Original Paper

Feasibility and Preliminary Outcomes of Gardening-Based Immersive Virtual Reality Cognitive Training in Older Adults With Dementia: Single-Group Pretest-Posttest Analysis

I-Ching Chuang[1,2*], PhD; Hui-Ju Wu[1*], PhD; Yih-Ru Wu[2,3*], MD; Jung Lung Hsu[2,3,4], PhD, MD; Ching-Yi Wu[1,5,6], SCD

[1]Department of Occupational Therapy and Graduate Institute of Behavioral Sciences, College of Medicine, Chang Gung University, Taoyuan, Taiwan, Taiwan

[2]Department of Neurology, Linkou Chang Gung Memorial Hospital, Taoyuan, Taiwan, Taiwan

[3]School of Medicine, College of Medicine, Chang Gung University, Taoyuan, Taiwan, Taiwan

[4]Department of Neurology, New Taipei Municipal TuCheng Hospital, Chang Gung Memorial Hospital, New Taipei City, Taiwan, Taiwan

[5]Healthy Aging Research Center, Chang Gung University, Taoyuan, Taiwan, Taiwan

[6]Department of Physical Medicine and Rehabilitation, Linkou Chang Gung Memorial Hospital, Taoyuan, Taiwan, Taiwan

*these authors contributed equally

Corresponding Author:

Jung Lung Hsu, PhD, MD
Department of Neurology, Linkou Chang Gung Memorial Hospital
No. 5, Fuxing Street, Guishan District
Taoyuan, Taiwan 333423
Taiwan
Phone: 886 3-328-1200 ext 2610
Email: tulu@ms36.hinet.net

Abstract

Background: Nonpharmacological interventions for cognitive problems play a critical role in dementia care, yet maintaining engagement and adherence remains challenging. Immersive virtual reality (VR) provides a promising platform for cognitive training, particularly when integrated with personally meaningful leisure activities that may enhance therapeutic resonance.

Objective: This study aimed to examine the feasibility of gardening-based immersive VR cognitive training and to explore pre-post changes in clinical outcomes among older adults with dementia.

Methods: This study reports an analysis of intervention-phase data from an ongoing registered randomized crossover clinical trial (ClinicalTrials.gov NCT07033468). For this report, the available data were analyzed using a single-group pretest-posttest approach; data from the waitlist-control period were not included. Between September 2024 and December 2025, 16 older adults with mild-to-moderate dementia were recruited through referral-based convenience sampling from a hospital and a dementia day care center in Taiwan. Participants completed a 15-session VR intervention over 5 weeks, involving gardening-based activities targeting multiple cognitive domains. Feasibility outcomes included VR acceptance, simulator sickness, and observed emotional responses during the first VR session. Cognitive outcomes included global cognition assessed using the Montreal Cognitive Assessment (MoCA) and domain-specific cognitive measures. Secondary outcomes included activities of daily living, depressive symptoms, behavioral and psychological symptoms of dementia, quality of life, and well-being. Paired *t* tests were used to examine pre-post differences, and the Holm-Bonferroni procedure was applied to adjust for multiple comparisons.

Results: Sixteen participants (5 men and 11 women; mean age 78.12, SD 6.61 years) completed feasibility assessments, 15 participants (4 men, 11 women; mean age 78.57, SD 6.58 years) completed the intervention, and 5 occupational therapists evaluated the usability of the VR system. VR acceptance significantly increased after the first session (t_{15}=–5.40, 95% CI –0.61 to –0.26; P<.001), while simulator sickness significantly decreased (t_{15}=2.42; 95% CI 0.34-5.27; P=.009). Emotional responses indicated high levels of pleasure (mean 3.38, SD 1.63) and alertness (mean 4.63, SD 0.89) with minimal negative affect. Usability was rated as acceptable (system usability scale: mean 70.5, SD 12.17). Global cognitive performance

was higher at postintervention than at baseline (MoCA: Cohen *d*=1.03; 95% CI –3.28 to –0.99; *P*=.001). No statistically significant pre-post differences were observed in domain-specific cognitive measures, activities of daily living, quality of life, or psychosocial outcomes.

Conclusions: Gardening-based immersive VR cognitive training appears feasible, acceptable, and well tolerated among older adults with dementia. The program extends existing VR approaches by embedding familiar, goal-directed gardening activities within an interactive cognitive training environment. By combining participant-centered feasibility outcomes with occupational therapist–rated usability, this study provides preliminary evidence relevant to the development and implementation of person-centered VR cognitive training in clinical and community dementia care. The favorable pre-post change in global cognition further supports investigation of this approach in larger controlled studies.

Trial Registration: ClinicalTrials.gov NCT07033468; https://clinicaltrials.gov/study/NCT07033468

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Keywords: cognitive training; leisure activities; feasibility; usability; immersive virtual reality; dementia

Introduction

The rapid growth of the aging population worldwide has led to a substantial increase in the prevalence of dementia. According to recent estimates [1], more than 60 million people are currently living with dementia globally, and this number is projected to rise steadily in the coming decades. Dementia is characterized by a progressive decline across multiple cognitive domains, including memory, executive function, language, and visuospatial abilities [2,3]. As the disease progresses, these impairments interfere with independence in activities of daily living (ADL) and contribute to increased long-term care needs. In addition to cognitive decline, behavioral and psychological symptoms of dementia (BPSD) are highly prevalent and are associated with poorer quality of life and increased caregiver burden [4]. Given the absence of curative treatments, interventions that aim to preserve cognitive function and maintain daily functioning remain central to dementia care.

Nonpharmacological interventions are widely recommended due to their safety and applicability for individuals with dementia. Various approaches, including physical exercise, cognitive training (CT), music therapy, art-based interventions, and animal-assisted therapy, have been investigated [5-9]. Among these, CT has received particular attention as a targeted intervention, given that cognitive impairment is the defining feature of dementia and is closely linked to functional decline [10]. Guided by the principles of neuroplasticity, CT uses systematic, task-oriented exercises to bolster neural resilience across diverse domains [11]. However, the overall effectiveness of traditional CT remains constrained, particularly in terms of long-term adherence and generalization to daily life [3,11]. A primary bottleneck for conventional CT is the “motivation gap”: traditional tasks are often repetitive and decontextualized, which may reduce engagement in individuals with cognitive impairment [5].

Engaging in leisure activities has been identified as a modifiable lifestyle factor that may enhance cognitive reserve [12,13]. Integrating leisure-based elements into CT may improve motivation and ecological validity [14]. Gardening serves as a multimodal intervention that harmonizes affective well-being with cognitive stimulation [15]. From a neurobiological perspective, this approach is particularly promising as it correlates with increased concentrations of neurotrophic factors such as brain-derived neurotrophic factor, which are essential for neuroplasticity and hippocampal-dependent memory [12]. Consequently, the synthesis of horticultural elements within standardized CT protocols represents a strategic shift toward more ecologically valid interventions. Such a strategy not only addresses the biological requirements for cognitive health but also ensures that the intervention remains contextually meaningful for users, potentially bridging the gap between clinical exercises and daily lives [11,14,15].

