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Effects of a 12-week digital training equipment program on cognitive function and mental health in older women: a randomized controlled trial

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Abstract

Objective: Combined interventions of physical activity and cognitive training have been shown to effectively enhance physical and mental factors in older adults. Digital-based tools offer various social advantages and may be more effective in improving the physical and mental well-being of older adults. As digital health content can simultaneously provide physical activity and cognitive training, this study aims to investigate the effects of a digital-based physical and cognitive training program on the physical and mental health of older women and to explore the potential of digital tools for older adults.

Methods: The participants, older women, engaged in the program three times a week for 12 weeks, with each session lasting 30 minutes (10 minutes for each of the three components). The content included digital health tools such as VR, motion tracking, and touchscreens designed for cognitive and physical fitness. Measurements were taken one week before and after the intervention for both groups, assessing body composition, cognitive function, depression, and quality of life.

Results: Data from 36 participants were analyzed. Interaction effects were observed in body fat mass ($P = .011$) and body fat percentage ($P = .01$), with improvements noted in the digital intervention group. Cognitive function ($P = .017$) and depression ($P = .017$) also showed significant improvements in the digital intervention group. Quality of life subdomains, including Physical Function ($P = .009$), Limitation of Physical Function ($P = .004$), and Pain ($P = .002$), demonstrated significant interaction effects, though no interaction effects were found in other subdomains.

Conclusion: This study found that digital-based combined interventions did not significantly impact body comb position but did improve cognitive function and depression in older women. These findings suggest that digital tools can be effectively utilized for the comprehensive management of cognitive function and mental health well-being. Such insights contribute to promoting healthy aging and provide an efficient method for managing the mental and physical health of older adults.

Keywords

Cognitive function, physical function, VR, motion tracking, depression, quality of life, older adults

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Highlights

- Aging is a factor that negatively affects cognitive function and mental health.
- However, digital health content for cognitive function and mental health is being utilized in various environments.
- Utilizing digital health content interventions can positively impact older adults by providing prevention and improvement measures for cognitive function and mental health.

Introduction

Population aging is a significant social phenomenon in modern society, showing a steadily increasing trend. As

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of 2022, the global population was estimated to be approximately 8 billion, with the older adults population aged 65 and older accounting for about 9.8% of the total population, equivalent to around 780 million people.[1] Meanwhile, in South Korea, the proportion of the older adults population aged 65 and older is higher than the global older adults population ratio, accounting for 17.5% of the total population as of 2022, according to Statistics Korea.[2] As life expectancy continues to increase, the proportion of the older adults population is consistently growing.

Issues related to physical health, such as a decline in physical stature, physical fitness, and metabolic function, are natural phenomena that occur with aging. Additionally, mental health issues, including cognitive decline, depression, and decreased quality of life, often coexist with physical health problems in the older adult population.[3,4] Previous research has shown that cognitive training, social activities, and healthy lifestyle habits are crucial for improving mental health in older adults.[5] Moreover, physical activity has been found to have a positive impact on mental health, underscoring the importance of managing mental well-being through regular physical engagement.[6] Consequently, various approaches are being studied to enhance and maintain mental health in older adults, highlighting the critical need for comprehensive management of both physical and mental health.

Recent research suggests that combined training interventions are more effective at improving cognition in older adults than separate physical or cognitive training.[7] Exergame-based training involves both physical activity or exercise and cognitive tasks, requiring participants to engage in both simultaneously.[8] Simultaneous physical-cognitive training is considered an effective method for enhancing cognitive function in middle-aged to older adults with cognitive impairments. Exergaming has emerged as a promising approach to efficiently implement this type of training by combining physical and cognitive challenges, making it a notable tool for improving cognitive abilities in this population.[9]

With a scarcity of specialized professionals to address the multifaceted mental and physical health challenges among the growing older adults demographic, digital healthcare methods are being introduced for convenience. In a study by Lee et al. (2023), it was reported that virtual reality (VR), 2D-based cognitive enhancement, and motion-sensing fitness systems were effective in improving both physical fitness and cognitive function in older adults. Additionally, the implementation of combined exercise programs was suggested as an effective intervention for preventing dementia and enhancing daily functional fitness in the elderly.[10] These intervention approaches provide comprehensive health management for older adults through tailored physical and cognitive training programs. These personalized programs aim to enhance the range and enthusiasm for physical activities.[11]

