and lesser risk of fall. Two groups showed no significant difference in the study (P value >.05).

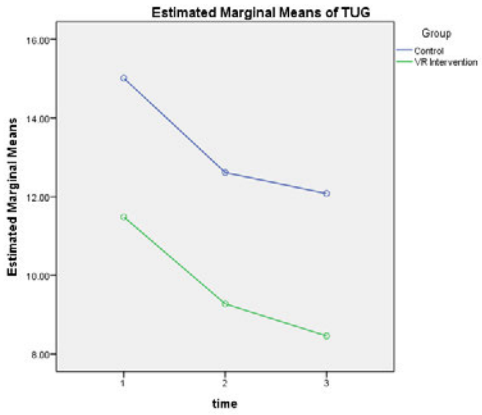


Figure 6. Change in fear of falling (Fall Efficacy Scale), a lessor score (FES-I<28) indicates lower level of fall concern. Two groups showed no significant difference in the study (p value >.05).

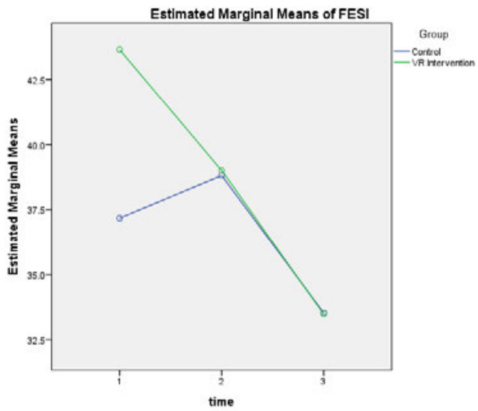
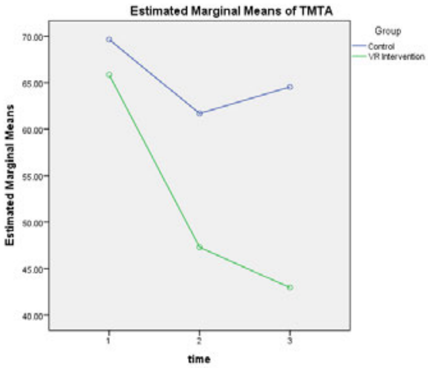
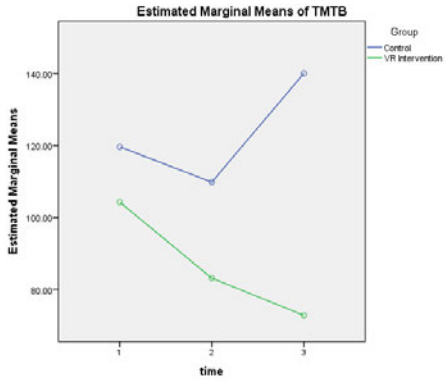


Figure 7 & 8. Change in executive function (Trial Making Test A & B), a shorter time indicates better level of executive function. VR group showed greater improvement than control group in the study (p value <.05).





5.2 Links and Implications

The VR CAVE program demonstrated effectiveness with promising evidence in reducing the risk of falls for older users. For instance, VR participants exhibited greater improvement in physical and cognitive performance with good sustainability. The incidence of recurrent falls in the VR group was lower than in the control group after a 6-month follow-up period. The participation and engagement of VR research were excellent, and the results were highly encouraging. Overall, the feedback regarding the usefulness and acceptance of VR participants was very positive. It is advisable that future studies invest resources in qualitative analysis to explore users' perceptions and acceptance further. To the end, service stakeholders and health professions could expand new scope of service by incorporating innovative VR CAVE technology into future rehabilitation and aged care services.

CHAPTER 6: DISCUSSION AND CONCLUSION

6.1 Introduction

This thesis reports on research that aimed to evaluate the VRT intervention for reducing the risk of falls among older adults with mild cognitive impairment and dementia from Hong Kong. This research aimed to answer the overarching research question: "What are significant effects on innovative VRT intervention in fall prevention for older adults with mild cognitive impairment?"

The project addressed the research gap in the reviewed literature and explored the perception and acceptance of older adults using VR technology application on promoting physical well-being such as functional mobility and cognitive awareness in falls prevention. The thesis concludes the research objectives to answer the overarching research question, three research questions of this research are explained and the findings are discussed in three quantitative studies. Initially, Objective one is to pilot a RCT feasible study to compare the intervention effects between VRT and exercise-based training on reducing the risk of falls. For Objective two, it is to investigate the VR participants' usability and acceptance on adoption of VRT application in fall prevention program. Lastly, the objective three is to evaluate the effectiveness of VRT intervention study on reducing the risk of falls for older adults with mild cognitive impairment in a longer effect. The research questions (RQs) posed were answered by employing a three-study quantitative research design. The research hypotheses were examined and presented in Chapters three to five.

Chapter 6 aims to summarise and conclude an in-depth discussion of the research findings in respective quantitative studies. The significant implications and the limitations of the research are outlined in this chapter. The summary and conclusion of the thesis for future work are presented and proposed.

6.2 Discussion on Research Findings

This research is to evaluate the VRT intervention effects relating to the risk factors of falls in falls prevention by examining the feasibility of an VR CAVE Fall Prevention model proposed in Chapter 2. The pilot RCT study of Objective 1 provided the preliminary findings, the research team republicated the same research model in the experimental study presented in the Objective 3. Chosen VR participants from Objectives 1 and 3 were recruited in the study 2- a VR usability and acceptance study.

This section provides detailed discussion and critical analysis of the results of the three quantitative studies that addressed the research questions in Chapter 1.

6.2.1 Study 1- Training Effects of VRT Training and Exercise-based Training on Falls Prevention - ClinicalTrials.gov (identifier number NCT05971420)

Our research found that VR CAVE training was more effective at simulating dual-mode cognitive-motor training than traditional exercise-based intervention (Irazoki et al. 2020). The results including functional mobility (TUG p=.002), balance (BBS p=.01) and cognition (HK-MoCA p=0.01) indicated greater improvement effects in VR group. The walk speed (6MWT) within the VR group showed significant improvement across three time points (Table 3 and Table 4, Chapter 3). However, the executive function showed no significant between two groups. It implied that the VR CAVE training could be improved in future program design. Considering the participants with mild cognitive impairment, they would have some difficulties and challenges in improving their executive functioning under the limitation of this research design.