To operationalize such contextually rich interventions, virtual reality (VR) has emerged as a promising tool for CT in older adults. Fully immersive VR provides a highly interactive and ecologically valid environment, allowing users to engage in realistic simulations of everyday or meaningful activities [16]. Compared with traditional approaches, VR offers several advantages, including enhanced sensory stimulation, real-time feedback, and the ability to tailor task difficulty to individual performance [17]. Previous studies have demonstrated that VR-based interventions can improve cognitive function, including global cognition, executive function, and visuospatial abilities, in older adults with and without cognitive impairment [17-19]. Moreover, immersive VR may enhance user engagement and motivation, which are critical factors for intervention success [20]. A recent systematic review of immersive and semi-immersive VR interventions for older adults with mild cognitive impairment, dementia, or cognitive frailty also found that supervised VR delivery was generally feasible and well tolerated, with promising findings across cognitive, mobility, and emotional or behavioral outcomes [21]. However, the review also identified considerable heterogeneity in intervention content, dosage, outcome measures, and methodological quality [21]. Beyond cognitive outcomes, a longitudinal observational study conducted in dementia day care centers in Taiwan found that culturally familiar immersive VR reminiscence was associated with improvements in BPSD after the intervention and at follow-up [22]. These findings support the potential relevance of immersive VR across cognitive, emotional, and behavioral domains of dementia care.

Despite these promising findings, several critical gaps persist. First, the evidence for immersive VR among people with established dementia remains limited by small samples, heterogeneous intervention protocols, and methodological concerns [21]. Second, many VR-based CT programs focus on simulated daily activities or use commercially available games that may not be tailored to the preferences and life experiences of older adults [23]. Although culturally familiar reminiscence content has been investigated [22], relatively few studies have incorporated meaningful, goal-directed leisure activities, such as gardening, into immersive VR CT for people with dementia. Integrating such activities may enhance the contextual relevance of CT and support participant engagement. Third, although previous studies have examined feasibility and acceptability, evaluations combining multiple dimensions of participant experience with health professionals' perspectives on system usability remain limited.

To address these gaps, this study developed a gardening-based CT program delivered through a fully immersive VR system. The program incorporated familiar, goal-directed gardening activities intended to promote engagement among older adults. The primary objective was to examine the feasibility of the intervention among older adults with dementia, including participant acceptance, simulator sickness, and emotional responses during VR use. System usability was also evaluated from the perspective of occupational therapists. The secondary objective was to explore pre-post changes in global and domain-specific cognitive function, ADL, quality of life, depressive symptoms, behavioral symptoms, and mental well-being. The feasibility evaluation may also provide useful information regarding intervention delivery, usability, and safety monitoring to support the ongoing randomized crossover trial. We hypothesized that (1) the program would demonstrate favorable feasibility and professional usability, reflected by increased VR acceptance, limited simulator sickness, predominantly positive emotional responses during the first VR session, and acceptable usability ratings from occupational therapists; and (2) participants would show favorable pre-post changes in global and domain-specific cognitive function, daily functioning, quality of life, and psychosocial outcomes.

Methods

Study Design

This study reports a feasibility-focused analysis of currently available intervention-phase data from an ongoing, registered randomized crossover trial (ClinicalTrials.gov: NCT07033468). This report used a single-group pretest-posttest design to evaluate the feasibility of gardening-based immersive VR CT, obtain supplementary professional usability ratings, and explore pre-post changes in clinical outcomes among older adults with dementia. Participant recruitment for the registered trial remains ongoing; therefore, the findings reported here should be considered preliminary.

Inclusion and Exclusion Criteria

Individuals were eligible for enrollment if they met the following inclusion criteria: (1) aged 55 years or above; (2) a formal diagnosis of mild-to-moderate dementia confirmed by a physician or documented in their medical records; (3) the ability to ambulate independently; (4) the capacity to understand and follow simple instructions, with or without assistance from a therapist or caregiver; and (5) the presence of at least one family member or caregiver with regular weekly contact. To ensure participant safety during the immersive VR intervention and to maintain the specificity of the sample, exclusion criteria included (1) dementia with Lewy bodies or neurodegenerative diseases of other specific etiologies (eg, Huntington disease, central nervous system infection, malnutrition, or metabolic disorders); (2) substance-induced cognitive impairment or Korsakoff syndrome; (3) severe medical conditions that could compromise safe participation, such as severe cardiovascular disease, dyspnea, or brain tumors; (4) a psychiatric diagnosis of psychosis within the preceding 6 months; (5) severe sensory impairments, including hearing loss or color blindness, that could impede task engagement; (6) a history of severe vertigo or epilepsy, which are contraindications for head-mounted display use; and (7) concurrent participation in other cognitive intervention studies.

Participant Characteristics

A total of 16 participants (5 men and 11 women) were enrolled (mean age 78.12, SD 6.61 years). Detailed demographic characteristics are presented in Table 1. Participants were recruited from the dementia outpatient clinic at New Taipei Municipal Tu Cheng Hospital and a community-based dementia day care center in Taiwan between September 2024 and December 2025. Consequently, 16 participants completed the feasibility assessments and 1 participant dropped out during the intervention. Therefore, 15 participants completed the 15-session VR intervention and were included in the final analyses.

Table 1. Demographic characteristics of participants.

Demographic characteristics	Feasibility (N=16)	Intervention (N=15)
Sex, n (%)		
Male	5 (31.25)	4 (26.70)
Female	11 (68.75)	11 (73.30)
Age (y), mean (SD)	78.12 (6.61)	78.57 (6.58)

Demographic characteristics	Feasibility (N=16)	Intervention (N=15)
Years of education, mean (SD)	7.88 (4.03)	8.00 (4.14)
Education status, n (%)		
College or above	1 (6.25)	1 (6.67)
Senior high school	4 (25)	4 (26.67)
Junior high school	2 (12.50)	2 (13.33)
Elementary school	8 (50)	7 (46.67)
No formal education	1 (6.25)	1 (6.67)

Sampling Procedures

A referral-based convenience sampling approach was used at both recruitment sites. At the hospital, attending outpatient physicians referred potentially eligible patients to the research team. At the community-based day care center, the center supervisor assisted in identifying potentially eligible attendees. In both settings, the research team confirmed eligibility, explained the study procedures, and obtained written informed consent before enrollment. The recruitment source was independent of subsequent randomization sequence allocation.

