Original Article

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Effectiveness of a Culturally Tailored Augmented Reality Cognitive-Physical Training Program on Executive Functions in Community-Dwelling Older Adults at Risk of Mild Cognitive Impairment: A Single-Arm Pre-Post Study

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Abstract:

Objective: To evaluate the effectiveness of an augmented reality (AR)-based cognitive-physical training program in enhancing executive functions, specifically inhibition, working memory, cognitive flexibility, and processing speed, among community-dwelling older adults at risk of mild cognitive impairment (MCI).

Material and Methods: A single-group pre-test/post-test design was conducted with 20 older adults aged 60 to 78 years (mean=66.8±4.6). Participants underwent 18 individual training sessions (45–60 minutes each), three times weekly over a period of 1.5 months. The intervention consisted of five AR-based modules that incorporated Kinect motion sensor technology to capture participants' body movements and translate them into interactive tasks. Each module targeted specific cognitive functions: memory (recalling and reproducing sequences), attention and inhibition (selective responses while ignoring distractors), cognitive flexibility (task switching), and processing speed (rapid responses to time-limited cues). Executive functions were assessed using computerized neuropsychological tasks before and after the intervention. Paired t-tests were used to compare pre- and post-intervention outcomes.

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Results: Significant improvements were observed in inhibition, cognitive flexibility, and processing speed, as evidenced by increased accuracy and reduced reaction times. Simple working memory accuracy also improved, although changes in reaction time were not statistically significant.

Conclusion: The AR-based cognitive-physical training program demonstrated positive effects on executive functions among community-dwelling older adults at risk of mild cognitive impairment. Participants showed improvements in cognitive flexibility, reaction time, and task performance. These findings highlight the value of culturally adapted interventions in supporting executive functioning. Further studies with larger samples and randomized controlled designs are warranted.

Keywords: augmented reality, cognitive-physical training, executive function, mild cognitive impairment, older adults

Introduction

Aging is characterized by progressive physiological deterioration, which increases vulnerability to neurological decline and associated impairments in both physical and cognitive functions[1,2]. Key hallmarks of neurodegenerative diseases such as Alzheimer's and Parkinson's include genomic instability and the accumulation of toxic proteins[1]. However, older adults aged 65 and above who actively engage in cognitive activities, such as reading, playing board games, or card games, demonstrate a reduced risk of dementia[3].

Executive functions (EFs), comprising inhibitory control, cognitive flexibility (also referred to as set-shifting), and working memory updating, are higher-order cognitive processes essential for goal-directed behavior and everyday functioning, consistent with the three-component model of executive functions[4]. A decline in EFs is a key feature of mild cognitive impairment (MCI) and is often among the earliest domains affected in cognitive decline. This decline is largely attributed to structural and functional alterations in the prefrontal cortex and its interconnected neural networks, which affect complex cognitive processes[1,5]. In non-amnestic MCI, which is highly prevalent among older adults in Thailand, deficits in executive functions, including working memory, cognitive flexibility, and inhibitory control, are particularly pronounced because these neural alterations disrupt the coordination of activity required for goal-directed behavior[6,7].

Given this central role, executive function was selected as the primary outcome in the present study, as the intervention was specifically designed to target core executive processes such as working memory, inhibitory control, and cognitive flexibility. Physical activity has been shown to benefit EFs by enhancing working memory, mental flexibility, and daily functioning in patients with neurodegenerative conditions[8]. Moreover, regular exercise contributes positively to psychological well-being and quality of life[9].

In Thailand, the aging population is increasingly affected by cognitive decline and functional disabilities[10]. Lifestyle factors, particularly sedentary behavior, which is prevalent in rural areas, are contributing to this trend and are associated with an increasing risk of cognitive impairment[11,12]. Conversely, older adults who maintain an active lifestyle tend to experience delayed cognitive decline and sustained functional performance[11]. Importantly, these challenges are not unique to Thailand; many developing countries are experiencing similar demographic transitions, limited access to exercise facilities, and a high prevalence of sedentary behavior among older adults. Accordingly, promoting physical activity and cognitive engagement in this population may represent a feasible intervention strategy with broader applicability, offering insights for supporting aging populations in other low- and middle-income countries.