When compared with traditional exercise group training, the simulated VR CAVE experiences were so interesting and stimulating for VR activity-based engagement. Though, the practice of Baduanjin exercise was healthy and a good balance exercise, the 8-step Baduanjin exercise was a routine repetitive training and less cognitive stimulation for the participants with cognitive impairment. In contrast, the VR participants showed good attention, engaging, interactive and good acceptance of VR use. Therefore, the VR group participants found greater training effects and significantly improvement on the physical and cognitive performances after the use of VR intervention.

Regarding the fear of falling, this study did not show any significant improvement between two groups (FESI p=.339). A recent review indicated that the fall efficacy scale international (FES-I) might not be sensitive and not reliable for community-dwelling older adults with cognitive frailty (Uemura et al. 2012). Practically, the 14-item self-reported questionnaire was cognitive demanding for the participants to understand the level of rating and make an accurate judgment in daily living tasks. During the data collection, the research team did observe the difficulties and challenges to interpret, and some participants found the questionnaire difficult to respond and comprehend the meaning. Besides, the participants were limited social engagement in community living during pandemic period. They were mostly staying at home with limited social activity. It impacted the validity and reliability of using FES-I as a measurement tool for fall efficacy particularly for participants with mild cognitive impairment. The findings of fear of falling existed a potential bias and shortcoming of design method. As a result, the VR CAVE Fall Prevention model was mostly achieved in the pilot RCT study.

6.2.2 Study 2 - VR Usability and Acceptance on Use of VRT Application

Based on the findings, PU, PE, UE, and IU were the most important factors to attract and influence the usability, users' behaviours, and perceptions to use a new VRT. The perceived factors were significant increases at three assessment time points. Although the PEOU and SNS were not a significant difference in the study, the overall means showed a small increase across time occasions. Constantly, the feedback of participants was positive, and they were willing to learn and fully engage with all VR sessions. Partly, the negative results might be reflective of the limitation on VR CAVE technology and the social impact during Covid-19 restrictions in Hong Kong. Therefore, the overall results of VR usability in older adults showed promising evidence on the usefulness and acceptance to use new VRT application in falls prevention training.

Table 1 (Chapter 4) shows the participants' group had a high risk of falls at T1 e.g., 54.8% of the participants had falls within 12 months. They reported to have biological and behavioural risk factors such as overweight, three chronic diseases per each participant and lack of physical activity. These health problems might limit physical activity and influence the factor of fear of falling, because they were worried about falling and experienced falls in the past. Based on their personal needs and falls concerns, they showed good intention to participate the CAVE VR study: it could induce a sampling bias and might influence the results of the study.

Our results were consistent with recent reviews and supported the usefulness of an innovative VR intervention in falls prevention, showed greater effects on reducing the risk factors of fall (Law et al., 2014; Stanmore et al., 2019). In particular, the physical and psychological outcomes were significantly improved or reduced, indicating the lesser risk of fall in the VR study. The fear of falling indicated a significant decrease after the VR training (T2) and the follow up (T3), but the participants maintained a high fall concern (FES-I ranging from 42.0 to 32.90), indicating a high fear of falling. Similarly with previous study (study 1), the training effect of VR CAVE training on fear of falling was unmet and not able to reduce the fall concern from high to moderate level (FES-I =20-27). The consequence of the high fear of falling in older community-dwelling adults may be associated with decreased physical activity and cognitive decline (Uemura et.al, 2012).

Study 2 confirmed the evidence to adopt the use of VR acceptance questionnaire (HK-version) based on TAM scale and reviewed literature to assess the perceived factors on influence the users' experience and behaviour in Hong Kong (Syed-Abdul et al, 2019). Comparatively, this questionnaire was easy to administer, and the participants found less difficulty to respond the self-rated questions. According to research findings, the used questionnaire was valid and reliable ($r > 0.361$; p value < 0.05) in different perceived factors except items PEOU1, PEOU3 and SN2. Responses to the question regarding the influence of friends and acquaintances (SN2) might have been misinterpreted from the participants under the impact of pandemic in Hong Kong because they had limited social connection and face-to-face interaction in community. They became less socially active and not often meeting peers as usual in daily living. Predictably, the peer influence and seeking friends support to trial new VR application might be minimized and overlooked. Based on the participants' behaviour and the observation from the research team, the new VR CAVE application was not easy for participants to manage at the beginning of the study. The technological support of VR CAVE technology was critical for an inexperienced user and the research support team, for example difficult to operate hand controller accurately and position the limbs sensor properly in different users. Similarly, our study indicated that the participants encountered difficulty using VR CAVE at the first trial, and they required additional help and guidance to engage with VR game activities when encountering any technical problem in the training session.

6.2.3 Study 3- Evaluation of Training Effects of VR Technology-based Training on Reducing the Risks of Falls in Older Adults with MCI

The evaluation study supported the greater improvement of health outcomes using technology-based cognitive motor training. The VR CAVE technology-based application was a potential training method with evidence on falls prevention program for older persons with mild cognitive impairment (Kim, & Pang, 2019; Kwan et al., 2021; Ng et al., 2019). This was the first pilot study using this new application of **VirCube** VR program to adopt as a fall prevention training program in community aged care service. The VR simultaneous cognitive-motor games were modified, and the purposes redesigned for training community-dwelling older adults in Hong Kong.