Sample Size, Power, and Precision

The registered randomized crossover trial has a planned enrollment of 30 participants. The present analysis included all available intervention-phase data at that time: 16 participants completed the first-session feasibility assessments and 15 participants completed the intervention and pre-post clinical assessments. No formal sample size calculation was performed specifically for this feasibility-focused analysis. The sample was not powered to establish clinical efficacy or reliably detect changes across multiple clinical outcomes. Therefore, the clinical outcome analyses were considered exploratory, and 95% CIs were reported to indicate the precision of the estimates.

Ethical Considerations

The study was approved by the Institutional Review Board of Chang Gung Memorial Hospital (approval number: 202400517B0). All procedures were conducted in accordance with the Declaration of Helsinki. The study was registered with a clinical trial registry (registration number: NCT07033468). All participants provided written informed consent prior to participation. For participants with cognitive impairment, consent was obtained in conjunction with caregivers when necessary. All participant data were anonymized to protect confidentiality. Personal identifying information was removed from the dataset, and participants were assigned unique study codes for data analysis and storage. Participants received a transportation subsidy of New Taiwan dollars (NT $250 [~US $8]; NT $1=US $0.03 as of October 14, 2026) after completing each of the pretest and posttest assessments. This paper does not contain any images or photographs in which individual participants could be identified.

Research Tools and Procedures

The intervention was delivered using the HTC VIVE Pro head-mounted display (HTC Corp; Figure 1), which provides a fully immersive VR experience. The system included handheld wireless controllers for interaction and a screen-mirroring function that allowed therapists to monitor participants' performance in real time. Participants were able to interact with the virtual environment independently, while therapists provided supervision and assistance when necessary. The VR program was designed around leisure-based gardening activities, including planting, fertilizing, watering, harvesting, producing plant-based essential oils, and packaging fruit gift boxes (Figure 2). Each activity was structured into 7 levels of difficulty (levels 1-7), progressing from simple to more complex tasks. The system automatically adjusted task difficulty in real time based on participants' performance. The activities were designed to target multiple cognitive domains, including attention, processing speed, memory, visuospatial ability, and executive function (Figure 3). Participants completed 15 sessions of VR training over a period of 5 weeks, with 3 sessions per week on nonconsecutive days. Each session lasted approximately 60 minutes. Each session consisted of a 5-minute warm-up, four 10-minute VR training segments, 2-to 3-minute rest periods between segments, and a 5-minute cooldown. During the warm-up phase, therapists provided instructions on task content and controller operation. Participants were allowed to perform in the training in either a seated or standing position based on their physical condition. Therapists provided verbal and physical assistance when participants experienced difficulty, particularly during early sessions. Participants were allowed to rest or discontinue the session if they experienced discomfort or fatigue. Participants' physical condition was monitored before and after each session to ensure safety.

Figure 1. Virtual reality equipment used in the intervention. The intervention was delivered using an HTC VIVE Pro head-mounted display and 2 handheld wireless controllers.



Figure 2. Representative gardening-based virtual reality training tasks: (A) harvest flowers by cutting mature blossoms; (B) water seedlings according to the target water level; (C) create bookmarks by selecting and arranging dried flowers and leaves; and (D) apply fertilizer to the appropriate pots based on the task instructions.



Figure 3. Example of the gardening-based virtual reality fruit harvesting task. (A) Memorize the target fruits and quantities displayed on the instruction panel. (B) Harvest the specified fruits using the virtual pruning tool. (C) Place the harvested fruits into the basket to complete the task.

