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Research Article

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

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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 the 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 the pretest, posttest, and follow-up. *Results*. The participants' group significantly showed improvements in reducing the risk factors 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 the use of VR technology applications. Perceived ease of use (PEOU) and social norms (SNs) had an inconsistent result, and some items had low validity. The findings indicated a positive training effect on fall prevention and high acceptance of the 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 the VR CAVE application was useful and innovative as an effective fall prevention training. Technically, the application of VR CAVE technology faces many challenges and is 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.

1. Introduction

Falls in older adults are 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 recommend healthcare professionals and aged care operators provide advice and support on fall 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], among 89,100 older adults, about 32% of older adults fell in the past 90 days. Importantly, a history of falls is found to be one of the predictors 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 has grown rapidly in recent years in aged care fields [9, 10]. There is evidence to support its use in fall prevention, as well as a reduction in fall risks among older adults living with cognitive impairment [11–13]. There is a research gap in the exploration of the usability and acceptance of the 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 and 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 underinvestigated [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].

2. Materials and Methods

This exploratory study involved a single-arm design and used a convenience sampling method to measure the changes in physical health outcomes at fall risk measurements and perceived factors based on the VR usability questionnaire (HK-version) at the pretest (T1), posttest (T2), and the follow-up (T3). As the study was carried out during the COVID-19 pandemic in Hong Kong between 2020 and 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 was applied in the study to understand participants' acceptance of a new technology in the 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 applications [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 the predictive factors in the acceptance of 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' perceptions to consider whether they should use VR. Perceived enjoyment (PE) was defined as older adults perceived using 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 older adults' behaviour during and after using VR technology intervention. In view of TAM and reviewed literature, the study adopted to use of the VR usability questionnaire (HK-version) as an instrument to compare the changes of these variables across the time intervals.

2.1. 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 the Berg Balance Scale (BBS), 6-minute walk test (6MWT), and Time Up and Go test (TUG) to assess the change in fall risk using the VRT intervention [23].

2.2. 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.

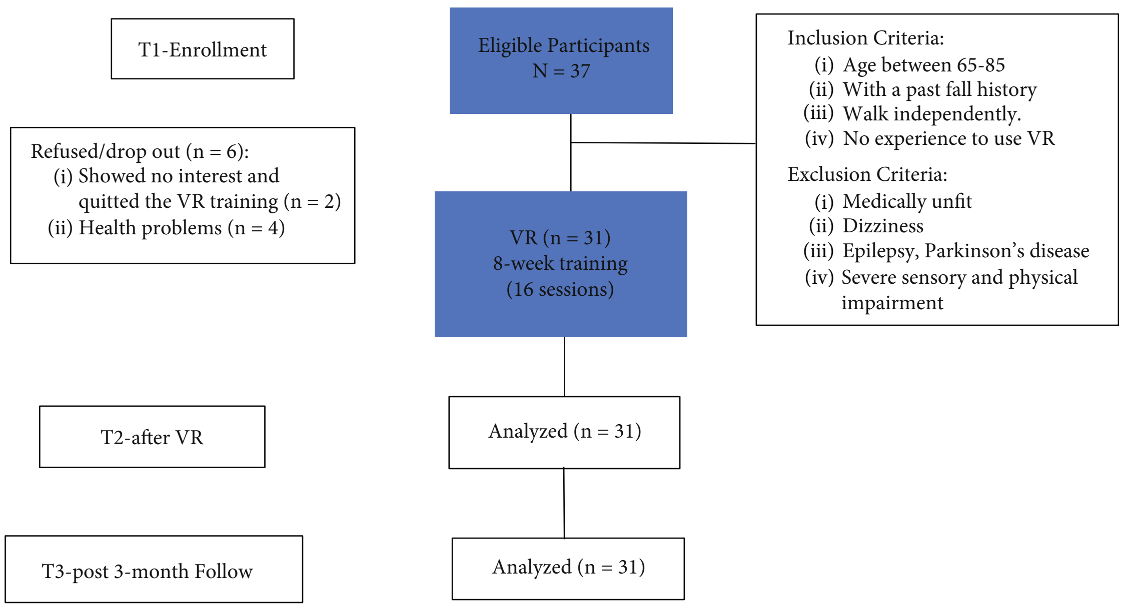


Figure 1: Flowchart of study.