Technological advances, such as augmented reality (AR) and virtual reality (VR), offer promising tools for cognitive and physical rehabilitation. These technologies provide immersive and interactive environments that support psychological well-being and social engagement among older adults[13,14]. AR applications, in particular, have demonstrated potential for improving cognitive rehabilitation in individuals with dementia and MCI by simulating real-world contexts[15,16]. Furthermore, AR-based interventions have been associated with improvements in motor skills, balance, and cognitive function in elderly populations[17,18.]

Combined cognitive-physical training, particularly when delivered through technology-based exergames, has proven effective in improving EFs, such as inhibition and processing speed[19]. Integrating AR technology into cognitive rehabilitation allows elderly individuals to engage with culturally and environmentally relevant simulations, which may contribute to improved quality of life[13,20]. This approach is particularly valuable in mitigating the effects of social isolation, such as those experienced during the COVID-19 pandemic.

Although various non-pharmacological interventions benefit older adults, a significant research gap exists in the use of AR for cognitive and functional enhancement, particularly in the Thai context. Few AR studies have integrated cognitive and physical components in a user-friendly format tailored for older populations. While AR can provide immersive, interactive experiences that enhance engagement, motivation, and adherence, most previous programs targeted only single domains, such as cognitive tasks or physical activity. To address this gap, the present study implements a multicomponent AR program designed to simultaneously improve executive functions, memory, and physical engagement.

In Thailand, where traditional lifestyles and community engagement play prominent roles, tailoring AR interventions to culturally relevant activities, familiar scenarios, and user-friendly interfaces is critical for optimizing accessibility and adherence among older adults with limited prior exposure to digital technologies. Given that older adults often experience multiple co-occurring challenges—including cognitive decline, physical frailty, and social isolation—multicomponent AR modules that address these domains in an integrated manner may produce greater gains in functional independence, cognitive performance, and overall well-being.

This study specifically evaluated the effectiveness of the "Multiple Cognitive and Physical Activity Augmented Reality Training (MU-COPART)" program in enhancing EFs among community-dwelling older adults with MCI in Bangkok, Nakhon Pathom, and Chon Buri, Thailand. The program delivers an accessible, home-based, culturally adapted, multicomponent intervention aimed at promoting executive functions and delaying cognitive decline, with potential applicability to similar aging populations in other settings.

Material and Methods

Participants

Community-dwelling older adults exhibiting signs of MCI were recruited through public announcements and voluntary enrollment at Subdistrict Health Promotion Hospitals or senior citizen clubs in Bangkok, Nakhon Pathom, and Chon Buri, Thailand. Inclusion criteria were: age ≥60 years, a score below 25 on the Montreal Cognitive Assessment (MoCA) – Thai version 7.1, indicating potential MCI[21] or below 20 on the Behavioral Assessment of the Dysexecutive Syndrome (BADS)[22,], normal vital signs, normal hand grip strength, sufficient proficiency in Thai, visual acuity >1.0 as measured by the Freiburg Visual Acuity and Contrast Test[23], and normal color vision based on a standard color blindness test. Exclusion criteria were a diagnosis of dementia or other neurological disorders, significant visual or hearing impairments that interfered with communication, or a high risk of falling, as indicated by the Timed Up and Go test.

The sample size was informed by prior virtual reality-based memory intervention studies, which reported effect sizes of approximately 0.357 and estimated sample sizes of 17 participants per group[24]. A priori power analysis using G*Power indicated that, for a repeated-measures design (three measurements: effect size f=0.36, α=0.05, power=0.90; correlation among repeated measures = 0.5), a minimum of 18 participants would be required. As this pilot study analyzed only two time points, paired t-tests were used for pre-post comparisons. To account for potential dropouts, twenty community-dwelling older adults were recruited.

The study was approved by the Mahidol University Institutional Review Board (COA No. MU-CIRB 2021/191.2709). Written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki, and participant confidentiality was strictly maintained.