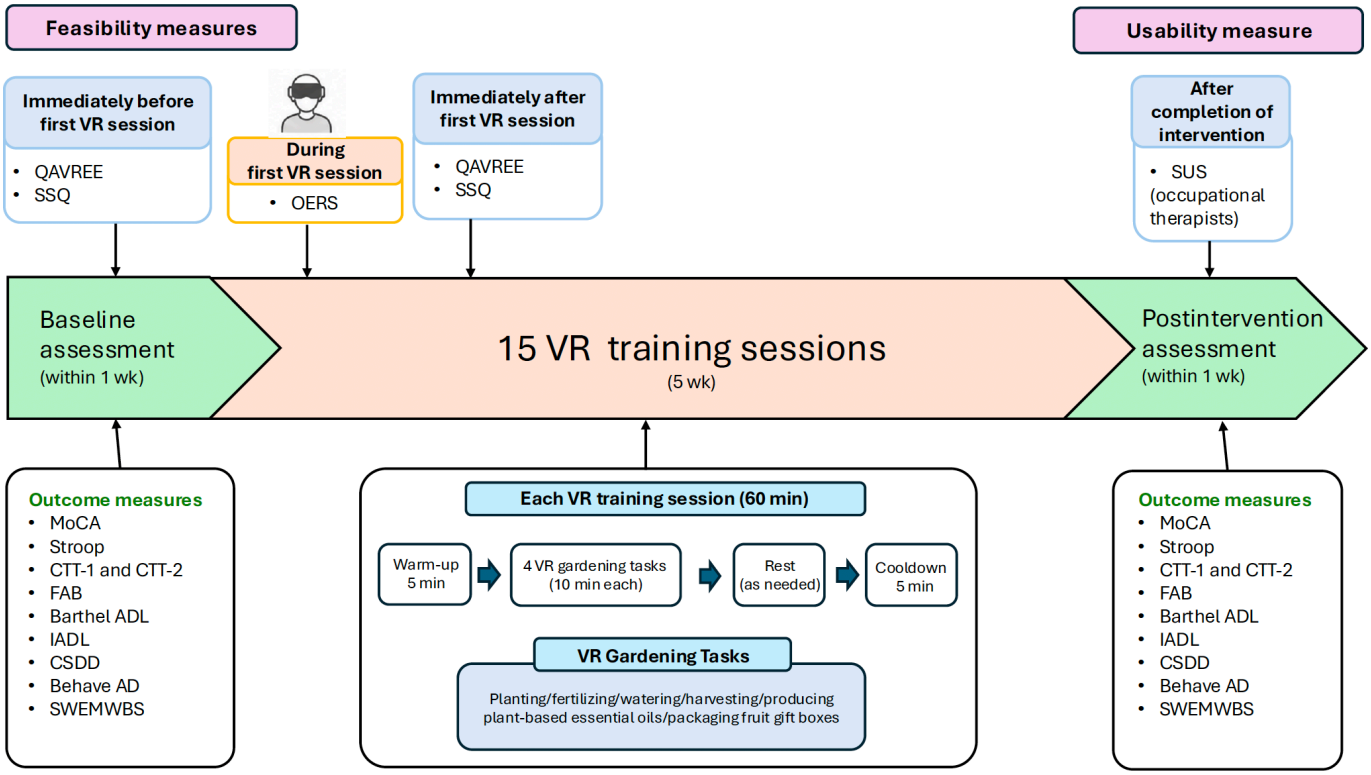


Measures and Covariates

Assessment Procedures

The feasibility measures included the Questionnaire of Acceptance of the Virtual Reality Experience Among the Elderly (QAVREE), the Simulator Sickness Questionnaire (SSQ), and the Observed Emotion Rating Scale (OERS). The QAVREE and SSQ were administered immediately before and after the first VR training session to evaluate participants' initial acceptance of the VR intervention and simulator sickness symptoms. The OERS was administered once during the first VR training session to assess participants' emotional responses while engaging in the intervention. The cognitive and secondary outcome measures were assessed within 1 week before the first intervention session (baseline) and within 1 week after completion of the 5-week intervention program (postintervention). All secondary outcome measures were completed during the same assessment visit. To minimize potential fatigue effects, the order of the cognitive assessments was varied across participants. Repeated assessments during the intervention period were not performed because the intervention was relatively short (~5 weeks), and repeated administration of cognitive tests could introduce practice effects and increase participant fatigue, thereby affecting the validity of the outcome measures. The study design and timing of all feasibility and outcome assessments are summarized in Figure 4.

Figure 4. Study design, intervention protocol, and assessment timeline. Baseline and postintervention outcome measures were assessed within 1 week before and after the 5-week intervention, respectively. Feasibility measures (Questionnaire of Acceptance of the Virtual Reality Experience Among the Elderly [QAVREE], Simulator Sickness Questionnaire [SSQ], and Observed Emotion Rating Scale [OERS]) were administered immediately before, during, and immediately after the first virtual reality (VR) session, whereas system usability (system usability scale [SUS]) was evaluated by occupational therapists after completion of the intervention. ADL: activities of daily living; BPSD: behavioral and psychological symptoms of dementia; CTT: Color Trails Test; CSDD: Cornell Scale for Depression in Dementia; DQoL: dementia quality of life; FAB: Frontal Assessment Battery; IADL: instrumental activities of daily living; MoCA: Montreal Cognitive Assessment; SWEMWBS: Short Warwick-Edinburgh Mental Well-Being Scale.



Feasibility and Usability

In the QAVREE, older adults report their subjective perceptions of perceived usefulness, perceived ease of use, perceived enjoyment, subjective norms, and user experience across 17 items. Responses are rated on a 5-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (5), with higher scores indicating greater acceptance. This self-report scale has demonstrated good reliability and validity [24]. In the SSQ, participants self-report symptoms related to nausea, oculomotor disturbance, and disorientation following the VR intervention. Previous studies have demonstrated that the SSQ is an effective tool for assessing cybersickness symptoms associated with immersive VR use in older adults and clinical populations [20].

The system usability scale (SUS) was administered to 5 occupational therapists involved in the intervention to evaluate the usability, functionality, and clinical applicability of the VR system from a professional perspective. This measure was completed by the occupational therapists rather than by the older adult participants themselves, given the cognitive demands associated with self-report usability assessments in individuals with dementia. The SUS consists of 10 items rated on a 5-point Likert scale, ranging from "strongly disagree" (1) "to strongly agree" (5), with higher scores indicating greater usability. The scale has demonstrated good reliability, validity, and sensitivity [25].

The OERS was used to assess participants' emotional responses during the VR intervention. The OERS evaluates both positive and negative emotions, including pleasure, anger, anxiety, sadness, and interest, exhibited by participants during the intervention. Emotional intensity was rated according to the duration of each observed emotion, categorized as never, less than 16 seconds, 16 to 59 seconds, 1 to 5 minutes, or more than 5 minutes. The OERS was originally developed for use with nursing home residents and has been shown to be effective in detecting mood changes in individuals with dementia [26].

Cognitive Outcomes

To evaluate cognitive function before and after the VR intervention, the Chinese version of the Montreal Cognitive Assessment (MoCA), the Stroop Color and Word Test (SCWT), the Color Trails Test (CTT), and the Frontal Assessment Battery (FAB) were administered as primary outcome measures.

The MoCA was used to assess global cognitive function and is a sensitive and valid screening tool for cognitive impairment [27]. The MoCA assesses multiple cognitive domains, including orientation to time and

place, attention, concentration, short-term memory, working memory, visuospatial abilities, language, and executive functions. Total scores range from 0 to 30, with scores below 26 indicating cognitive impairment; higher scores indicate better cognitive function.

The SCWT was used to assess the ability to inhibit cognitive interference [28]. Participants were required to read the words under congruent and incongruent color conditions. Performance on the SCWT was evaluated based on reaction time, with longer reaction times indicating poorer inhibitory control.

The CTT was used to assess cognitive flexibility and is sensitive in detecting early dementia [29]. The assessment consists of 2 parts. In the first part, participants are required to rapidly connect numbered circles in sequence from 1 to 25. In the second part, the task is similar but requires participants to alternately connect circles of 2 different colors (yellow and pink) while maintaining the numerical sequence. Shorter completion times reflect better performance.

The FAB is a brief tool designed to evaluate executive function and has demonstrated good sensitivity and validity in detecting executive dysfunction. The battery consists of 6 subtests assessing conceptualization, mental flexibility, motor programming, sensitivity to interference, inhibitory control, and environmental autonomy [30].

Secondary Outcomes

The secondary outcomes included ADL, emotional status, clinical symptoms, and quality of life, assessed using the Barthel Index (BI), the Lawton instrumental activities of daily living (IADL) scale, the Cornell Scale for Depression in Dementia (CSDD), measures of BPSD, the Chinese version of dementia quality of life (DQoL) instrument, and the Short Warwick-Edinburgh Mental Well-Being Scale (SWEMWBS).

The BI was used to assess ADL and is recommended for the functional assessment of older adults [31]. Total scores range from 0 to 100, with lower scores indicating poorer ADL function and greater dependence on assistance from others.

The Lawton IADL scale is an appropriate instrument for assessing independent living skills in older adults [32] and is sensitive in detecting early and less severe functional decline. The scale includes 8 domains: using the telephone, shopping, food preparation, housekeeping, laundry, transportation, medication management, and financial management [33]. Total scores range from 0 to 10, with lower scores indicating poorer IADL function and greater functional decline.

The Chinese version of the CSDD was used to assess depressive symptoms during the intervention to monitor potential effects of VR on mood. The scale comprises 19 items across 5 domains, with item scores ranging from 0 (“absent”) to 2 (“severe”). Total scores above 10 indicate probable depression, whereas scores below 6 suggest the absence of clinically significant depressive symptoms. The Chinese version has demonstrated good validity and reliability [34].

BPSD were assessed to evaluate symptoms such as delusions, anxiety, and other neuropsychiatric manifestations. BPSD represent one of the most burdensome aspects of dementia care for caregivers, and in clinical practice, they are often more readily observable and responsive to intervention [35].