2.3. Inclusion Criteria. The inclusion criteria were (1) aged 65 years to 85 years, (2) having a history of falls within 2 years, (3) having no experience of VR, and (4) being able to walk independently and to be able to access the VR research centre.

2.4. 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.

2.5. Intervention. A new VRT application called VirCube VR for the rehab program was used in the VR training. The VR CAVE program was set up for research purposes, fully managed by the Department of Rehabilitation Sciences at The Hong Kong Polytechnic University. It was a VR and 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 exercises, 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. The setup of the VirCube VR application is displayed in pictures A to G (see Table 1).

2.6. 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-19 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, a 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 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 for the participants' feedback on experiencing full immersive VR game activities and checked and cleaned all VR-wearing devices before the next session. Full immersive VR game activities for preventing falls are displayed and documented with a detailed description (see Additional File 1 in the Supplementary Materials).

2.7. 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, fall history, cognitive status, and other medical history (Table 1). Risk 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.

2.8. VR Usability—Outcome Measure. Participants were asked to fill in a VR usability questionnaire (Appendix 1 in the Supplementary Materials) at pretest (time 1), posttest

Table 1: Set up of VirCube VR application.

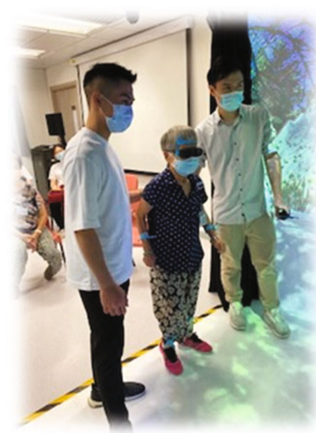
Picture A. VR headset (3D stereoscopic eyewear)	
Picture B. CAVE VR room design Specifications: Room size: 2 metre × 2 metre 4 overhead projectors	
Picture C. Sensors attached to headset and limbs	
Picture D: VR sport exercise (soccer)	

Table 1: Continued.

Picture E: VR physical exercise (jogging)	
Picture F. VR cognitive motorgame (IADL-community shopping)	
Picture G. Executive function VR game (emergency handling)	

(time 2), and 3-month follow-up (time 3). The HK-version questionnaire was based on the TAM scale and Venkatesh studies (Appendix 1: VR Questionnaire in the Supplementary Materials). 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, and 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 score indicated greater user perception and acceptance of VR.

2.9. 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 a 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 a chair, walk 3 metres, turn around, walk back to the chair, and sit down, and the time taken was recorded [25]. The older persons with ages between 65 and 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.

2.10. Psychological Consideration. Fear of falling is associated with a range of adverse health and psychosocial outcomes, including increased risk of falls, poorer physical functioning, and a more rapid decline in cognitive function and well-being [26]. The Falls Efficacy Scale-International (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 the community is divided into three levels, a score of 16-19 indicating low concern of falling, a score of 20-27 indicating moderate concern, and a score of 28-64 indicating high concern [27].

2.11. Statistical Methods. The statistical outcomes were analysed using SPSS version 27. 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, body mass index, history of falls, other health history, such as chronic pain and disease, and history of fracture.

To compare the outcome measures within subjects in the same group from pretest, posttest, and follow-up, one-way repeated measures ANOVA was used in SPSS analysis. The time factor was used as the independent variable, and the dependent variables included each subset of the VR acceptance questionnaire and 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.