Procedure

A single-group pretest-posttest design was employed to evaluate the effects of an occupational therapy intervention on executive functions in older adults at risk of MCI. Pre- and post-intervention differences were analyzed using paired t-tests. No control group was included to ensure that all at-risk older adults could receive the potentially beneficial intervention. Given the pilot nature of the study, as well as time and budgetary constraints, the inclusion of a separate control group was deemed unfeasible. The study was registered with the Thai Clinical Trials Registry (TCTR20220629004). Twenty community-dwelling older adults were voluntarily recruited through Subdistrict Health Promotion Hospitals and senior citizen clubs in Bangkok, Nakhon Pathom, and Chon Buri, Thailand. Following baseline assessments, participants completed a six-week intervention consisting of 18 sessions, after which post-intervention assessments were conducted to measure changes in executive functioning.

Interventions

The intervention program, Multiple Cognitive and Physical Activity Augmented Reality Training (MU-COPART), was developed based on five theoretical frameworks to enhance EFs in older adults with MCI. 1) Neural Plasticity Theory highlights the role of repeated sensory and motor stimulation in promoting neuroplastic changes that support cognitive improvement[5,13,15]. 2) The Dynamic Interactional Model and Multicultural Approach emphasize the interaction between the person, task, and environment, incorporating culturally meaningful contexts to foster metacognitive awareness and facilitate strategy transfer to daily life through structured practice[25]. 3) The Social Cognitive Framework focuses on increasing motivation, self-efficacy, and social reinforcement by integrating culturally familiar and engaging activities to support sustained participation[3,26]. 4) Dual-Coding Theory supports the use of combined visual and verbal stimuli to improve learning and memory retention, applied in MU-COPART through paired images and audio prompts[27]. And, 5) The Cognitive Theory of Virtual Reality Learning emphasizes experiential, sensorimotor-based learning within interactive environments[13,16]. AR is used to engage attention, working memory, and cognitive flexibility through embodied actions. Drawing upon these principles, MU-COPART was developed as a home-based intervention consisting of five AR modules grounded in Thai cultural contexts. Each module incorporates physical activities, such as walking, marching, arm swinging, square stepping, and lateral walking, aimed at promoting various aspects of cognitive function.

Sukjai Trekking (เดินป่าสุขใจ – Doen Pa Suk Jai; Inhibition and Environmental Awareness)

As shown in Figure 2a, Sukjai Trekking was designed with a focus on environmental perception, incorporating a green-themed background to support individuals' inhibition and self-control skills. Participants are prompted to select a target image that corresponds to an audio cue, featuring basic animals or fruits. To complete each level, participants are required to perform hand-rolling movements and walk along the designated path. This activity draws on Neural Plasticity Theory by providing repeated sensory and motor stimulation to promote neuroplastic changes that support cognitive improvement[5,15]. The combination of visual and auditory stimuli aligns with the Dual-Coding Theory, thereby facilitating memory retention and learning[27]. Moreover, the program incorporates principles from the Dynamic Interactional Model and Multicultural Approach by embedding culturally relevant, structured tasks that foster metacognitive awareness and encourage the transfer of strategies to daily life[25].

Delicious Menu (เมนูน่าอร่อย – Menu Na Aroi; Working Memory)

As illustrated in Figure 2b, the Delicious Menu module features familiar traditional Thai dishes, similar to those commonly found in daily home-cooked meals, such as crispy pork spicy salad, salty fried chicken, stir-fried morning glory, pad Thai, and tom yum kung. This activity aims to enhance participants' working memory and recognition performance.

Participants perform arm-swinging movements while interacting with images of dishes paired with verbal prompts, consistent with the Dual-Coding Theory[27]. Repeated cognitive and motor engagement supports the Neural Plasticity Theory by reinforcing neural connections[5,15]. By incorporating culturally familiar foods, the activity further applies the Dynamic Interactional Model and Multicultural Approach, providing meaningful context that encourages participant engagement and facilitates the transfer of strategies to everyday routines[25].

Fun Festival (เทศกาลน่าสนุก – Thetsakan Na Sanuk; Cognitive Flexibility and Inhibition)

Figure 2c depicts the Fun Festival activity, which is designed to improve cognitive flexibility and inhibition skills. Participants complete this activity by marching. Drawing from culturally familiar Thai events—such as Songkran, the Chinese Lunar New Year, temple fairs, and the Loy Krathong festival—participants are asked to select pictorial stimuli that correspond to each festival scenario. This activity reflects the Social Cognitive Framework by enhancing motivation, self-efficacy, and social reinforcement within engaging, culturally relevant contexts[13,26,28]. The Neural Plasticity Theory is applied through repeated multisensory and motor involvement[5,15], while the Dynamic Interactional Model and Multicultural Approach support the interactions among the individual, the task, and the environment, fostering metacognitive awareness and promoting the transfer of strategies to real-life settings[25].