The Chinese version of DQoL was used to assess quality of life in individuals with dementia during the VR intervention. The scale comprises 29 items across 5 domains: positive affect, negative affect, a sense of aesthetics, feelings of belonging, and self-esteem. Item scores range from 0 to 5, with higher scores indicating a better quality of life. The Chinese version of the DQoL has been validated in Taiwanese individuals with dementia who had Mini-Mental State Examination scores greater than 10 [36].

The SWEMWBS is a 7-item self-report measure of mental well-being and was used to evaluate participants’ overall emotional well-being. Higher scores indicate better mental health. The scale has demonstrated good reliability and validity, and it has been shown to be associated with anxiety and depression [37].

Statistical Analysis

All analyses were conducted using IBM SPSS Statistics (version 24). Descriptive statistics (means, SDs, and percentages) were used to summarize participant characteristics and outcome measures. Two-tailed paired-samples *t* tests were used to examine differences between preintervention and postintervention outcomes. Effect sizes were calculated using Cohen *d*, and 95% CIs were calculated for all point estimates. Statistical significance was set at $P<.05$. Paired-samples *t* tests were used to examine pre-post differences. To control the familywise error rate associated with multiple comparisons, Holm-Bonferroni correction was applied across all clinical outcomes eligible for inferential testing. Because no variability was observed in the BI scores, inferential testing could not be performed for this outcome. Three outcome measures had missing data at one or both time points: the CCT-1 (1/15 participant, 6.67%), the CCT-2 (2/15 participants, 13.33%), and the DQoL scale (3/15 participants, 20%). Little’s missing completely at random (MCAR) test was nonsignificant ($\chi^2_{18}=19.1$; $P=.39$), indicating that the missing data were consistent with the MCAR assumption. Paired-samples *t* tests were conducted using all available paired observations for each outcome measure; therefore, sample sizes and corresponding degrees of freedom varied across analyses according to data availability. Given the small amount of missing data, the pilot nature of the study, and the finding that missingness was consistent with the MCAR assumption, multiple imputations were not considered necessary and were therefore not performed.

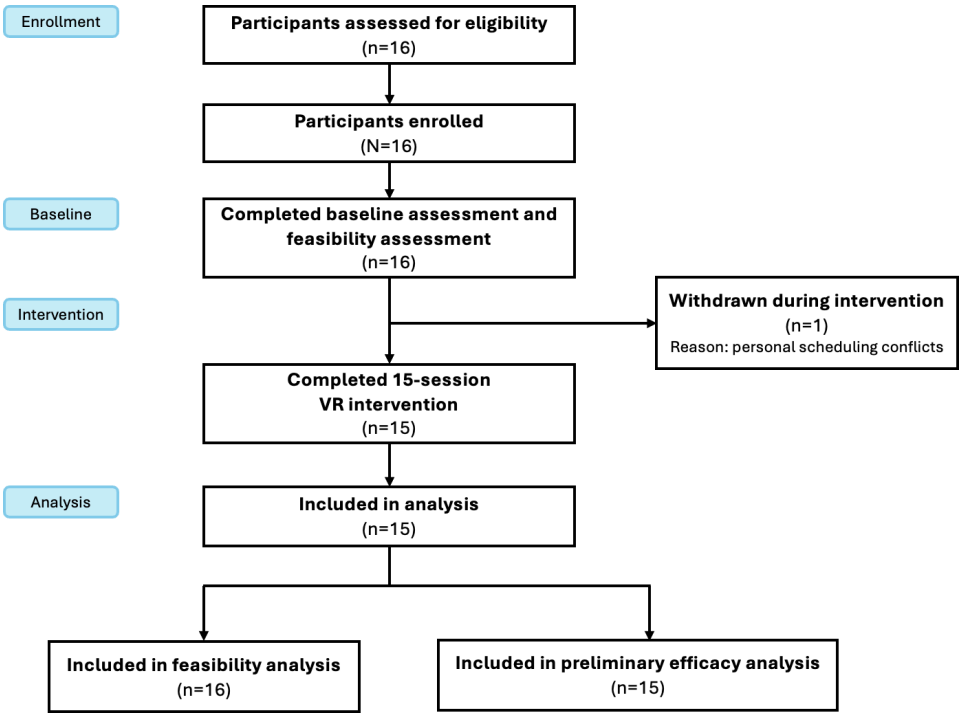
Results

Participant Characteristics

A total of 16 participants were enrolled and completed baseline assessments and feasibility evaluations following

the first VR session. One participant withdrew before the second session due to scheduling conflicts unrelated to the intervention. Consequently, 15 participants completed the full 15-session program and were included in the pre-post outcome analyses. Participant flow across study stages is provided in Figure 5.

Figure 5. Participant flow through the feasibility and exploratory pre-post clinical outcome analyses. VR: virtual reality.



Detailed demographic characteristics are presented in Table 1. Among the enrolled participants (N=16), the majority were women (n=11, 68.75%) with a mean age of 78.12 (SD 6.61) years. The participants generally had low educational attainment, with a mean of 7.88 (SD 4.03) years of formal schooling. Half of the sample (n=8, 50%) had completed only elementary school, while only 1 participant (6.25%) had received college-level education. The demographic profile of the participants who completed the full intervention (n=15) remained consistent with the baseline sample (mean age 78.57, SD 6.58 years; mean education 8.00, SD 4.14 years).

Feasibility Outcomes

VR Acceptance

VR acceptance significantly increased following the first VR session. The mean QAVREE score increased from 3.42 (SD 0.44) before the session to 3.85 (SD 0.39) immediately following the session (t_{15}=–5.40, 95% CI –0.61 to –0.26; P<.001), indicating enhanced positive attitudes toward the VR intervention.

Simulator Sickness

Simulator sickness, as measured by the SSQ, showed a significant reduction after the first VR session. The total SSQ score decreased from a mean of 5.61 (SD 6.26) preintervention to 2.81 (SD 3.48) postintervention (t_{15}=2.42, 95% CI 0.34-5.27; P=.03). Subscale analyses further revealed the following: nausea significantly decreased from a mean of 4.77 (SD 4.93) preintervention to 1.19 (SD 3.26) postintervention (t_{15}=3.00, 95% CI 1.04-6.12; P=.009). Disorientation significantly decreased from a mean of 9.57 (SD 14.12) preintervention to 3.48 (SD 6.23) postintervention (t_{15}=2.41, 95% CI 0.69-11.49; P=.03). Oculomotor symptoms showed no significant change (mean score preintervention: 5.21, SD 7.17; mean score postintervention: 4.74, SD 6.11; t_{15}=0.44; P=.67).

