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Effects of immersive leisure-based virtual reality cognitive training on cognitive and physical function in community-based older adults: A randomized controlled trial

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Abstract

Background: Older adults are at risk of developing cognitive impairments, and cognitive training is commonly used to enhance cognitive function in this population. The effectiveness of cognitive training is further optimized with the integration of leisure-based activities, such as horticultural therapy. However, to the best of our knowledge, there is a lack of studies examining the effect of integrating virtual reality (VR) with leisure-based activities to provide real-world experiences and enhance cognitive outcomes in older adults. Furthermore, while immersive VR cognitive training has demonstrated effectiveness in enhancing multiple cognitive domains, methodological limitations—such as the absence of control groups or the use of passive controls—hinder the ability to draw conclusive conclusions regarding its comparative effectiveness.

Objective: This study conducted immersive leisure-based VR cognitive training in community-dwelling older adults to investigate its effectiveness on cognitive and physical functions. We employed an active control group in which participants received well-arranged leisure activities without focusing on cognitive components.

Methods: This cluster randomized controlled trial was conducted in the community facilities in northern Taiwan between 2022 and 2023. The VR cognitive training group received simulated gardening activities, such as planting, fertilizing, and harvesting, and tasks involving cognitive challenges, such as producing plant essential oils, for 60 min daily, 2 days per week, for 8 weeks. The control group received non-cognitive training. The outcomes evaluated were cognitive function assessed by Montreal Cognitive Assessment (MoCA), immediate memory assessed by Wechsler Memory Scale (WMS)-Word List, working memory and mental flexibility assessed by WMS-Digit Span Forward, WMS-Digit Span Backward, and WMG-Digit Span Sequencing (DSS), and physical function assessed by the Timed Up and Go (TUG) test.

Results: The study recruited 137 older adults. After VR cognitive training, higher significant improvements were seen in MoCA ($p < 0.001$), WMS-DSS ($p = 0.015$), and TUG (0.008*) compared with the control group.

Conclusions: This study is the first to examine the effects of fully immersive, leisure-based VR cognitive training on cognitive and physical function in community-dwelling older adults, highlighting its potential as a promising tool for promoting health compared to the non-cognitive training commonly used in community facilities.

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Cognitive training, leisure activities, fully immersive virtual reality training, older adults, community-dwelling

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Introduction

The aging process may impair functions of the brain, in particular cognitive function.[1] Thus, because many Taiwanese live an old age (65 years and older),[2] the prevalence of impaired cognitive function is expected to rise as well. The prevalence of impaired cognitive function has been reported to be between 2.3% and 22% in Taiwan.[3,4] Impaired cognitive function is associated with disability in performing basic and instrumental activities of daily living (ADL).[5] Disability in accomplishing ADL can lead to reduced social participation that can further worsen the decline in cognitive function and result in reduced quality of life.[6,7] It is also associated with an increased risk of death.[8] Thus, effective interventions that help prevent or reduce cognitive decline and improve cognitive function among this population are needed.

One such intervention is cognitive training, an umbrella term used for interventions that use repetitive practice of cognitive or physical tasks and intellectually demanding activities with the sole goal of enhancing general cognitive ability.[9–12] Cognitive training helps to improve cognitive domains such as overall cognitive function, executive function, memory, attention, visual-spatial function, processing speed, balance, and grip strength.[13–16] However, the effects depend on the severity of the cognitive impairment and the specific cognitive domain to be trained.[17]

Adapting cognitive training to include leisure activities makes interventions for older adults more effective, enjoyable, and meaningful.[18] To make cognitive training more practicable and easier to implement in community settings, leisure-based approaches using activities linked to one's life experiences, such as horticultural therapy, are used.[18,19] Horticultural therapy, in particular, has been shown to enhance the physical, cognitive, and social well-being of older adults.[20] However, for leisure-based cognitive training to be effective, adherence to the protocols is needed. For older people, adherence to the training is always difficult.[21] This could be due to a lack of adequate motivation to perform such an activity, because they may have decreased insight into their own need to do the activity.