3. Results

3.1. Characteristics of the Participants. Table 2 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, most commonly in older adults such as knee osteoarthritis (OA), osteoporosis, chronic pain, and hypertension. In addition, the study assessed the participants' cognition by a Hong Kong version of the Montreal Cognitive Test (HK-MoCA), and 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 3 shows the validity test of the VR usability questionnaire, and it indicated that PU ($p < 0.005$), PE ($p < 0.001$), UE ($p < 0.005$), and IU ($p < 0.001$) items were tested as high validity ($p$value ≤ 0.05 and Pearson's product-momentcoefficient > 0.361) [29]. However, three items only such as PEOU1 ($p = 0.075$), PEOU3 ($p = 0.123$), and SN2 ($p = 0.061$) were tested as not significant (p value > 0.05 and rxy < 0.361). Predictably, the VR acceptance questionnaire (HK-version) was a good validity test in the study.

Table 2: 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 (0.631)
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 4 shows summary statistics and frequency distributions of variables in the VR usability questionnaire. The mean (M) value was ranging from 3.03 to 4.45, and the standard deviation (SD) was ≤1.3292 in time 1 (T1). The mean (M) value was ranging from 3.48 to 4.68, and the standard deviation (SD) was ≤0.922 in time 2 (T2), whereas the mean (M) value was ranging from 3.191 to 4.81, and the standard deviation (SD) was ≤1.078 in time 3 (T3). The trend of each subset of variables (mean values) was increasing at different time assessment points.

Table 5 shows the internal consistency and reliability of the dependent variables, and Cronbach's α ranged from 0.532 to 0.833. PU, PEOU, PE, and UE showed higher internal consistency and reliability; however, SNs ($\alpha = 0.532$) and IU ($\alpha = 0.642$) indicated a lesser internal consistency and reliability. Cronbach's α reliability analysis indicates an acceptable reliability when $\alpha > 0.700$.

3.2. Results on VR Usability in Older Adults. Table 6 shows there was an overall significant difference between the means at different time points from pretest, posttest, and follow-up in perceived usefulness (PU) ($F(1.975, 59.250) = 4.685$, $p < 0.05$), perceived enjoyment (PE) ($F(1.690, 50.703) = 4.852$, $p < 0.05$), user experience (UE) ($F(1.745, 52.353) = 3.289$, $p < 0.05$), and intention to use (IU) ($F(1.976, 59.286) = 6.716$, $p < 0.005$). In particular, the participants' group indicated a significant difference ($p = 0.011$) in user experience (UE) after VR training. Besides, PU ($p = 0.018$), PE ($p = 0.017$), and IU ($p = 0.005$)

Table 3: 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)	0.774	0.001
VR improves engagement and motivates daily activities (PU2)	0.537	0.002
VR is an efficient tool to raise my mood (PU3)	0.800	0.001
Perceived ease of use (PEOU)		
It is easy for me to become skilful at using VR (PEOU1)	0.324	0.075
Learning to operate VR was easy for me (PEOU2)	0.378	0.036
Overall, I find it easy to use VR (PEOU3)	0.283	0.123
Perceived enjoyment (PU)		
I find VR very attractive to use (PE1)	0.873	0.001
I enjoy using VR (PE2)	0.809	0.001
I have fun when I use VR (PE3)	0.656	0.001
Social norms (SNs)		
My family members think I should use VR (SN1)	0.696	0.001
People who are friends and acquaintance have influence on my intention to use VR (SN2)	0.341	0.061
People who take care of me encourage me to use VR (SN3)	0.473	0.001
User experience (UE)		
VR will give me new experience (UE1)	0.670	0.001
VR was comfortable to use (UE2)	0.694	0.001
Overall, I had a positive experience when using VR (UE3)	0.576	0.001
Intention to use (IU)		
In the future, I intend to use the device for mental relaxation (IU1)	0.661	0.001
In the future, VR will help keep my mind sharp and alert (IU2)	0.770	0.001

were found significantly different 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 mean scores of all perceived factors were increasing over time effects.