Emotional Responses During VR Use

Participants' emotional responses observed during the first VR training session are summarized in Table 2. Overall, the participants demonstrated predominantly positive affect while engaging in the intervention. The mean pleasure score was 3.38 (SD 1.63; range: 1-5), indicating moderate to high levels of positive emotional experience. General alertness was also high, with a mean score of 4.63 (SD 0.89; range: 2-5), suggesting a high degree of sustained attention and psychological engagement during the intervention.

Table 2. Observed emotional responses during the first virtual reality training session.

Observed Emotion Rating Scale	Mean (SD; range)
Pleasure	3.38 (1.63; 1-5)

Observed Emotion Rating Scale	Mean (SD; range)
Anger	1.00 (0; 1-1)
Anxiety	1.19 (0.75; 1-4)
Sadness	1.00 (0; 1-1)
General alertness	4.63 (0.89; 2-5)

Conversely, negative emotional responses were minimal. Anger and sadness both yielded mean scores of 1.00 (SD 0), indicating that these emotions were not observed during the session. Anxiety levels remained very low, with a mean score of 1.19 (SD 0.75), further supporting the psychological safety and tolerability of the gardening-based immersive VR intervention.

Professional Usability Assessment

Professional usability of the VR system was evaluated by 5 occupational therapists (2 men and 3 women) from the participating sites rather than by the older adult participants themselves, given the cognitive demands associated with self-report usability assessments in individuals with dementia. The mean SUS score, as rated by the occupational therapists, was 70.5 (SD 12.17, 95% CI 55.4-85.6). According to established SUS interpretation benchmarks, this score exceeded the industry average of 68, indicating that the VR system demonstrated acceptable to good usability for clinical implementation in dementia care from the perspective of experienced occupational therapists.

Exploratory Pre-Post Clinical Outcomes

Global Cognitive Function

As shown in Table 3, MoCA scores were higher at postintervention than at baseline. The mean score increased from 16.13 (SD 3.94) to 18.27 (SD 5.19), corresponding to a mean within-participant change of –2.13 (95% CI –3.28 to –0.99; t_{14}=–4.00, Cohen d=1.03; P=.001).

Table 3. Preintervention and postintervention outcome measures.

Measurements	Preintervention, mean (SD)	Postintervention, mean (SD)	t test (df)[a]	P value	Cohen d	Mean difference (95% CI)
MoCA[b] (score)	16.13 (3.94)	18.27 (5.19)	–4.000 (14)	.001	1.03	–2.13 (–3.28 to –0.99)
Stroop (s)	48.87 (18.52)	57.52 (18.94)	–1.298 (14)	.22	0.34	–8.65 (–22.95 to 5.64)
CTT-1[c] (s)	55.50 (32.93)	51.61 (29.75)	0.434 (13)	.67	0.12	3.89 (–15.47 to 23.24)
CTT-2 (s)	149.28 (77.99)	124.71 (58.06)	1.869 (12)	.09	0.52	24.57 (–4.07 to 53.22)
FAB[d] (score)	6.33 (3.48)	7.73 (4.42)	–1.796 (14)	.09	0.46	–1.40 (–3.07 to 0.27)
ADL[e] (score)	99.00 (3.87)	99.00 (3.87)	—[f]	—[f]	—[f]	—[f]
IADL[g] (score)	6.93 (1.28)	6.80 (1.27)	0.619 (14)	.55	0.16	0.13 (–0.33 to 0.60)
CSDD[h] (score)	3.00 (4.19)	2.07 (2.46)	1.360 (14)	.19	0.35	0.93 (–0.54 to 2.41)
BPSD[i] (score)	0.13 (0.52)	0.00 (0)	1.000 (14)	.33	0.26	0.13 (–0.15 to 0.42)
DQoL[j] (score)	100.73 (16.99)	103.64 (15.27)	–1.088 (10)	.30	0.33	–2.91 (–8.87 to 3.05)
SWEMWBS[k] (score)	27.00 (4.57)	27.00 (5.31)	0.000 (14)	>.99	0	0.00 (–1.95 to 1.95)

[a]CTT-1 (n=14), CTT-2 (n=13), and DQoL (n=11) reflect listwise-deleted cases with missing data at one or both time points.
[b]MoCA: Montreal Cognitive Assessment.
[c]CTT: Color Trails Test.
[d]FAB: Frontal Assessment Battery.
[e]ADL: activities of daily living.
[f]The Barthel Index ADL score showed zero variance in the pre-post difference (no participant changed score), so the t test statistic is not defined.
[g]IADL: instrumental activities of daily living.
[h]CSDD: Cornell Scale for Depression in Dementia.
[i]BPSD: behavioral and psychological symptoms of dementia.
[j]DQoL: dementia quality of life.
[k]SWEMWBS: Short Warwick-Edinburgh Mental Well-Being Scale.

Domain-Specific Cognitive Outcomes

No statistically significant pre-post differences were observed in the domain-specific cognitive outcomes (Table 3). The paired comparisons yielded Cohen d values of 0.34 for the Stroop test (P=.22), 0.12 for CTT-1 (P=.67), 0.52 for CTT-2 (P=.09), and 0.46 for the FAB (P=.09). All comparisons remained nonsignificant after Holm-Bonferroni correction (adjusted P≥.77).

ADL

Functional independence remained stable throughout the study period. No significant changes were observed in the BI scores, which showed a ceiling effect with consistent scores at both time points (mean 99.00, SD 3.87; t_{14}=0.00; P>.99). Similarly, IADL scores showed no significant deviation from baseline (preintervention: 6.93 vs postintervention: 6.80; t_{14}=0.62; d=0.16; mean difference [MD]=0.13, 95% CI –0.33 to 0.60; P=.55).

Emotional and Behavioral Outcomes

Psychological symptoms remained low and stable postintervention. A nonsignificant reduction in depressive symptoms was observed on the CSDD, decreasing from 3.00 (SD 4.19) to 2.07 (SD 2.46) with a moderate effect size (Cohen d=0.35; MD=0.93, 95% CI –0.54 to 2.41; P=.19). Behavioral symptoms, as measured by the BPSD, were minimal at baseline and remained near zero postintervention (Cohen d=0.26; MD=0.13, 95% CI –0.15 to 0.42; P=.33).

Quality of Life and Well-Being

No significant changes were observed in quality of life or mental well-being. The DQoL total score showed a slight, nonsignificant increase from a mean of 100.73 (SD 16.99) before the intervention to 103.64 (SD 15.27) after the intervention (t_{10}=–1.09; MD=–2.91, 95% CI –8.87 to 3.05; Cohen d=0.33; P=.30). Mental well-being, assessed via the SWEMWBS, remained unchanged with mean scores of 27.00 (SD 4.57) before the intervention and 27.00 (SD 5.31) after the intervention (t_{14}=0.00; P>.99).