To help improve motivation for and increase adherence to leisure-based cognitive activity, virtual reality (VR) is used.[22,23] Virtual reality is a computer-generated simulation, such as a set of images and sounds that represent a real place or situation, that a person can interact with in a seemingly real or physical way by using special electronic equipment.[24] It can be non-immersive, semi-immersive, or immersive.[24] Non-immersive VR simulations are usually a computer-generated environment, such as video game, that allows the person to remain aware of and keep control of their physical environment.[25] Semi-immersive VR gives the patient a partial illusion of being in a real environment or situation. Immersive VR gives participants a complete illusion of being in a real environment[26] and helps participants to experience high levels of flow, motivation, and presence.[27]

Immersive VR cognitive training has been shown to enhance multiple cognitive domains in older adults, both with and without cognitive decline, including global cognition, memory, visuospatial abilities, and executive function.[28–34] Additionally, participants who underwent immersive VR cognitive training exhibited greater improvements in processing speed, working memory, and executive function compared to the control group.[29–33] Beyond cognitive benefits, they also demonstrated enhanced gait speed and mobility following the training.[31] However, some of these studies lacked a control group,[28–34] while others included controls that received no training[29,30,33] or only health education.[31,32] One study incorporated an exercise training group as a control group.[31] However, discrepancies in training dosage across groups were observed. These methodological variations limit the ability to establish clear evidence regarding the comparative effectiveness of fully immersive VR cognitive training and other interventions.

Therefore, this study conducted immersive leisure-based VR cognitive training in community-dwelling older adults to investigate its effectiveness on cognitive and physical functions. We employed an active control group in which participants received well-arranged leisure activities without focusing on cognitive components. We hypothesized that immersive leisure-based VR cognitive training would result in greater improvements in cognitive and physical functions compared to the active control group in community-dwelling older adults.

Materials and methods

Study design

The study was a cluster randomized controlled trial aimed at identifying the intervention effects of immersive leisure-based VR cognitive training on cognitive function and physical function for community-based older adults. A cluster randomized trial was used because it is a valid approach for the evaluation of certain interventions such as interventions for health promotion.[35]

The study was registered on ClinicalTrials.gov (NCT05227495). The study was approved by the Chang Gung Memorial Hospital Institutional Review Board (IRB:202100553B0) and was conducted in accordance with Helsinki Declaration. All participants provided written informed consent before the commencement of the study.

Study participants

Participants were recruited from community facilities. The inclusion criteria were (1) age ≥60 years, (2) ≥21 points on the Mini-Mental State Examination, and (3) the ability to follow instructions. The exclusion criteria included a diagnosis of dementia, a history of motion sickness, or symptoms that could interfere with VR training.

Sample size calculation

Given no prior published research investigated the effects of immersive, leisure-based VR cognitive training on both cognitive and physical function in community-dwelling older adults, we estimated the sample size based on previous studies examining the effects of combined cognitive and physical VR training on cognitive and physical function in this population.[36,37] Since our outcomes included global cognitive function, memory, and mobility, we calculated the sample size based on measures related to these cognitive and physical domains. The calculated effect sizes (Cohen's d) were 0.37 for Montreal Cognitive Assessment (MoCA), 0.48 for Digit Span Forward (DSF), 0.60 for Digit Span Backward (DSB), and 0.30 for Timed Up and Go (TUG). Using G*Power 3.1 software with a power of 0.80 and a two-sided Type I error of 0.05, the minimum required total sample size for this study was 90 participants. To account for a potential 25% dropout rate, a total of 113 participants were included in the study.

Randomization process

An independent research assistant, blinded to the process and procedures, used a computer-generated random number program to assign participants randomly to the VR group or the control group. A 1:1 allocation ratio was used to assign 152 participants evenly between the two training groups. The research assistant informed the therapists of the assigned groups to conduct the respective interventions. Over the course of the study, 15 participants dropped out, leaving 137 participants who completed all the training sessions (Figure 1).