The research findings supported that this tailor-made VR CAVE program had promising evidence to improve the physical and cognitive performances to reducing the intrinsic risk factors of falls for VR participants. Our results were consistent with recent reviews that the participants' results supported the usefulness of VR intervention in falls prevention, showed greater improvement on health outcomes and fully engaged with full-immersive VR games redesigned for people with old age (Law et al., 2014; Stanmore et al., 2019). However, the study design faced shortcomings in invested manpower resources in addition to the VR system and facilities accessibility during COVID pandemic in Hong Kong. This study also examined a practice guideline on the fall prevention protocol for older adults, the optimal frequency of VR CAVE training was recommended as 2-day per week for 8 weeks, each VR CAVE session within 45 minutes, 16 training sessions in total (Kim & Pang, 2019; Law et al., 2014; Yang et al., 2020).

Consistently with the pilot study (Objective 1), the findings did not show significant improvement in executive function and fear concern of falling between two groups. Possibly, the design of VR CAVE program primarily focused on cognitive-motor intervention (dual-task component) which might not have a training effect on other risk factors such as psychological fear of falling and the decision making or problem-solving skills. In addition, the fall efficacy international scale (FES-I) might not be a reliable assessment tool to assess the fear concern of falling specifically for older adults with mild cognitive impairment or dementia. The overall findings of two quantitative studies concluded the proposed VR CAVE Fall Prevention model was served as a dual-task training model. The training effect was effective in promoting cognitive-motor function in older adults with mild cognitive impairment.

6.3 Implications of the Thesis

The findings of this research have implications in three key areas: Significance of VR CAVE technology and benefits in health outcome and service innovations in age care.

6.3.1 *Significance of VR CAVE Technology*

Innovative VR CAVE technology shows great promising evidence on training, learning and social engagement through full-immersive virtual learning and interactive gaming experience (Theodoropoulos et al., 2023). The research participants reported good fun and enjoyable experience and they were motivative and showed eagerness to fully engage with every VR CAVE training session. Compared with commonly VR device such as head mounted display (HMD) headset, 3D stereoscopic eyewear and motion sensors and CAVE room are more age-friendly design for older population (Tuena et al., 2023). Practically, VR CAVE set up and wearable devices are more comfortable and good interactive learning environment, also resulting less or even eliminating the VR motion sickness for older user. It implies the application of VR CAVE technology has greater potential to develop in aged care service.

Currently, the setup cost for a VR CAVE is expensive and not easily accessible to the public. The VR CAVE facility is less commonly used in community aged care facilities in Hong Kong. Alternatively, if a portable mobile CAVE, a Mini CAVE unit, could be designed, it could reduce costs and be more flexible to place and set up in different aged care facilities. This would allow more service members of DECCs to attend similar training sessions and experience VR CAVE activities.

Lastly, VR CAVE technology has already been used for research and review in different industries including tourism, product design, engineering, medicine, and healthcare. However, there is limited research on studying the effectiveness of VR CAVE applications in aged care service. To my best of knowledge, this doctoral research is a first pioneering research project using innovative VR CAVE technology-based application on fall prevention for older adults with mild cognitive impairment in Hong Kong. Potentially, it could attract research interest and lead to more investment in health technology research in ageing population.

6.3.2 *Benefits in Health Outcomes*

This research supports the benefit of human technology in aged care service. VR technology as a kind of human-computer interaction could achieve possible health outcomes by VR technology-based training. The VR participants had significant improvement in health outcomes including cognitive function and physical balance to reduce the risk of fall and potential fall risk after 6 months study. Potentially, the participants could lower risk of fall and cognitive decline (Montero-Odasso et al, 2020). In addition, the participants were more social engagement and training commitment during the training period. They became more socially active and good connection with peers and positive emotion in daily living. Therefore, the technology engagement could reduce the users' social isolation and loneliness particularly at pandemic (Gao, Lee, & McDonough, 2020; Chen et al., 2023).

6.3.3 *Service Innovations in Age Care*

This research provides an alternative fall prevention training strategy using a VR technology approach. The VR CAVE application has been proven to be effective and suggests a useful training protocol for a fall prevention program for older adults. Inevitably, social and care service providers are willing to adopt new technology approaches to be a part of care services in the post-pandemic era. Therefore, these service innovations in aged care could help and provide a solution to overcome the challenges of deploying VR in aged care (Zhao, 2020). According to the findings in Study 2, older participants perceived a good user experience, acceptance, and an intention to use the new VR CAVE technology. The VirCube VR for Rehab program has been proven to be a cognitive-motor training program in fall prevention for older adults. As preventing falls for older adults is one of the health policies in the local government, this research evidence using VR CAVE technology for aged care services could be published and promoted for service stakeholders. Possibly, VR CAVE technology application as a new service innovation in aged care could be recommended for policy stakeholders to invest in VR CAVE technology and resources in future aged care services.

6.4 Research Limitations and Future Use

This research findings are subjected to various limitations. Compared with similar VR research (Chau et al., 2021; Ng et al., 2019; Zahabi & Abdul, 2020), the sampling and the recruitment process for this research faces many challenges and restrictions particularly at COVID-19 pandemic. The sample size of the three-qualitative studies is relatively small. Only Study 1 is a small pilot randomized control trial study. The research methodology is using a convenience sampling method and Study 2 and 3 are not randomized control trial studies, it can lead to volunteer bias and affect the generalizability of findings in the local aging population (Nikolopoulou, 2022). To improve the data reliability and generalizability, it is recommended that future similar research employs a random sampling technique and randomized control study design to gather larger sample size and representative data to uphold the research quality and overall generalizability.

Secondly, all standardized tests are taken repeatedly at three assessments periods. Potentially, paper-pencil screening assessments may create the learning effects such as cognitive screen test (HK-MoCA) and two executive function tests (TMTA and TMTB). These results may be a potential bias if those participants have good memorizing skills. Fortunately, each time interval measurement takes about 3 months, the learning effect should be minimized as possible. From the previous discussion presented in this chapter, it evaluates the fall efficacy test (FESI) measuring the fear concern of falling not to be a best option for the participants with mild cognitive impairment or risk of cognitive decline. Comparatively, this questionnaire design requires a higher level of logical and problem-solving skills to interpret and respond the self-rated questions. This 16-item questionnaire is found to be a more abstract and cognitive demand. By reviewing, some participants did respond difficulty to make quick decision and required further clarification for some questions. To minimize the learning effects and potential bias in the questionnaire design in future research, it is advisable to have a random check of the subjects' results and inter-rated by different examiners for testing the internal validity.