Discussion

Principal Findings

This study primarily examined the feasibility and professionally rated usability of gardening-based immersive VR CT and explored pre-post changes in clinical outcomes among older adults with dementia. Participants responded favorably to the VR experience, experienced limited simulator sickness, displayed predominantly positive emotional responses, and generally completed the supervised program. Occupational therapists also rated the system as acceptably usable. The clinical outcome of global cognitive function was higher postintervention, whereas the domain-specific cognitive, functional, quality-of-life, and psychosocial outcomes showed no clear changes after correction for multiple comparisons. These findings provide preliminary support for the feasibility of integrating familiar, goal-directed activities into immersive VR CT for individuals with dementia.

Feasibility, Acceptance, Tolerability, and Professionally Rated Usability

The findings provide encouraging support for the feasibility of immersive VR CT among older adults with mild-to-moderate dementia. Participants reported greater acceptance after their initial VR experience, suggesting that direct exposure with appropriate guidance may help them become more comfortable with unfamiliar technology. This finding is consistent with previous research indicating that multisensory interaction and realistic virtual environments can facilitate acceptance and engagement among older adults [16,20]. Simulator sickness symptoms were limited and decreased after the first session, particularly for nausea and disorientation. This pattern may reflect growing familiarity with the equipment and greater confidence following guided exposure. As cybersickness is a common barrier to VR implementation, these findings support the tolerability of immersive VR when delivered in a supervised setting with appropriate monitoring and individualized rest periods [20]. The observed emotional responses further support the feasibility of the program. Pleasure and general alertness were frequently observed, whereas negative emotional responses were uncommon. The familiar gardening context, clear activity goals, and an interactive experience may have contributed to participants' positive responses and willingness to engage in CT. This is particularly relevant because motivation and engagement are important components of successful CTs [5].

Therapist-rated usability remains underexplored in immersive VR CT for people with dementia. Chuang et al [38] reported moderately favorable professional usability ratings for a gardening-based immersive VR CT system developed for community-dwelling older adults, whereas Lau et al [39] obtained positive occupational therapist feedback on a VR-based reminiscence therapy prototype for people with dementia. This study extends this work by obtaining usability ratings from occupational therapists who directly supported repeated VR training among older adults with mild-to-moderate dementia. Their favorable ratings suggest that the system and its delivery procedures were manageable within a supervised setting and highlight the value of incorporating therapists' perspectives into the development of VR interventions for dementia care. Beyond demonstrating feasibility, these findings may help identify practical considerations for subsequent implementation, particularly regarding intervention delivery procedures, usability, and safety monitoring. Such information may support further refinement of the VR training program as the ongoing randomized crossover trial progresses.

Primary Clinical Outcome

Global Cognitive Function

Global cognitive performance, as measured by the MoCA, was significantly higher at postintervention than at baseline, with a large within-participant standardized difference. This finding is broadly consistent with previous systematic reviews and meta-analyses reporting favorable cognitive outcomes following VR-based interventions among individuals with mild cognitive impairment or dementia [17-19]. In this study, the gardening-based VR program incorporated different activities designed to target specific cognitive domains, including attention, processing speed, memory, visuospatial abilities, and executive function. Together, these activities provided a structured approach to CT that addressed multiple cognitive domains within an interactive virtual

environment. The observed improvement in MoCA performance may be associated with the broad range of cognitive abilities addressed by the training program. As the MoCA assesses multiple cognitive domains, the inclusion of different domain-specific training activities may help explain the favorable change in global cognitive performance. These findings suggest that incorporating a variety of targeted cognitive exercises within an immersive VR program may be a promising approach to providing comprehensive CT for older adults with dementia.

Domain-Specific Cognitive Outcomes

In contrast to the improvement observed in global cognitive performance, no statistically significant pre-post differences were found in domain-specific cognitive measures, including the Stroop test, CTT-1 and CTT-2, and FAB. Although moderate within-participant standardized differences were observed on the FAB and CTT-2, these findings remained nonsignificant after Holm-Bonferroni correction. This discrepancy between global and domain-specific cognitive outcomes is broadly consistent with previous meta-analytic evidence indicating variability in the effects of VR-based interventions across different cognitive domains among individuals with mild cognitive impairment or dementia [19]. The findings indicate that favorable changes in global cognitive performance are not necessarily accompanied by corresponding improvements in specific cognitive abilities, highlighting the importance of examining outcomes across multiple cognitive domains.

Several considerations may help explain the absence of significant changes in domain-specific cognitive outcomes. First, although the VR program included activities specifically designed to train different cognitive abilities, including attention, processing speed, memory, visuospatial abilities, and executive functions, the training tasks may differ from standardized neuropsychological assessments in terms of stimulus presentation, cognitive demands, and response requirements. These differences may influence the extent to which training-related changes are reflected in standardized cognitive test performance. Second, the duration and distribution of training across cognitive domains may have influenced the findings. Although the 5-week intervention provided repeated practice across multiple cognitive abilities, the amount of training devoted to each specific domain may have varied depending on the activities performed. In addition, improvements in trained cognitive tasks may not necessarily generalize to untrained neuropsychological assessments. These considerations highlight the importance of examining domain-specific training dosage and the transfer of cognitive skills when evaluating multidomain VR CT programs. Future studies could examine changes in performance within individual VR training activities alongside standardized neuropsychological assessments to better understand whether improvements in trained tasks extend to broader cognitive abilities.

Secondary Clinical Outcomes: Functional and Psychosocial Outcomes

ADL, quality of life, depressive symptoms, behavioral symptoms, and mental well-being remained generally stable. This finding is consistent with previous research suggesting that changes in cognitive performance do not necessarily translate directly into broader functional or psychosocial outcomes [40]. The participants' relatively preserved basic daily functioning and low baseline levels of depressive and behavioral symptoms may also have left limited room for measurable change. Broader changes in daily functioning and psychosocial well-being may require longer intervention periods or a more comprehensive approach that directly incorporates physical activity, social participation, emotional support, and opportunities to apply trained skills in everyday situations [6,40]. Future development of the program could therefore connect virtual gardening activities with real-world tasks or caregiver-supported practice to promote transfer from the virtual environment to daily participation.

Meaningful Activity Design

A distinctive feature of this program is the integration of familiar gardening activities into an immersive VR environment for people with dementia. Meaningful leisure activities are central to person-centered dementia care and have been associated with cognitive engagement and cognitive reserve [12-15]. Gardening provides recognizable goals and contextual cues that can connect an unfamiliar digital environment with activities encountered in everyday life. The positive emotional responses observed during the initial session suggest that this familiar activity context was well received and may encourage participation in CT. Although the VR tasks required participants to learn specific procedures and respond to progressively complex cognitive demands, the gardening context provided a coherent structure for completing these tasks. Cognitive-scaffolding models propose that existing knowledge and preserved abilities can support performance when individuals encounter new cognitive challenges [41]. Activities such as planting, watering, harvesting, and organizing gardening products allowed participants to practice attention, memory, sequencing, visuospatial processing, and problem-solving within recognizable situations. Embedding cognitive demands within familiar occupations may therefore make technology-assisted training more understandable, relevant, and engaging than decontextualized cognitive exercises.