Intervention

The study was conducted in the activity room of a community facility. All participants received training for 60 min per day, 2 days per week, for 8 weeks.

Virtual reality group. The VR interface system used the HTC VIVE PRO, an immersive VR system featuring a head-mounted display and two wireless controllers. Older adults can operate the system independently, or a therapist can manage it as needed. Additionally, the system includes a screen mirroring function, allowing the display to be projected onto an external device for real-time monitoring of the user's progress and interactions.

The VR cognitive training group received simulated gardening activities, including planting, fertilizing, and harvesting, and tasks involving cognitive challenges, such as producing plant essential oils. The difficulty of each activity is categorized into seven levels, with level 1 being the easiest and level 7 the most challenging. Participants began at level 1, and the training difficulty was gradually increased depending on participant's performance. These gardening activities aimed to enhance attention, processing speed, memory, spatial relations, and executive function. Each VR training session consisted of 4–5 segments, with each activity lasting 6–10 min and a 3–5 min rest between segments to prevent motion sickness. Occupational therapists guided the sessions. When older adults had difficulty understanding the operations or tasks in the early stages of training, therapists provided verbal and physical assistance. Participants could choose to sit or stand during the cognitive training VR sessions based on their physical condition.

Control group. Participants in the control group received non-cognitive training, including leisure activities such as team cooperation games or simple craft activities, which aimed to promote social interaction and engage participants without focusing on high-level cognitive demands.

Outcomes

The primary outcome evaluated was cognitive function. It was assessed using the MoCA, Word List (WL), Digit Span of the Wechsler Memory Scale–third edition (WMS-III), and the color trials test (CTT) to assess cognition in older adults. The secondary outcome assessed was physical function, which was evaluated using the TUG test.

Montreal Cognitive Assessment. The MoCA is a highly sensitive measure for the assessment of global cognitive function, which includes orientation, attention, memory, naming, visual-spatial skills, executive function, language, and abstraction.[38] It is widely recognized as a reliable and well-validated measure of cognitive function.[39] It consists of 12 items, and its scores range from 0 to 30 points.[38] The higher scores symbolize better global cognitive function.

Word List, DSF, DSB, Digit Span Sequencing subtest of the Chinese version of the WMS, Third Edition. The Chinese