Thirdly, the VR CAVE technology and program design exists limited functions and focuses on intrinsic factors of fall risk reduction as a dual-task virtual simulated training program. As falls prevention is complex to manage, and a multifactorial program is used to reduce multiple risks of falls due to their complexity (WHO, 2008; Morello et al., 2019). The psychological factor of fear of falls and other risk factors did not be addressed in the research. Based on the reviewed literature, the risk factor of fear of falling was one of the contributing risk factors of falling presented in Chapter 2. Therefore, it is recommended that similar research considers a study investigating on the psychological nexus of VR on physical activities in older adult (Chirico et al., 2024).

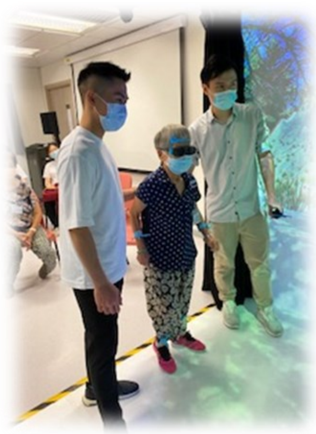
Fourthly, the findings of Study 2 reported that VR participants actively engaged with the training, displaying a positive perception towards the application of VR technology. Other benefits of the study included good social and peer support, and enjoyment of learning VR technology. Certainly, the positive effect of face-to-face interaction and interactive learning could promote mental and physical activity, eliminating social isolation and boredom during the pandemic (Gao, Lee, & McDonough, 2020; Ng et al., 2019). However, the Study 2 reported primarily on quantitative findings, more qualitative analysis on users' usability and investigations such as a participant-observational, culture-based qualitative analysis or ethnographic study would be recommended in a follow-up study.

For Study 3, presented in Chapter 5, the challenges and limitations for data collection were unexpectedly high. Data collection for follow-up was suspended during a Hong Kong lockdown from late January 2022 to May 2022. This doctoral research consumed additional manpower resources and faced difficulties in tackling research logistics, including participants' accessibility, VR CAVE facility arrangement, and other technical issues. During this lockdown period, the VR CAVE training centre located at the Hong Kong Polytechnic University and all DECCs suspended all research projects and daily services in Hong Kong. The 3-month follow-up measurement in Study 3 was delayed, potentially impacting the dropout rate as some participants refused to continue the study. As an alternative, the research team adopted a special arrangement to maintain contact with the participants through telephone calls and other social means, e.g., WhatsApp groups. Inevitably, the research adopted the intention-to-treat method for data analysis. Lastly, if this research has the chance to conduct a follow-up study, it is worthy to plan a longitudinal study to investigate the long-term effect of VR training.

6.5 Summary

This doctoral study supports promising evidence on the effects of Virtual Reality CAVE technology-based training on preventing falls among community-dwelling older adults with mild cognitive impairment from Hong Kong. Among the three quantitative studies, the results do not prove the training effect to reduce the fear of falling and executive functions by this special VirCube VR for Rehab program. The VR CAVE program is innovative, cognitive stimulating, and provides a fully immersive gaming learning environment. Study 1 supports the VR CAVE program has greater improvement in falls prevention than a traditional exercise-based program. Study 2 shows positive perceptions and users' experiences adopting new VR CAVE technology in older adults. Study 3 reaffirms the effectiveness of the VirCube VR for Rehab program in reducing the physical and cognitive risk factors of falls in older adults. To attract similar research interests using full-immersive VR CAVE technology, a user-friendly accessible design of VR CAVE technology is recommended to invest in the future. For future development, similar studies should be replicated by comparing different VR applications with a larger sample and a randomized control trial study design to generalize greater evidence on evaluating the effectiveness and acceptance of adopting new VR technology in rehabilitation and aged care services.

APPENDIX A- EQUIPMENT OF VIRCUBE VR APPLICATION

Picture A. VR headset (3D stereoscopic eyewear)	
Picture B. CAVE VR Room Design Specifications: Room size: 2 metre x 2 metre 4 overhead projectors	
Picture C. Sensors attached to headset and limbs.	

Picture D: Physical VR exercise (soccer)	
Picture E: Physical VR exercise (jogging)	
Picture F. Cognitive motor VR game (IADL-community shopping)	
Picture G. Executive function VR game (emergency handling)	

Table A.1 Picture A to G

APPENDIX B- VIRCUBE VR GAME TRAINING PROTOCOL

VR Game 1: **Emergency handling**

Purpose: Cognitive training - executive function (Problem-solving skill)

Grading: N/A

Device: 3D stereoscopic eyewear, hand controller, hand trackers

Fire drill exercise  	Sequencing: 1. When fire alarm on, participant moves tracker to point out and touch three important things (key, mobile & wet towel) for evacuation. 2. Participant walks to the front door and use tracker to unlock the door (balance and hand-eye coordination) 3. Participant uses tracker to select different escape routes (judgement) 4. Participant chooses either route 1(lift) or route 2(up/downstairs) to get out of fire scene safely (decision making)    VR trial (video sample) IADL.mp4

Table B.1 VR game 1

VR Game 2: **Community Living Skill Practice**

Purpose: Cognitive training – executive function (classification & calculation)

Grading: 3 levels (Level 1- free choice; Level 2: shopping items- 2-3; Level 3: shopping items- 3-5)

Device: 3D stereoscopic eyewear, hand controller

Shopping  orientation	Sequencing & Grading: 1. Participant uses hand controller selects a level of activity 2. Participant remembers a shopping list (memory skill) 3. Participant goes to the selected shopping regions (making decision) 4. Participant chooses and pick up the correct no. of items (classification & counting) 5. Participant checks and goes to cashier for payment (calculation)   VR trial (video sample) Shopping.mp4