Sea Pleasure (ทะเล พาเพลิน – Thale Pha Plern; Working Memory and Recognition)

As demonstrated in Figure 2d, Sea Pleasure immerses participants in a seaside environment featuring marine animals and beach-related items. Participants perform square stepping while memorizing a target image to complete the task. This activity is designed to strengthen working memory and recognition abilities. The module is grounded in the Neural Plasticity Theory, utilizing repeated sensorimotor stimulation to enhance cognitive functioning[5,15], and also incorporates the Cognitive Theory of Virtual Reality Learning, which emphasizes experiential, sensorimotor-based learning within an interactive environment[13,26].

Sequential Order (ตัวเลข เรียงลำดับ - Tua Lek Riang Lamdap; Goal-Directed Movement and Sequencing)

Shown in Figure 2e, the Sequential Order module focuses on numerical perception and the sequencing of actions to support goal-directed movements, including marching and lateral walking. This physical activity is designed to enhance participants' inhibition and self-control abilities. Neural Plasticity Theory is addressed through repeated cognitive-motor sequencing activities[5,15], while the Cognitive Theory of Virtual Reality Learning emphasizes experiential, interactive, sensorimotor-based learning[13,26]. Additionally, the Dynamic Interactional Model and Multicultural Approach are applied by structuring culturally meaningful tasks that facilitate the transfer of sequencing and goal-directed strategies to daily life, thereby enhancing inhibition and self-control skills[25].

These activities were delivered through a Kinect® motion sensor connected to a laptop, providing real-time feedback and interaction. Figure 1 presents the sequence of steps involved in using the MU-COPART program and performing the associated physical activities, while Figure 2 shows screenshots of the five AR modules, each designed with culturally relevant Thai themes to create an immersive and engaging experience. Participants completed three sessions per week, each lasting 45–60 minutes, for a total of 18 sessions over six weeks. During training, participants were informed that they could take breaks, drink water, or have a snack at any time during or at the end of each activity. No adverse events related to augmented reality use (e.g., motion sickness, dizziness, or eye strain) were observed throughout the program.