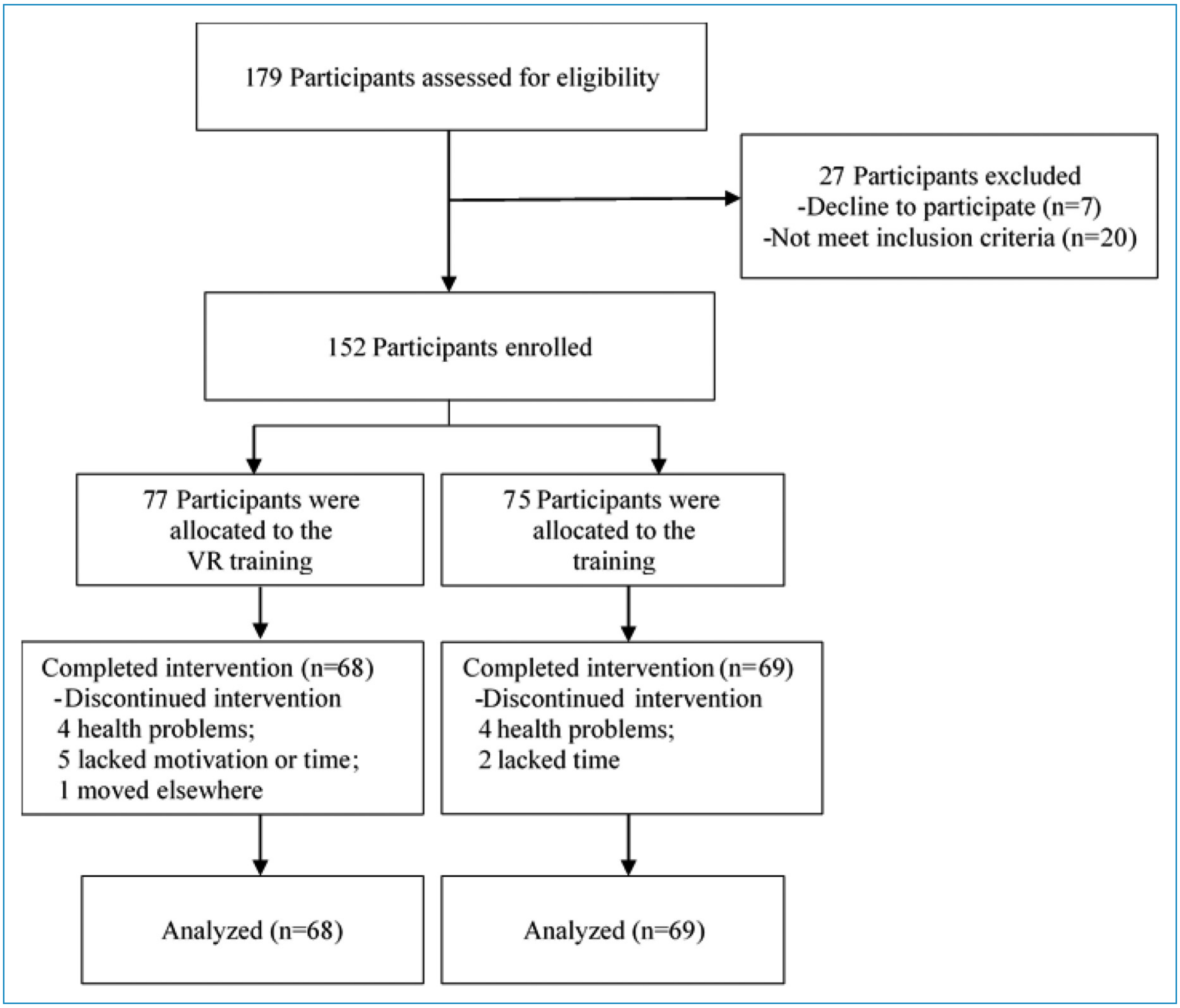

Figure 1. Flowchart of participant disposition throughout the study.

version of the WMS-III is a valid and reliable measure.[40] Word List subtest from the WMS-III is used to measure immediate memory. In WL, participants are presented with 12 unrelated words over four trials and asked to recall them immediately after each presentation. Higher WL scores signify better immediate memory, respectively. In the WMS DSF subtest, participants are required to repeat a sequence of numbers verbatim, with the number of digits increasing as the task progresses. This task tests sustained attention and memory, especially when the number of digits surpasses the participant's ability to repeat them without rehearsal. The WMS DSB task also engages working memory, as participants are required to repeat the digits in reverse order from how they were originally presented, necessitating mental manipulation of the information before responding. The WMS Digit Span Sequencing (DSS) task requires participants to arrange digits according to their numerical value, which involves not only working memory but also quantitative reasoning. The increased cognitive demands of the WMS-DSS task place additional strain on both working memory and attention.

Color Trials Test. We used the Taiwanese version of the CTT[41] to evaluate sustained and selective attention. In this assessment, participants are presented with numbered circles printed on pink and yellow backgrounds. In CTT Part 1 (CTT-1), participants are instructed to connect the circles numbered 1–25 in sequential order as quickly as possible using a pencil. For CTT Part 2 (CTT-2), participants must again connect the circles numbered 1–25 in order, but this time they must alternate between pink and yellow circles. During the test, the time taken to complete each part is recorded, with shorter times indicating better performance. The reliability and validity of this test have been well established in healthy adults.[41]

Timed Up and Go. The TUG test is a reliable and valid measure of mobility, balance, and lower extremity

Table 1. Demographic characteristics of the study participants.