Table B.2 VR game 2

VR Game 3: **Jogging and balancing exercise**

Purpose: Physical balance and safe walking training

Grading: 3 levels (Level 1-by hand trackers; Level 2- by hand trackers & obstacle; Level 3- by hand/foot trackers & obstacles)

Device: 3D stereoscopic eyewear, hand and foot trackers

Jogging in the  park	Sequencing & Grading: 1. Participant uses hand trackers selects a level of activity 2. Participant runs with arms movement and keeps on a running path (upper limb balance) 3. Participant runs with upper and lower limbs trackers and follows a running path (whole body balance & physical training) 4. Participant runs and avoids hitting any obstacle on a running path (advance physical balance and coordination skill) 5. Participant runs faster and overcomes more    obstacles (physical and cognitive training) VR trial (video samples) physical.mp4 balancetraining.mp4

Table B.3 VR game 3

VR Game 4: **Balance & weight-shifting exercise**

Purpose: Cognitive-motor training and advanced balance exercise

Grading: 4 levels:

Level 1- defender (keeping); Level 2-attacker (attacking); Level 3- penalty kick (attacking); Level 4- penalty kick (goalkeeping)-

Device: 3D stereoscopic eyewear, hand controller, hand, and foot trackers

Soccer exercise	Sequencing & Grading:
 	1. Participant uses hand controller selects a level of activity 2. Participant wears hand and foot trackers, practices passing a soccer to other player (balance & stability) 3. Participant runs and kicks a soccer to different position (balancing & weight shifting training) 4. Participant kicks a soccer to goalkeeper repeatedly (balancing, stability, weight-shift training to prevent falling) 5. Participant as a goalkeeper uses hand and foot trackers to defend the goal (advance limbs balancing and coordination, ball tracking exercise, spatial orientation & higher executive function skill)   VR trial (video sample) balance.mp4 goal.mp4

Table B.4 VR game 4

APPENDIX C- ACCEPTANCE OF THE VIRTUAL REALITY (VR) EXPERIENCE AMONG THE ELDERLY: QUESTIONNAIRE

- **Perceived usefulness (PU)**
  1. VR is useful to me for entertainment.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree

  2. VR improves engagement and motivates my daily activities.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree

  3. VR is an efficient tool to raise my mood.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree

- **Perceived ease of use (PEOU)**
  1. It is easy for me to become skilful at using VR.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree

- Strongly agree

2. Learning to operate VR was easy for me.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

3. Overall I find it easy to use VR.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

❖ **Perceived enjoyment (PE)**

1. I find VR very attractive to use.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

2. I enjoy using VR.
   - Strongly disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly agree

3. I have fun when I use VR.
   - Strongly disagree
   - Disagree

- Neutral
- Agree
- Strongly agree

❖ **Subjective norms (SNs)**

1. My family members think I should use VR.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree

2. People who are friends and acquaintances have influence on my intention to use VR.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

3. People who take care of me encourage me to use VR.
    - Strongly disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly agree

- **User experience (UE)**
  1. VR will give me new experiences.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree

  2. VR was comfortable to use.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree

  3. Overall, I had a positive experience when using VR.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree
- **Intentions to use (IU)**
  1. In the future, I intend to use the device for mental relaxation.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree
  2. In the future, VR will help keep my mind sharp and alert.
     - Strongly disagree
     - Disagree
     - Neutral
     - Agree
     - Strongly agree

REFERENCES

Baus, O., & Bouchard, S. (2014). Moving from virtual reality exposure-based therapy to augmented reality exposure-based therapy: a review. *Frontiers in human neuroscience*, *8*, 112. https://doi.org/10.3389/fnhum.2014.00112

Borges, S. D. M., Radanovic, M., & Forlenza, O. V. (2015). Fear of falling and falls in older adults with mild cognitive impairment and Alzheimer's disease. *Aging, Neuropsychology, and Cognition*, *22*(3), 312-321. https://doi.org/10.1080/13825585.2014.933770

Boulton, E., Hawley-Hague, H., Vereijken, B., Clifford, A., Guldemond, N., Pfeiffer, K., ... & Todd, C. (2016). Developing the FARSEEING Taxonomy of Technologies: Classification and description of technology use (including ICT) in falls prevention studies. *Journal of biomedical informatics*, *61*, 132-140. https://doi.org/10.1016/j.jbi.2016.03.017

Breslow, N. E., & Day, N. E. (1986). Statistical methods in cancer research volume II–the design and analysis of cohort studies. *IARC Scientific Publications). Statistical Methods in Cancer Research*, *1*.

Chau, P. H., Kwok, Y. Y. J., Chan, M. K. M., Kwan, K. Y. D., Wong, K. L., Tang, Y. H., ... & Leung, M. K. (2021). Feasibility, acceptability, and efficacy of virtual reality training for older adults and people with disabilities: single-arm pre-post study. *Journal of Medical Internet Research*, *23*(5), e27640. https://doi.org/10.2196/27640

Chen H, Levkoff SE, Kort H, McCollum QA and Ory MG (2023) Editorial: Technological innovations to address social isolation and loneliness in older adults. *Front. Public Health* 11:1139266. https://doi: 10.3389/fpubh.2023.1139266

Chirico, A., Avellone, M., Palombi, T., Alivernini, F., Alessandri, G., Filosa, L., & Lucidi, F. (2024). Exploring the Psychological Nexus of Virtual and Augmented Reality on Physical Activity in Older Adults: A Rapid Review. *Behavioral Sciences*,*14*(1), 31. https://doi.org/10.3390/bs14010031

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models.*Management science*,*35*(8), 982-1003. https://doi.org/10.1287/mnsc.35.8.982

D'Cunha, N. M., Nguyen, D., Naumovski, N., McKune, A. J., Kellett, J., Georgousopoulou, E. N., ... & Isbel, S. (2019). A mini-review of virtual reality-based interventions to promote well-being for people living with dementia and mild cognitive impairment. *erontology*, *65*(4), 430-440. https://doi.org/10.1159/000500040