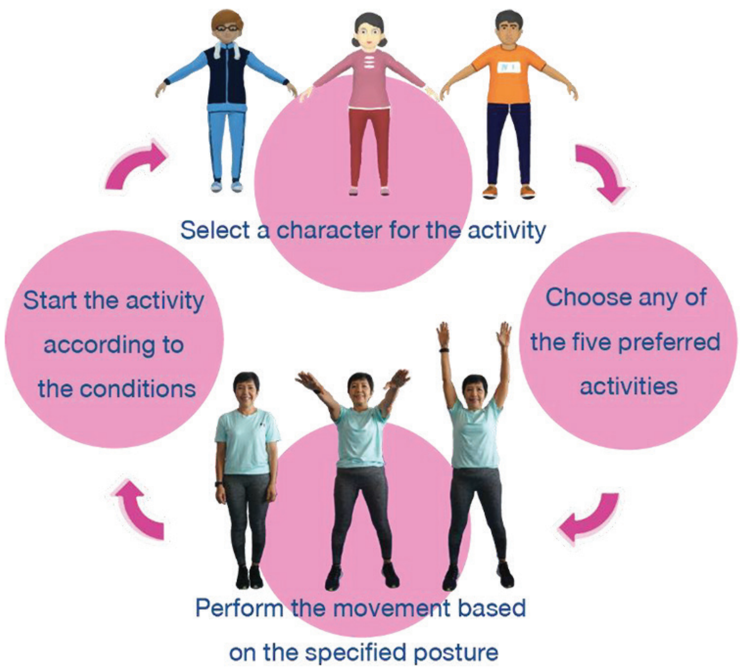
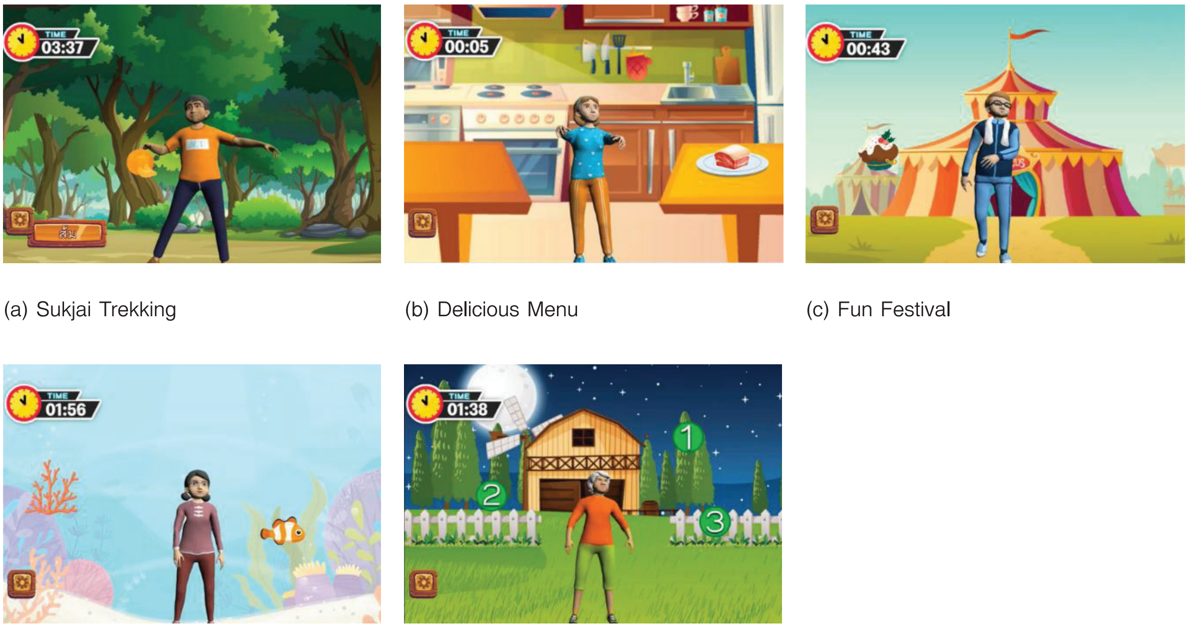


Figure 1 Sequence of steps involved in utilizing the MU-COPART program and engaging in the corresponding physical activities



(a) Sukjai Trekking (b) Delicious Menu (c) Fun Festival

(d) Sea Pleasure (e) Sequential Order

Figure 2 Visual representations of the five AR modules, designed with culturally meaningful Thai themes to enhance engagement and immersion

Computer-based assessments of executive functions using PEBL

The Psychology Experiment Building Language (PEBL) is an open-source software platform that offers a comprehensive set of computerized cognitive tests for assessing executive functions (EFs)[29]. In this study, three specific PEBL tasks were used: the Flanker Task, the Digit Span Test, and the Berg Card Sorting Test. Each was designed to evaluate the distinct domains of executive function, as described below.

Flanker task

The Flanker Task, also referred to as the Eriksen Flanker Task, measures selective attention and inhibitory control. Participants are instructed to press the left or right arrow key corresponding to the direction of a central target stimulus, which is flanked by incongruent distractor stimuli[29]. This task was selected because it specifically targets inhibitory control, a core domain of executive function, and has been widely used in both clinical and research settings for older adults. Recent studies have demonstrated good reliability for this task, with average intraclass correlation coefficients (ICC) of approximately 0.745, though values may vary depending on the environment and participant characteristics[30]. The parameters used include accuracy to assess overall response correctness, congruent mean and reaction time (RT) to examine processing speed and performance in non-conflicting trials, and incongruent mean and RT to measure inhibitory control and the cost of interference.

Digit span test

The Digit Span task is one of the most widely used measures of working memory capacity and is typically administered in two conditions. In the forward condition, participants recall digit sequences in the same order, primarily reflecting short-term storage or simple span capacity, such as visual working memory span in the visual version[31]. The backward condition, in contrast, requires sequence manipulation and is generally considered a measure of more complex working memory; however, it was not included in the present study. The forward condition was selected because it specifically targets short-term and simple working memory—a core component of cognitive function—and is suitable for older adults due to its lower cognitive demands. Individuals with normal memory can recall approximately seven digits[32]. The test has shown strong internal consistency and reliability across multiple studies. The parameters used included accuracy scores (to assess correct recall of digit sequences), RT in milliseconds (to evaluate processing and retrieval speed), and RT for each memory span (to examine performance across increasing levels of difficulty, reflecting memory capacity and efficiency)[29].