Variable	Group		t	p
	Experimental ($n = 68$)	Control ($n = 69$)		
Age (years)	69.37 ± 4.82	73.36 ± 6.30	−4.172	<0.0001*
Sex, n				
Female	57	60		
Male	11	9		
Education level (years)	12.38 ± 4.07	11.04 ± 4.19	1.896	0.060
MMSE scores	28.63 ± 1.69	28.0 6 ± 1.97	1.830	0.069

MMSE: Mini-Mental State Examination.

function.[42] The score represents the time taken to complete the test in seconds, averaged over three trials for each participant.

All outcome assessments were conducted at baseline and immediately after the training by a trained research assistant who was blinded to the treatment allocation. These assessments took place in a quiet space at the community facility and lasted approximately 1.5–2 h, including scheduled breaks. In cases where participants were unable to complete the assessments in a single session, the evaluation was split into two sessions to be completed within three days. The assessments were not administered in a fixed sequence.

Data analysis

Baseline characteristics of the participants were analyzed using descriptive statistics and the dependent t test. Improvement in the outcomes of interest from baseline to the post-intervention period was assessed using the paired t test. The differences in the outcomes of interest post-intervention were analyzed using analysis of covariance to control for the influence of the baseline scores in the outcomes of interest on the post-intervention effects. The effect size was calculated using eta squared (η^2), with values of 0.01, 0.06, and 0.14 indicating small, moderate, and large effects, respectively. All analyses were done using SSPS 23 software. The significance level was set at $p < 0.05$.

Results

Characteristics of the study participants

The study participants were 137 adults (117 women) with mean age of 71.38 ± 5.94 years (range, 60–80 years). The participants had a mean MMSE score of 28.34 ± 1.85 points (range, 22–30 points), and all of them had at least an elementary school education. See Table 1 for the details of the baseline characteristics of the study participants. Based on the results presented in Table 1, a significant difference in age was observed between the VR group and the control group. Therefore, age was incorporated as a covariate in the subsequent analysis.

Improvement from baseline to post-intervention

Significant improvement ($p < 0.05$) was seen in the experimental group in MoCA, WMS-DSB, and CTT-2 time and in the control group in CTT-1 time. In both groups, only WMS-WL improved significantly ($p < 0.05$). The only significant decrease occurred for the CTT-2 time scores in the control group. Supplementary Table 1 provides more details of the results.

Comparative effects of leisure-based cognitive training and the control

The result showed that immersive VR-based cognitive training significantly improved MoCA, WMS-DSS, and TUG scores better than in the control ($p < 0.05$). The effect size corresponded to a small to moderate range ($\eta^2 = 0.027$–0.06). However, there were no significant differences between the immersive VR-based cognitive training and the control group in the WMS-WL, CTT-1 time, and CTT-2 time scores. Please see Table 2 for more information.

Discussion

To the best of our knowledge, this is the first study to evaluate the effectiveness of fully immersive leisure-based VR cognitive training on cognitive and physical function in

Table 2. Analysis of covariance results of the outcome measures.

	Experimental ($n = 68$)		Control ($n = 69$)			
	Baseline	Post	Baseline	Post	Between groups f value	p value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
MoCA	27.90 ± 2.14	28.54 ± 1.61	26.45 ± 3.12	26.87 ± 2.79	4.988	<0.001*
WMS-WL	29.94 ± 6.90	33.70 ± 8.01	28.25 ± 8.01	30.88 ± 7.85	3.008	0.085
WMS-DSF	12.34 ± 2.28	12.47 ± 2.22	12.12 ± 2.76	11.74 ± 3.06	3.104	0.079
WMS-DSB	7.87 ± 2.89	7.21 ± 2.68	6.62 ± 3.12	6.45 ± 2.57	0.057	0.811
WMS-DSS	8.13 ± 2.01	8.40 ± 1.70	6.63 ± 2.80	6.83 ± 2.50	6.036	0.015*
CTT-1 time	41.66 ± 14.59	40.00 ± 15.61	49.06 ± 19.70	44.58 ± 19.17	1.610	0.207
CTIT-2 time	95.00 ± 28.84	87.60 ± 31.06	103.07 ± 35.22	111.14 ± 41.43	1.388	0.241
TUG	8.60 ± 1.63	8.24 ± 1.39	9.30 ± 1.92	9.40 ± 2.36	7.349	0.008*