Delbaere, K., Kochan, N.A., Close, J. C., Menant, J. C., Sturnieks, D. L, Brodaty, D., Sachedev, P. S., & Lord, S. R. (2012). Mild cognitive impairment as a predictor of falls in community-dwelling older people. *Am J Geriatric Psychiatry. 20*(10):845-853. https://doi.org/10.1097/JGP.0b013e31824afbc4

Eisapour, M., Cao, S., Domenicucci, L., & Boger, J. (2018, September). Virtual reality exergames for people living with dementia based on exercise therapy best practices. In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 62, No. 1, pp. 528-532). Sage CA: Los Angeles, CA: SAGE Publications. https://doi.org/10.1177/1541931218621120

Enright, P. L., McBurnie, M. A., Bittner, V., Tracy, R. P., McNamara, R., Arnold, A., & Newman, A. B. (2003). The 6-min walk test: a quick measure of functional status in elderly adults. *Chest, 123*(2), 387-398. https://doi.org/10.1378/chest.123.2.387

Freeman, J. V., Walters, S, J. &Campbell, M. J. (2009*).* How to Display Data, John Wiley & Sons, Incorporated, 2008. *ProQuest E-book Central*. https://urn.fi/URN:ISBN:978-952-03-1407-1

Fadhel, K. (2002), Positivist and Hermeneutic Paradigm: A Critical Evaluation under their Structure of Scientific Practice. *The Sosland Journal*, 21-28.

Gao, Z., Lee, J., & McDonough, D. (2020). Virtual Reality Exercise a Coping Strategy for Health and Wellness Promotion in Older Adults during the COVID-19 Pandemic. *Journal of Clinical Medicine. 9*,1986; https://doi:10.3990/jcm9061986

Gillespie, L. D., Robertson, M. C., Gillespie, W. J., Lamb, S. E., Gates, S., & Cumming, R. G. (2009). Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev. 2*:CD007146. https://doi.org/10.1002/14651858.CD007146.pub3

Greene, B. R., O'Donovan, A., Romero-Ortuno, R., Cogan, L., Scanaill, C. N., & Kenny, R. A. (2010). Quantitative falls risk assessment using the timed up and go test. *IEEE Transactions on Biomedical Engineering, 57*(12), 2918-2926. https:// doi.10.1109/TBME.2010.2083659

Hadjistavropoulos, T., Delbaere, K., & Fitzgerald, T. D. (2011). Reconceptualizing the role of fear of falling and balance confidence in fall risk. *Journal of Aging and Health*, 23, 3–23. https://doi.org/10.1177/0898264310378039

Hamm, J., Money, A. G., Atwal, A., & Paraskevopoulos, I. (2016). Fall prevention intervention technologies: A conceptual framework and survey of the state of the art. *J Biomed Inform, 59*, 319-345. https://doi:10.1016/j.jbi.2015.12.013

Hsiao, C. H., & Yang, C. (2011). The intellectual development of the technology acceptance model: A co-citation analysis. *International Journal of Information Management*,*31*(2), 128-136. https://doi.org/10.1016/j.ijinfomgt.2010.07.003

Irazoki, E., Contreras-Somoza, L. M., Toribio-Guzman, J. M., Jenaro-Rio, C., van der Roest, H., & Franco-Martin, M. A. (2020). Technologies for Cognitive Training and Cognitive Rehabilitation for People With Mild Cognitive Impairment and Dementia. A Systematic Review. *Front Psychol, 11*, 648. https://doi:10.3389/fpsyg.2020.00648

Kamal, S. A., Shafiq, M., & Kakria, P. (2020, 2020/02/01/). Investigating acceptance of telemedicine services through an extended technology acceptance model (TAM). *Technology in Society, 60*, 101212. https://doi.org/https://doi.org/10.1016/j.techsoc.2019.101212

Kim, O., Pang, Y., & Kim, J. H. (2019). The effectiveness of virtual reality for people with mild cognitive impairment or dementia: a meta-analysis. *BMC psychiatry*, *19*(1), 1-10. https://doi.org/10.1186/s12888-019-2180-x

Lamb, S. E., Jørstad-Stein, E. C., Hauer, K., Becker, C., & Prevention of Falls Network Europe and Outcomes Consensus Group. (2005). Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. *Journal of the American Geriatrics Society*, *53*(9), 1618-1622. https://doi.org/10.1111/j.1532-5415.2005.53455.x

Lam, F. M. H., Leung, J. C. S., & Kwok, T. C. Y. (2019). The Clinical Potential of Frailty Indicators on Identifying Recurrent Fallers in the Community: The Mr. Os and Ms. OS Cohort Study in Hong Kong. *J Am Med Dir Assoc, 20*(12), 1605-1610. https://doi:10.1016/j.jamda.2019.06.019

Law, L.L., Barnett, F., Yau, M.K., & Gray, M.A. (2014). Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: a systematic review. Ageing Res Rev. 2014; 15:61–75. https://doi.org/10.1016/j.arr.2014.02.008

Leung, D. D. M. (2019). Influence of functional, psychological, and environmental factors on falls among community-dwelling older adults in Hong Kong. *Psychogeriatrics, 19*(3), 228-235. https://doi:10.1111/psyg.12386

Liu-Ambrose, T. Y., Ashe, M. C., Graf, P., Beattie, B. L., & Khan, K. M. (2008). Increased risk of falling in older community-dwelling women with mild cognitive impairment. *Phys Ther. 88*(12):1482–91. https://doi.org/10.2522/ptj.20080117

Liu-Ambrose, T., Nagamatsu, L. S., Hsu, C. L., & Bolandzadeh, N. (2012). Emerging concept: ‘central benefit model ‘of exercise in falls prevention. *British journal of sports medicine*. https://doi.org/10.1136/bjsports-2011-090725

Logan, P. A., Coupland, C. A., Gladman, J. R., Sahota, O., Stoner-Hobbs, V., Robertson, K., ... & Avery, A. J. (2010). Community falls prevention for people who call an emergency ambulance after a fall: randomised controlled trial. *Bmj,340*. https://doi.org/10.1136/bmj.c2102

Ning, X (2012). An Empirical Study of User Experience (UX) Factors Affecting Continued Usage Intention of Smartphone. 9(4), 91-118.