Berg card sorting test (BCST)

The BCST is a brief assessment tool for cognitive flexibility, particularly mental set shifting. In this task, participants are presented with four reference cards and one stimulus card, each displaying unique combinations of shapes and colors (e.g., one red triangle, two green stars, three yellow crosses, four blue circles). Using a computer mouse, participants must match the stimulus card to the correct reference card based on rules that change without explicit cues. Feedback is provided after each attempt, and the sorting rule changes once 10 consecutive correct matches are achieved[29]. This test was selected for its specific focus on cognitive flexibility, a core domain of executive function, as its performance is most strongly associated with shifting[4]. The BCST has demonstrated strong psychometric properties and provides a reliable, time-efficient measure for assessing executive function[33]. Outcome measures in this study included the percentage of correct responses to assess overall accuracy, perseverative errors to examine difficulties in shifting mental sets, and RT in milliseconds to evaluate processing speed.

Statistical analysis

Descriptive statistics were used to summarize participant characteristics. Paired t-tests were performed to assess pre- and post-intervention changes in EFs, including inhibition, working memory, and cognitive flexibility. All analyses were conducted using IBM SPSS Statistics for Windows, version 30.0 (IBM Corp., Armonk, NY, USA). A significant level of p-value<0.05 was used for all comparisons. Confidence intervals were reported to indicate the precision of the estimates.

Results

The demographic characteristics of the participants are summarized in Table 1. A total of 20 community-dwelling older adults from Bangkok, Nakhon Pathom, and Chon Buri voluntarily enrolled in the study. All participants were members of Subdistrict Health Promotion Hospitals or local senior citizen clubs. The majority of participants were female (n=14, 70.0%), and ages ranged from 60 to 78 years (M=66.8, S.D.=4.6). All met the eligibility criteria for being at risk of mild cognitive impairment, as determined by screening scores on the MoCA and BADS.

Following the implementation of MU-COPART across 18 sessions over six weeks, improvements were observed in multiple executive function domains—including inhibition, working memory, and cognitive flexibility. Table 2 presents the descriptive statistics for the executive function outcome measures, including means, standard deviations, and minimum and maximum values. Moreover, the table displays the distribution characteristics of these measures, specifically skewness and kurtosis. Most variables demonstrated approximate normality, with skewness values ranging between –2 and +2, and kurtosis values between –7 and +7, consistent with the criteria for a normal distribution[34]. One exception was noted in the post-intervention response time for the Digit Span Test, which exhibited a kurtosis value outside the acceptable range, suggesting a potential deviation from normality for this measure.

Table 1 Demographic and cognitive profiles of community-dwelling older adults prior to the intervention (n=20)

Characteristic	Value
Gender, n (%)	
Male	6 (30.0%)
Female	14 (70.0%)
Age range: 60–78 years; mean (S.D.)	66.8 (4.6)
MoCA score range	15-24
MoCA score, mean (S.D.)	19.95 (2.74)
BADS score range	4-17
BADS score, mean (S.D.)	12.35 (3.28)

MoCA=montreal cognitive assessment, BADS=behavioral assessment of the dysexecutive syndrome, S.D.=standard deviation

Table 2 Descriptive and distribution characteristics of executive function outcomes pre- and post-intervention (n=20)