Clinical Implications

The findings suggest that gardening-based immersive VR CT is a feasible approach for providing structured CT to older adults with dementia in supervised hospital and day care settings. By incorporating different activities targeting specific cognitive domains within a familiar gardening context, the program provides opportunities to engage participants in CT through interactive and goal-directed tasks. This approach may serve as a complement to conventional CT by presenting cognitive challenges within recognizable activity contexts. Furthermore, the favorable acceptance and

emotional responses observed in this study suggest that such an approach may support participation and engagement among individuals with dementia.

An important consideration for clinical application is the flexibility of VR training to accommodate individual abilities and needs. In the present program, task difficulty was automatically adjusted according to participants' performance, allowing cognitive challenges to be adapted to different levels of ability. In addition, flexible seated or standing participation, therapist monitoring, and opportunities for assistance and rest enabled the training to be delivered according to participants' physical conditions and support needs. These features may facilitate individualized CT while maintaining an appropriate level of challenge and participant comfort. The favorable professionally rated usability findings further suggest that the system and its delivery procedures were manageable within a supervised care setting.

Several practical considerations are important for broader clinical implementation. Individuals with dementia may differ considerably in their cognitive abilities, familiarity with technology, and need for assistance. Therefore, appropriate participant selection, staff training, equipment management, and monitoring of participant responses should be addressed when incorporating immersive VR into clinical or community-based services. These considerations highlight the importance of establishing appropriate implementation procedures to support the safe and effective delivery of individualized VR CT in dementia care.

Limitations

Several limitations should be acknowledged. First, although the registered study uses a randomized crossover design, this report analyzes only the intervention-phase data using a single-group pre-post approach. The absence of a concurrent control condition limits causal inference; therefore, the higher postintervention MoCA score cannot be attributed solely to the VR program. Practice effects associated with repeated testing, natural fluctuations in cognitive performance, regression to the mean, social interaction, and attention from study personnel remain possible explanations. Completion of the ongoing registered trial will allow controlled comparisons and evaluation of potential period and sequence effects.

Second, the small referral-based convenience sample recruited from 2 settings limits statistical precision and generalizability. Participants who agreed to enroll may have been more receptive to technology, medically stable, or able to follow instructions than the broader population of people with dementia. Participants also demonstrated relatively preserved basic daily functioning, limiting the applicability of the findings to individuals with more advanced dementia or greater support needs. Missing data further reduced the available sample for some outcomes. Although Holm-Bonferroni correction was applied to the secondary clinical outcomes, the study was not powered to establish clinical efficacy or reliably detect changes across multiple outcomes.

Third, participant acceptance, simulator sickness, and emotional responses were assessed only during the initial VR session and may not capture changes in experience or tolerability over repeated use. Usability was evaluated by a small group of occupational therapists who were directly involved in delivering the program. Their familiarity with the system may have influenced their ratings, and these findings may not represent the perspectives of other professionals or service settings. Moreover, the SUS results reflect therapist-rated rather than participant-reported usability.

Finally, the study did not include long-term follow-up; therefore, the maintenance of the observed cognitive findings and their transfer to everyday functioning could not be determined. Participants' previous gardening experience, personal interest in gardening, and perceptions of the meaningfulness of the activities were not systematically assessed. The study also did not compare gardening activities with other VR content, making it difficult to determine whether the favorable acceptance and emotional responses were specifically related to the gardening theme. Future research should complete the controlled analysis of the ongoing registered trial and evaluate the program in larger and more diverse samples. Repeated assessments of acceptance and simulator sickness across the intervention, participant-reported usability, evaluations by independent health professionals, and longer-term follow-up should be incorporated. Further studies could also examine whether tailoring VR content to participants' interests and previous life experiences strengthens engagement and whether gardening-based activities offer advantages over other familiar or meaningful VR activities.

Conclusions

This study provides preliminary support for the feasibility, acceptability, and tolerability of gardening-based immersive VR CT among older adults with dementia. Its distinctive contribution is the integration of familiar, goal-directed gardening activities into an interactive CT environment. This extends existing VR approaches by demonstrating how a meaningful leisure activity can be translated into structured digital tasks for people with dementia. The study also combines participant-centered feasibility outcomes with occupational therapist–rated usability, thereby providing complementary perspectives on both the VR experience and its potential delivery in care settings. The favorable pre-post change observed in global cognition provides an additional rationale for further controlled evaluation. More broadly, the findings illustrate how immersive technology can be designed around meaningful occupations rather than technology-driven tasks alone. This person-centered design principle may guide the development of digital cognitive interventions that are more closely connected to the interests and everyday experiences of older adults. In clinical and community dementia care, gardening-based immersive VR may offer occupational therapists and other care professionals an engaging platform for delivering structured cognitive activities. Larger controlled studies with longer follow-up are needed to determine its clinical effectiveness, sustained benefits, and applicability across diverse dementia care settings.

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Generative AI Use

The authors declare the use of generative AI (GenAI) in the research and writing process. According to the GAIDeT taxonomy (2026), the following tasks were delegated to the GenAI tools under full human supervision: proofreading and editing, translation, and publication support. The generative AI tool used was ChatGPT (GPT-5.6 Sol; OpenAI). Responsibility for the final manuscript lies entirely with the authors. GenAI tools are not listed as authors and do not bear responsibility for the final outcomes.

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Data Availability

The datasets used and/or analyzed during this study are available from the corresponding author upon reasonable request.

Authors' Contributions

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

Conflicts of Interest

None declared.

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Abbreviations

ADL: activities of daily living
BI: Barthel Index
BPSD: behavioral and psychological symptoms of dementia
CSDD: Cornell Scale for Depression in Dementia
CT: cognitive training
CTT: Color Trails Test
DQoL: dementia quality of life
FAB: Frontal Assessment Battery
IADL: instrumental activities of daily living
MCAR: missing completely at random
MD: mean difference
MoCA: Montreal Cognitive Assessment
OERS: Observed Emotion Rating Scale
QAVREE: Questionnaire of Acceptance of the Virtual Reality Experience Among the Elderly
SCWT: Stroop Color and Word Test
SSQ: Simulator Sickness Questionnaire
SUS: system usability scale
SWEMWBS: Short Warwick-Edinburgh Mental Well-Being Scale
VR: virtual reality

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