Mahzar, E., Shi, C.& Laura, D. et al. (2018). Virtual Reality Exergames for People Living with Dementia Based on Exercise Therapy Best Practices. *Proceedings of the Human Factors & Ergonomics Society Annual Meeting.* https://doi.org/10.1177/1541931218621120

Mertens, D. M. (2015). *Research and Evaluation in Education and Psychology.* 4th Edn. Los Angeles: Sage.

Mirelman, A, Rochester, L., & Maidan, I (2016). Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): a randomized controlled trial. *Lancet. 388*(10050):1170–82. https://doi.org/10.1016/S0140-6736(16)31325-3

Montero-Odasso, M. M., & Camicioli, R. (2020). *Falls and Cognition in Older Persons. Fundamental, Assessments and Therapeutic Options*. Springer Nature Switzerland AG. ISBN 978-3-030-24233-6.

Montero-Odasso, M. M., Verghese, J., Beauchet, O., & Hausdorff, J. M. (2012). Gait and cognition: a complementary approach to understanding brain function and the risk of falling. *Journal of American Geriatric Society, 60*, 2121-36. https://doi.org/10.1111/j.1532-5415.2012.04209.x

Montero-Odasso, M. M., & Speechley, M. (2018). Falls in cognitively impaired older adults: implications for risk assessment and prevention. *J Am Geriatr Soc. 66*(2):367–75. https://doi.org/10.1111/jgs.15219

Moreno, A., Wal, K. J., Thangavelu, K., Vraven, L., Ward, E., & Dissanyaka, N. N. (2019). A systemic review of the use of virtual and its effects on cognition in individuals with neurocognitive disorders. Alzheimer's Dementia. *Transl. Res. Clin. Interv.5*, 834-850. https://doi.org/10.1016/j.trci.2019.09.016

Morello, R. T., Soh, S. E., Behm, K., Egan, A., Ayton, D., Hill, K., ... & Barker, A. L. (2019). Multifactorial falls prevention programmes for older adults presenting to the emergency department with a fall: systematic review and meta-analysis. *Injury prevention*, *25*(6), 557-564.https://doi.org/10.1136/injuryprev-2019-043214

Muir, S. W., Gopaul, K., & Montero-Odasso, M. M. (2012). The role of cognitive impairment in fall risk among older adults: a systematic review and meta-analysis. *Age Ageing. 41*(3):299–308. https://doi.org/10.1093/ageing/afs012

Muir, S. W., Berg, K., Chesworth, B., Klar, N., & Speechley, M. (2010). Application of a fall screening algorithm stratified fall risk but missed preventive opportunities in community-dwelling older adults: a prospective study. *J Geriatr Phys Ther*. 33,165–72.

Muir, S. W., Berg, K., Chesworth, B., & Speechley, M. (2008). Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study. *Physical therapy, 88*(4), 449-459. https://doi.org/10.2522/ptj.20070251

Myers, A. H., Baker, S. P., Van Natta, M. L., Abbey, H., & Robinson, E. G. (1991). Risk factors associated with falls and injuries among elderly institutionalized persons. *Am J Epidemiol.133*(11),1179–90. https://doi.org/10.1093/oxfordjournals.aje.a115830

Nasreddine, Z.S., Philips, N., Be'dirian, V., Charbonneau, S., Whitehead, P., Colin, I., Cummings, J.L., Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool for Mild Cognitive Impairment. J Am Geriatr Soc 53,695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x

Ng, Y. L., Ma, F., Ho, F. K., Ip, P., & Fu, K. W. (2019). Effectiveness of virtual and augmented reality-enhanced exercise on physical activity, psychological outcomes, and physical performance: A systematic review and meta-analysis of randomized controlled trials. *Computers in Human Behavior*, *99*, 278-291. https://doi.org/10.1016/j.chb.2019.05.026

Nikolopoulou, K. (2022). What Is Convenience Sampling? | Definition & Examples. Scribbr. https://www.scribbr.com/methodology/convenience-sampling/

Ohman, H., Savikko, N., & Strandberg, T. E. (2016). Effects of exercise on cognition: the Finnish Alzheimer disease exercise trial: a randomized, controlled trial. *Journal of American Geriatric Society: 64*:731-38. https://doi.org/10.1111/jgs.14059

Okonkwo, O. C., Wadley, V. G., Ball, K., Vance, D. E., & Crowe, M. (2008). Dissociations in visual attention deficits among persons with mild cognitive impairment. *Aging,* *Neuropsychology, and Cognition, 15*(4), 492-505. https://doi.org/10.1080/13825580701844414

Panel for Prevention of Falls in Older Adults (2011). American Geriatrics Society, Society BG. Summary of the updated American Geriatrics Society/British geriatrics society clinical practice guideline for prevention of falls in older persons. *J Am Geriatr Soc. 59*(1),148–57. https://doi.org/10.1111/j.1532-5415.2010.03234.x

Peeters, G., van Schoor, N. M., Cooper, R., Tooth, L., & Kenny, R. A. (2018). Should prevention of falls start earlier? Co-ordinated analyses of harmonised data on falls in middle-aged adults across four population-based cohort studies. *PLoS one*, *13*(8), e0201989. https://doi.org/10.1371/journal.pone.0201989

Peeters, G., Bennettb, C., Donoghued, O. A., Kennellya, S., & Kenny, A. K. (2020). Understanding the aetiology of fear of falling from the perspective of a fear avoidance model – A narrative review. *Clinical Psychology Review*.79,101862 https://doi.org/10.1016/j.cpr.2020.101862

Population Census 2021- Main tables. (n.d.). https://www.census2021.gov.hk/en/main_tables.html

Qian, X. X., Chau, P. H., Kwan, C. W., Lou, V. W., Leung, A. Y. M., Ho, M., . . . Chi, I. (2019). Seasonal pattern of single falls and recurrent falls amongst community-dwelling older adults first applying for long-term care services in Hong Kong. *Age Ageing, 49*(1), 125-129. doi:10.1093/ageing/afz139 https://doi.org/10.1093/ageing/afz139

Rubenstein, L., & Josephson, K. R. (2006). Falls and their prevention in elderly people: what does the evidence show? *Med Clin North Am; 90*,807-24. https://doi.org/10.1016/j.mcna.2006.05.013

Scheffer, A. C., Schuurmans, M. J., van Dijk, N., van der Hooft, T., & de Rooij, S. E. (2008). Fear of falling: Measurement strategy, prevalence, risk factors and consequences among older persons. Age and Ageing, 37,19–24. https://doi.org/10.1093/ageing/afm169

Shema, S. R., Bezalel, P., & Sberlo, Z. et al. (2017). Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training. *Journal of Alternative Medicine Research; 9*(2),171-175.