Variables	Mean (S.D.)		Min-Max		Skewness		Kurtosis	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Flanker Task								
Accuracy scores	116.45 (42.02)	146.75 (13.49)	26-160	115-160	-0.93	-1.28	-0.50	0.76
Congruent mean	30.5 (10.53)	37.45 (3.19)	8-40	29-40	-1.04	-1.52	-0.42	1.75
Incongruent mean	26.25 (11.58)	33.80 (6.61)	0-40	17-40	-0.73	-1.39	-0.35	1.14
RT in ms	605.67 (79.33)	558.55 (55.09)	487.08-735.07	470.13-644.66	0.16	-0.38	-1.78	-1.31
Congruent mean (ms)	594.04 (82.62)	553.62 (55.54)	474.25-733.53	456.28-662.18	0.31	-0.15	-0.96	-0.71
Incongruent mean (ms)	645.88 (80.30)	604.34 (74.04)	517.90-794.40	487.55-705.40	0.95	-0.13	-1.03	-1.30
Digit span test								
Accuracy scores	4.70 (2.08)	6.85 (2.06)	1-10	4-13	0.64	1.75	0.91	3.84
RT in ms	7,214.53 (2,078.73)	9,812.71 (10,791.41)	4,061.10-12,493.67	2,472.00-54,335.00	0.65	4.07	0.99	17.42
RT in each memory span	2,047.09 (1,578.95)	1,569.61 (1,836.71)	469.07-7,265.00	395.33-9,055.83	2.16	3.91	5.74	16.44
Berg card sorting test								
Percentage of correct responses	61.05 (16.96)	81.10 (5.96)	30.47-88.79	64.84-88.68	-0.18	-1.30	-1.15	1.63
Perseverative errors	32.80 (24.44)	15.15 (6.24)	0.00-88.00	7.00-35.00	0.97	1.73	0.31	4.48
RT in ms	5,143.48 (3,261.92)	3,252.38 (1,045.57)	2,326.60-12,634.70	1,907.95-795.33	1.53	1.09	1.08	0.56

RT=response time, ms=millisecond, S.D.=standard deviation

Paired t-test analyses (Table 3) revealed significant improvements in participants' executive function performance following the MU-COPART program.

For the Flanker Task, participants' accuracy scores increased significantly from pre-test to post-test, with a large effect size (Cohen's d=-0.75, 95% CI [-1.24, -0.25]; t=-3.37, p-value<0.001). Incongruent reaction times (RT) decreased from pre-test to post-test, with a medium effect size (Cohen's d=0.47, 95% CI [0.01, 0.93]; t=2.12, p-value<0.05), indicating improvements in selective attention and inhibitory control. Overall RT also decreased significantly, with a medium-to-large effect size (Cohen's d=0.60, 95% CI [0.11, 1.07]; t=2.67, p-value<0.05), reflecting enhanced general processing speed following the AR-based cognitive training.

For the Digit Span Test, participants' accuracy scores improved significantly from pre-test to post-test, with a large effect size (Cohen's d=-1.27, 95% CI [-1.85, -0.67]; t=-5.67, p-value<0.001), indicating enhanced simple working memory performance. No significant changes were observed in overall RT, which slightly increased from pre- to post-test (Cohen's d=-0.24, 95% CI [-0.68, 0.21]; t=-1.09, p-value>0.05), or in RT per memory span (Cohen's d=0.21, 95% CI [-0.24, -0.65]; t=0.94, p-value>0.05), suggesting that response speed did not change significantly despite improved accuracy.

For the Berg's Card Sorting Test (BCST), participants' percentage of correct responses increased from pre-test to post-test, indicating a large improvement in performance (Cohen's d=-1.28, 95% CI [-1.87, -0.68]; t=-5.74, p-value<0.001). Conversely, perseverative errors decreased from pre-test to post-test, also showing a large effect (Cohen's d=0.76, 95% CI [0.25, 1.25]; t=3.38, p-value<0.01). Additionally, participants' reaction times were significantly reduced from pre-test to post-test, reflecting enhanced cognitive flexibility (Cohen's d=0.64, 95% CI [0.15, 1.11]; t= 2.85, p-value<0.05). Overall, these findings highlight the positive effects of MU-COPART on executive functioning among older adults at risk of mild cognitive impairment.

Table 3 Comparison of executive function outcomes in MCI participants before and after the MU-COPART Program (n=20)