3.3. Results on Health Outcomes (Risk Factors of Falls). The research found an overall significant difference between the mean difference at different time points in all health outcomes shown in Table 5 (6MWT, TUG, and FES-I, $p < 0.001$; BBS, $p < 0.05$). By comparison, walk speed (6WMT), functional mobility (TUG), and fear of falling (FES-I) were found to have significant differences ($p < 0.001$) when comparing T3 with T1. Significantly, physical performance such as walk speed (6MWT) and functional mobility (TUG) showed greater improvement ($p < 0.001$) after VR training (T2). The overall health outcomes showed greater improvement indicating a lesser risk of predictive fall after the study.

4. Discussion

This exploratory study found improvements in usability and acceptance of the use of VRT application for preventing falls among Chinese older adults. The participants' group significantly showed improvement in 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 the VR session was closely monitored and tailor-made for the participants.

The study confirmed the evidence to adopt the use of a VR acceptance questionnaire (HK-version) based on the 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 for items PEOU1, PEOU3, and SN2. Responses to the question regarding the influence of friends and acquaintances (SN2) might have been misinterpreted by the participants under the impact of the pandemic in Hong Kong because they had limited social connection and face-to-face interaction in the community. They became less socially active and did not often meet peers as usual in daily living. Predictably, 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 limb sensor properly in different users. Though the new VR CAVE

Table 4: 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 (0.615)	4.61 (0.558)	4.65 (0.486)
PU2	4.23(0.669)	4.35 (0.608)	4.55 (0.624)
PU3	4.35 (0.669)	4.42 (0.564)	4.58 (0.564)
Perceived ease of use (PEOU)			
PEOU1	3.65 (0.985)	3.90 (0.539)	3.87 (0.806)
PEOU2	3.90 (0.870)	3.87 (0.922)	4.19 (0.792)
PEOU3	3.97 (0.651)	4.19 (0.654)	4.26 (0.631)
Perceived enjoyment (PU)			
PE1	4.32 (0.702)	4.48 (0.626)	4.58 (0.620)
PE2	4.35 (0.709)	4.52 (0.508)	4.65 (0.608)
PE3	4.42 (0.564)	4.68 (0.475)	4.81 (0.402)
Social norms (SNs)			
SN1	3.77 (0.884)	3.97 (0.706)	4.13 (0.670)
SN2	3.03 (1.329)	3.48 (1.061)	3.191 (1.078)
SN3	4.10 (0.908)	4.16 (0.735)	4.29 (0.643)
User experience (UE)			
UE1	4.45 (0.568)	4.61 (0.495)	4.61 (0.558)
UE2	4.13 (0.718)	4.39 (0.558)	4.32 (0.599)
UE3	4.42 (0.502)	4.61 (0.495)	4.52 (0.570)
Intention to use (IU)			
IU1	3.90 (0.790)	4.23 (0.617)	4.52 (0.570)
IU2	4.29 (0.588)	4.48 (0.570)	4.52 (0.626)

T1: before VR training; T2: after VR training; T2: post 3 months follow-up.

Table 5: Cronbach's α values before VR training (T1).

Items	T1 Cronbach's α
Perceived usefulness (PU)	0.781
Perceived ease of use (PEOU)	0.730
Perceived enjoyment (PE)	0.833
Social norms (SNs)	0.532
User experience (UE)	0.778
Intention to use (IU)	0.642

technology encountered some technical limitations, it indicated a great potential to develop and invest the high-tech application in the 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 in VR game activities during 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 in attracting and influencing 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 significantly different in the study, the overall means showed a small increase across time occasions. Constantly, the feedback from participants was positive, and they were willing to learn and fully engage with all 6 VR sessions. Partly, the negative results might be reflective of the limitation of VR CAVE technology and the social impact of COVID-19 restrictions in Hong Kong. Therefore, the overall results of VR usability in older adults showed promising evidence on the usefulness and acceptance of using new VRT application in fall prevention training.