Smith, J. K., & Heshusius, L. (1986). Closing down the conversation: The end of the quantitative-qualitative debate among educational inquirers. *Educational researcher*, *15*(1), 4-12. https://doi.org/10.3102/0013189X015001004

Stanmore, E. K., Mavroeidi, A., de Jong, L. D., Skelton, D. A., Sutton, C. J., Benedetto, V., ... & Todd, C. (2019). The effectiveness and cost-effectiveness of strength and balance Exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: a multi-centre, cluster randomised controlled trial. *BMC medicine*, *17*, 1-14. https://doi.org/10.1186/s12916-019-1278-9

Social Welfare Department. (n.d.). *Elderly Centres | Community Support | Services for the Elderly | Public Services | Social Welfare Department*. https://www.swd.gov.hk/en/pubsvc/elderly/cat_commsupp/elderly_centres/

Thapa, N., Park, H. J., Yang, J., Son, H., Lee, M. J., Kang, S. W., Park, K. W., & Park, H. (2020). The Effect of a Virtual Reality-Based Intervention Program on Cognitive in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial. *Journal of Clinical Medicine 9*,1283; doi:10.3390. https://doi.org/10.3390/jcm9051283

Theodoropoulos, A., Stavropoulou, D., Papadopoulos, P., Platis, N., & Lepouras, G. (2023, May). Developing an Interactive VR CAVE for Immersive Shared Gaming Experiences. In *Virtual Worlds* (Vol. 2, No. 2, pp. 162-181). MDPI. https://doi.org/10.3390/virtualworlds2020010

Tsang, W. W., & Fu, A. S. (2015). Effectiveness of exergaming training in reducing risk and incidence of falls in frail older adults with a history of falls. *Arch Physical Medicine Rehabilitation,96*,2096-102. https://doi.org/10.1016/j.apmr.2015.08.427

Tuena, C., Serino, S., Stramba-Badiale, C., Pedroli, E., Goulene, K. M., Stramba-Badiale, M., & Riva, G. (2023). Usability of an Embodied CAVE System for Spatial Navigation Training in Mild Cognitive Impairment.*Journal of Clinical Medicine*,*12*(5), 1949. https://doi.org/10.3390/jcm12051949

Uemura, K., Shimada, H., Makizako, H., Yoshida, D., Doi, T., & Tsutsumimoto, K. (2012). A lower prevalence of self-reported fear of falling is associated with memory decline among older adults. *Gerontology. 58*(5),413–8. https://doi.org/10.1159/000336988

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425-478. https://doi.org/10.2307/30036540

Verghese, J., Robbins, M., & Holtzer, R. (2008). Gait dysfunction in mild cognitive impairment syndromes *Am Geriatric Soc.;56*(7),1244. https://doi.org/10.1111/j.1532-5415.2008.01758.x

Welmer, A. K., Rizzuto, D., Laukka, E. J., Johnell, K., & Fratiglioni, L. (2017). Cognitive and physical function in relation to the risk of injurious falls in older adults: a population-based study. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *72*(5), 669-675. *s* https://doi.org/10.1093/gerona/glw141

World Health Organization. (2008). WHO global report on falls prevention in older age. World Health Organization. https://apps.who.int/iris/handle/10665/43811

World Health Organization (2017). Dementia: key facts No362. WHO, https://www.who.int/en/news-room/fact-sheets/detail/dementia

World Health Organization (2019). Falls Prevention in Older Persons. https://www.who.int/ageing/projects/falls/prevention/older/age/en/.

World Health Organization. (2020). Preventing and managing COVID-19 across long-term care services: Policy brief, 24 July 2020.

World Health Organization. (2021). Step safely: strategies for preventing and managing falls across the life-course.

Yang, C. M., Hsieh, J. S. C., Chen, Y. C., Yang, S. Y., & Lin, H. C. K. (2020). Effects of Kinect exergames on balance training among community older adults: A randomized controlled trial. *Medicine*, *99*(28). https://doi.org/10.1097/ MD.0000000000021228.

Yardley, L., Beyer, N., Hauer, K., Kempen, G., Piot-Ziegler, C., & Todd, C. (2005). Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and ageing, 34*(6), 614-619. https://doi.org/10.1093/ageing/afi196

Yogev-Seligmann, G., Hausdorff, J. M. & Giladi, N. (2008). The role of executive function and attention in gait. *Mov Disorder. 23(3),*329–42.Hamm, J., Money, A. G., Atwal, A., & Paraskevopoulos, I. (2016). Fall prevention intervention technologies: A conceptual framework and survey of the state of the art. *J Biomed Inform, 59*, 319-345. https://doi:10.1016/j.jbi.2015.12.013

Zahabi, M., & Abdul Razak, A. M. (2020). Adaptive virtual reality-based training: a systematic literature review and framework. *Virtual Reality*, *24*, 725-752. https://doi.org/10.1007/s10055-020-00434-w

Zhao, W., Baker, S., & Waycott, J. (2020, December). Challenges of deploying VR in aged care: a two-phase exploration study. In *Proceedings of the 32nd Australian Conference on Human-Computer Interaction* (pp. 87-98). https://doi.org/10.1145/3441000.3441018