Variables	Mean (S.D.)	Std. Error	t-test	df	p-value
Flanker task					
Accuracy scores	-30.00 (39.85)	8.91	-3.367	19.00	0.003
Congruent mean	-6.95 (10.24)	2.29	-3.035	19.00	0.007
Incongruent mean	-7.55 (10.63)	2.38	-3.175	19.00	0.005
RT in ms	47.12 (79.00)	17.66	2.668	19.00	0.015
Congruent mean (ms)	40.42 (85.54)	19.13	2.113	19.00	0.048
Incongruent mean (ms)	41.54 (87.73)	19.62	2.118	19.00	0.048
Digit span test					
Accuracy scores	-2.15 (1.69)	0.38	-5.67	19.00	<0.001
RT in ms	-2,598.18 (10,706.88)	2,394.13	-1.09	19.00	0.29
RA in each memory span	477.48 (2,269.73)	507.53	0.94	19.00	0.36
Berg card sorting test					
Percentage of correct responses	-20.05 (15.63)	3.50	-5.74	19.00	<0.001
Perseverative errors	17.65 (23.33)	5.22	3.38	19.00	0.003
RT in ms	1,891.10 (2,962.62)	662.46	2.85	19.00	0.01

RT=response time, RA=response accuracy, ms=milliseconds, S.D.=standard deviation, df=degrees of freedom, Std. Error=standard error, MCI=mild cognitive impairment, MU-COPART=multiple cognitive and physical activity augmented reality training

Discussion

This study evaluated the effects of a sustained, culturally tailored cognitive-physical intervention—MU-COPART—on executive functions, specifically inhibition, working memory, and cognitive flexibility, in community-dwelling older adults with mild cognitive impairment (MCI). The results demonstrated significant improvements in response accuracy and processing speed across executive function domains, as assessed by the Flanker Task, Digit Span Test, and Berg Card Sorting Test following 18 sessions of MU-COPART. These findings support the program's effectiveness in enhancing executive function performance within this population. The observed cognitive gains suggest that regular engagement in physical activity integrated with AR may help maintain and improve executive functioning in older adults with MCI. Despite the absence of a control group, due to ethical and practical constraints, the significant results, combined with high participant adherence, indicate the potential value of this multisensory and culturally relevant intervention.

The findings align with prior research emphasizing the roles of physical activity and cognitive stimulation as nonpharmacological strategies for delaying cognitive decline and enhancing executive functions[15,19,35]. Similar benefits have been reported in studies that combine physical and cognitive training through VR or AR technologies, which not only stimulate brain activity but also increase motivation and engagement[16,36,37]. Among community-dwelling older adults with MCI, immersive and interactive interventions—such as VR-based exercise—have demonstrated positive effects on cognitive performance and adherence to exercise programs[28,35,38]. Consistent with current findings, this study adds to the growing body of evidence supporting immersive, interactive AR-based interventions for enhancing cognitive and daily functioning in individuals with MCI[26,39]. Minor variations in outcomes compared to other studies may stem from differences in intervention duration, participant characteristics, or technological platforms. Nevertheless, MU-COPART's integration of culturally adapted content, sensorimotor interaction, and cognitive challenges likely contributed to its effectiveness and participant engagement.

Several limitations should be acknowledged. First, the small sample size and lack of a control group limit generalizability and the strength of causal conclusions. Second, the short duration of the intervention may not fully capture long-term effects. Third, the MU-COPART program requires a laptop and motion sensor camera, which may pose accessibility barriers for some older adults, particularly those with limited technological proficiency or more advanced cognitive decline. Finally, improvements in executive function scores may partly reflect practice or learning effects, as participants could have become more familiar with the tests during the second administration.

Despite these considerations, the findings provide promising preliminary evidence that AR-based cognitive-physical interventions may promote executive function in older adults with MCI. To our knowledge, this is a culturally adapted program tailored to the Thai context for this population. With appropriate adaptation, such interventions could be implemented in diverse settings worldwide to support cognitive health and functional independence in aging populations.

Future studies should investigate the long-term effects and sustainability of AR-based cognitive-physical interventions using larger, randomized controlled trials. The development of more user-friendly platforms, such as mobile applications, along with the incorporation of caregiver involvement and community-based strategies, could enhance accessibility, adherence, and real-world effectiveness. From a practical perspective, integrating culturally relevant, technology-assisted interventions like MU-COPART into health promotion strategies offers an innovative approach to address cognitive aging and promote healthy aging across diverse cultural contexts.

Conclusion

The MU-COPART AR-based cognitive-physical training program may effectively enhance executive functions in older Thai adults with mild cognitive impairment. These findings provide preliminary evidence supporting the use of culturally tailored, technology-assisted interventions to promote cognitive health.

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Conflict of interest

The authors declare that there are no conflicts of interest related to this study.

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