MoCA: Montreal Cognitive Assessment; WMS-WL: Wechsler Memory Scale-Word List; WMS-DSF: Wechsler Memory Scale- Digit Span Forward; WMS-DSB: Wechsler Memory Scale-Digit Span Backward; WMS-DSS: Wechsler Memory Scale- Digit Span Sequencing; CTT-1 time: Color Trails Test-Part 1-time; CTT-2 time: Color Trails Test-Part 2-time; TUG: Timed Up and Go.
*Statistically significant ($p < 0.05$).

community-dwelling older adults. The findings suggest that this type of training can serve as an effective intervention for improving cognitive and physical health in this population. Specifically, compared to the active control group, participants in the VR cognitive training group demonstrated significantly greater improvements across several measures, including the MoCA, WMS-DSS, and TUG test. These findings are consistent with our hypothesis. These results highlight the potential of immersive leisure-based VR cognitive training, compared to non-cognitive training commonly used in community facilities, as a promising tool for promoting health among older adults.

Our findings reveal that global cognitive function, as measured by the MoCA, showed significantly greater improvement in the VR cognitive training group compared with the control group. Some studies have demonstrated that traditional cognitive leisure activities, such as dancing, music, reading, and playing chess or cards, can improve global cognitive function compared with passive control activities.[43–47] However, to make these activities more structured and practical for older adults, ensuring better compliance and adherence, we introduced VR as an innovative approach. Virtual reality creates an immersive environment that mimics real-life scenarios,[48] which enhances participants' motivation and encourages them to engage in the required tasks for functional recovery.[26,27,48] In addition, our findings align with previous studies, which have demonstrated that immersive VR cognitive training positively affects global cognitive function.[30,34] Notably, this study employed a more rigorous design than previous studies by implementing a well-structured active control group with scheduled leisure activities. The findings demonstrated positive effects, further validating the superior efficacy of leisure-based VR cognitive training.[29–33]

For working memory and quantitative reasoning functions, as measured by the WMS-DSS, the VR cognitive training group demonstrated significantly greater positive changes compared with the control group. These findings build on previous research on non-immersive VR cognitive-motor training, which demonstrated significant improvements in sustained attention, as measured by the WMS-DSF, during basic ADL tasks.[49] Through the use of immersive VR, our study reveals a broader scope of improvement in memory functions, extending beyond selective attention to include enhancements in working memory and quantitative reasoning. Working memory and quantitative reasoning are regarded as higher-order cognitive abilities and are commonly classified under executive functions. The content of our VR training activities included tasks such as fertilizing, watering flowers, and harvesting. These tasks required participants to engage in various cognitive processes, including memorizing instructions, calculating the appropriate volume of water, and promptly selecting the correct tools. Designed to heavily involve working memory and mental reasoning, these activities promoted active cognitive engagement, which contributed to the observed improvements in cognitive performance. In addition, VR cognitive training provides multiple sensory stimuli, which may increase cerebral blood flow in the prefrontal cortex as well as in the middle and posterior cingulate cortices, likely due to heightened brain activity during the cognitive training process.[49] As a result, immersive VR cognitive training could lead to improvements in higher-order cognitive abilities.