Table 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 having biological and behavioural risk factors such as being overweight, three chronic diseases per 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 fall concerns, they showed good intentions to participate in 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

Table 6: Change in outcomes measures over the three assessments time points.

Outcome measures	Pretest ($M + SD$)	Posttest ($M + SD$)	Follow-up ($M + SD$)	T2 vs. T1 ($^*P < 0.05$)	T3 vs. T1 ($^*P < 0.05$)	Within group ($^*P < 0.05$)
Items						
PU	12.97 (1.622)	13.39 (1.407)	13.77 (1.334)	0.391	0.018	0.013
PEOU	11.45 (2.047)	11.97 (1.622)	12.32 (1.815)	0.741	0.110	0.103
PE	13.10 (1.720)	13.68 (1.43)	14.03 (1.472)	0.321	0.017	0.011
SNs	10.90 (2.286)	11.61 (1.764)	11.61 (1.564)	0.416	0.251	0.127
UE	13.00 (1.506)	13.01 (1.337)	13.45 (1.329)	0.011	0.328	0.044
IU	8.19 (1.195)	8.71 (1.039)	9.03 (1.110)	0.100	0.005	0.020
Risk factors						
Balance (BBS)	51.29 (4.811)	53.13 (3.519)	53.65 (4.278)	0.133	0.088	0.036
6MWT (metre)	324.48 (64.22)	379.75 (70.31)	382.02 (70.03)	0.001**	001**	0.001**
TUG (second)	11.25 (2.71)	8.97 (2.01)	8.23 (1.95)	0.001**	0.001**	0.001**
FES-I	42.19 (9.34)	37.87 (10.47)	32.90 (10.03)	0.115	0.001**	0.001**

Outcome measure: a better outcome is represented by an increase 6 subset of items, BBS, and 6MWT and a decrease in TUG and FES-I. PU: perceived usefulness; PEOU: perceived ease of use; PE: perceived enjoyment; SNs: social norms; UE: user experience; IU: intention to use; M: mean; SD: standard deviation; BBS: Berg Balance Scale; 6MWT: six-minute walk test; TUG: Time Up and Go test; FES-I: Fall Efficacy Scale-International. $^*P$ value: significant at <0.05 level of significance. $^{**}P < 0.005$.

VR intervention in fall prevention, showing greater effects on reducing the risk factors of falls [31, 32]. 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 the 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 [33].

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 better physical condition. They became more physically active and showed intention to accept and use VR in the future.

In general, the participants enjoyed and fully engaged with simulated VR games redesigned for people with old age [31, 32]. 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 adjustments and modifications for the older adults using new 3D handy eyewear, sensor devices, and spacious CAVE settings. Therefore, the VR CAVE design in the VR session could increase participants' engagement and stimulate a better user experience. In conclusion, the study supported that the VR CAVE application was a useful and innovative fall prevention training application, and the older adults perceived the usefulness and enjoyment of the use of new technology in aged care services.

4.1. 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 the 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 participating in the study. Secondly, the study was not a randomized control trial design, and 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 a CAVE system design to assess usability and acceptance of the use of VR among the older population. Fourthly, the study reported primarily on quantitative findings, and 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, and 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.

5. 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 that the VR CAVE application for preventing falls was useful and innovative. The study also shows positive perceptions and users' experiences of 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 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 the usability and acceptance of adopting new VR technology in rehabilitation and aged care services.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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).

Consent

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.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

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.

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Supplementary Materials

We have included several supplementary files, including the additional files containing the VR training program (comprising 4 fully immersive VR games) and 3 video clips for VR demonstration, as well as the VR usability questionnaire file (Hong Kong version), which is focused on evaluating the acceptance of virtual reality (VR) experiences among older adults (see Appendix 1 in the Supplementary Materials). *(Supplementary Materials)*

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