The significance of good cognitive function cannot be overemphasized. It is needed to accomplish both basic and instrumental ADL, such as walking, eating, and shopping, that are necessary for functional independence and quality of life.[5–7] Working memory also mediates the relationship between physical function and ADL.[50] Similarly, improving balance and lower extremity function can encourage and increase physical activity, which is associated with improved brain health and function.[51] The VR cognitive training group in our study demonstrated significant improvements in mobility, balance, and lower extremity function compared with the control group. Our results align with and build upon previous studies, suggesting that, compared to health education programs or passive control groups, immersive VR-based cognitive training can enhance physical function—including mobility and gait speed—by engaging participants in dynamic, task-oriented virtual environments that simulate real-life scenarios.[31,52,53]

Our VR training tasks required older adults to maintain dynamic balance in a standing or seated position, which may help improve their balance and lower extremity function. Gait speed is fundamentally influenced by the interplay between motor skills and cognitive functions, including executive function and attention, underscoring its critical relationship with cognitive performance. Consequently, improvements in cognitive performance, as facilitated by targeted cognitive training, are likely to yield concomitant enhancements in gait speed, reflecting the interconnected nature of these domains.[31]

The results indicated that there were no significant differences in selective attention, as measured by CTT-2, between the VR cognitive training group and the control group. However, within the VR experimental group, selective attention significantly improved after training, whereas the control group exhibited a significant decline. This contrasting trend ultimately led to no significant differences when comparing the two groups.

Implications

The findings of this study have policy, practice, and research implications. For the policy and research implications, it is important a policy is made that will promote the use of VR leisure-based cognitive training among Taiwanese and anywhere else there are people at risk of progressive cognitive function decline. This is because the population in Taiwan has a long life expectancy, and therefore, the decline in cognitive function due to advancing age may be common. Similarly, further research is needed to determine the effective home-based and/or telerehabilitation-based VR leisure-based cognitive training. This may help with improving access to VR leisure-based cognitive training.

Limitations

The current study has some limitations. First, the participants in the study were older adults living in the community who regularly took part in various community activities. Their naturally proactive and engaged demeanor could have contributed to achieving more positive training results. Consequently, the findings of this study may not be generalizable to all older adults. Second, this study did not include follow-up assessments, so the long-term effects and subsequent changes in the training could not be determined. Third, the study did not use physiological indicators to evaluate changes in brain structure and function. Future studies should incorporate neurophysiologic equipment to confirm the alignment between the physiologic and neuropsychologic outcomes of this training. Fourth, the sample in this study was predominantly composed of women, which may introduce potential biases in the observed results. Gender differences in cognitive and physical function, engagement with technology-based interventions, and preferences for leisure activities could have influenced the study outcomes. Additionally, the limited representation of older men may affect the generalizability of the findings. Future research should aim for a more balanced gender distribution to enhance the applicability of the results.

Conclusion

This study is the first to investigate the effects of fully immersive, leisure-focused VR cognitive training on both cognitive and physical functions in community-dwelling older adults. The findings suggest that this innovative approach holds significant potential as an effective intervention for enhancing cognitive functions, such as global cognitive function and working memory, as well as physical function, including mobility, balance, and gait speed in this population. These results highlight the potential of immersive leisure-based VR cognitive training, compared to noncognitive training commonly used in community facilities, as a promising tool for promoting health among older adults. By incorporating leisure activities as background tasks to enhance motivation and practice, alongside fully immersive cognitive training, this approach could prove to be an effective strategy for advancing health promotion in community-dwelling older adults.

Authors' note

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Guarantor

CYW

Statements and declarations

Ethics approval and consent to participate

This study was conducted with the approval of The Chang Gung University Institutional Review Board. Before participation, all participants were informed of the experimental procedure and each provided informed consent. All methods were conducted in accordance with relevant guidelines and regulations. Research involving human participants, human material, or human data was performed in accordance with the Declaration of Helsinki.

Contributorship

ICC and CYW contributed to the study design, coordination, and project management. ICC, AA, ICC, and CYW interpreted data and drafted and revised the manuscript. AA performed the data analyses and helped to draft the manuscript. YRW participated in subject recruitment and provided consultation. All authors read and approved the final manuscript.

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Conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Supplemental material

Supplemental material for this article is available online.

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