In regions with limited access to healthcare professionals, it is crucial to explore how various digital devices (such as virtual reality, AI cameras, and touch screens) can be effectively utilized to improve both the physical and psychological well-being of older adults. These tools play a significant role in enhancing health and welfare services for older populations. The ultimate goal is to develop and provide physical activity programs that can improve the quality of life for older adults by confirming the wide range of benefits these interventions offer. In line with the goal of improving older adults' quality of life, the selection of these digital technologies is well-founded due to their individual and synergistic benefits. Virtual reality (VR) provides immersive environments that boost engagement and motivation in both physical and cognitive exercises.[12] Motion tracking technology enables precise monitoring and feedback on physical activities, which is essential for tailoring interventions to individual needs and ensuring correct technique.[13] Additionally, touch screens offer an accessible and intuitive interface, making cognitive training programs more user-friendly and effective for older adults.[14]

Building on this foundation, a randomized controlled trial is being conducted to assess the effects of a 12-week digital-based exercise program on the mental health and cognitive function of older women. This study aims to explore new possibilities for managing both the mental health and psychological well-being of older adults. By examining changes across various indicators, it addresses the important social issues of mental decline and cognitive impairment, ultimately contributing to enhanced quality of life and sustained independence for this population.

Methods

Participants

The sample size for the study was calculated using G*Power software with the following parameters: F-tests, ANOVA: Repeated measures, within-between interaction; A priori: Compute required sample size—given α, power, and effect size. The alpha level (α) was set at 5%, the power (β) at 80%, and the effect size at 0.25, which represents a medium effect size according to Cohen's guidelines.[15] The study design included two groups and two measurements, with an assumed correlation among repeated measures of 0.5[16] and a nonsphericity correction factor (ϵ) of 1, assuming sphericity was satisfied.[17] Based on these parameters, the required number of participants was calculated to be 34.

Considering a 30% dropout rate, the adjusted sample size was increased to 50 participants. However, due to the uncertainty regarding participant retention for post-measurements, an additional five participants were recruited as a precautionary measure, resulting in a final sample size of 55 participants.[18]

We recruited 55 older adult women aged 65 and older to participate in the study. According to the following exclusion criteria, two participants were excluded. All potential participants underwent a preliminary screening conducted by licensed nurses to assess vision, hearing, and communication abilities before completing the Par-Q & You questionnaire and the Health History Questionnaire (HHQ).

- Individuals with cardiovascular diseases or disorders
- Individuals with musculoskeletal diseases or disorders
- Individuals with visual or hearing impairments
- Individuals with physical activity limitations
- Individuals with communication limitations

All participants were provided with explanations regarding the research procedures, potential risks, and benefits of participation, and they voluntarily signed informed consent forms before proceeding.

The participants were randomly assigned by the research administrator to two groups: an exercise group ($n = 26$) and a control group ($n = 27$). This random assignment, conducted by the research administrator, ensured that key demographic characteristics such as age, weight, and body composition were balanced between the groups. The administrators responsible for the measurements were blinded to the participants' group allocation.

To verify the outcome of the random assignment, we evaluated the balance of major demographic characteristics such as age, weight, and body composition between the two groups. The analysis using t-tests showed no statistically significant differences between the groups in terms of age, weight, and body composition ($P > .05$). The characteristics of the participants in the study are presented in Table 1.

However, due to health issues and personal schedules, participants dropped out during the study (exercise group: 7 participants, control group: 10 participants). Thus, data from a total of 36 participants, comprising 19 in the exercise group and 17 in the control group, were included in the final analysis.

Table 1. The digital-based healthcare program sequence.

Variables	Frequency	Duration	Contents	Intensity
Digital-based health care program	3 days/ week	10 min	VR content	–
		10 min	Motion tracking content	RPE 11–13
		10 min	Touch screen content	–

The study was conducted with approval from the Institutional Review Board (KHGIRB-22-372) before commencement and was registered in the Clinical Trials Registration (KCT0008574). The trial design for the study participants is presented in Figure 1.

Measurement methods

Anthropometry and body composition. Height, weight, and body composition were evaluated using an anthropometer and bioelectrical impedance analysis. Measurements comprised height (cm), weight (kg), fat mass (FM), percent body fat (%BF), and fat-free mass (FFM). Body mass index (BMI) was computed by dividing weight (kg) by the square of height (m^2).

Cognitive function. Cognitive function was assessed using the Montreal Cognitive Assessment (MoCA). The MoCA is a cognitive screening tool designed to differentiate mild cognitive impairment (MCI) from normal cognition. It includes sub-items such as visuospatial/executive function, naming, attention, language-sentence repetition, abstraction, delayed recall, and orientation. The total score is 30, with a cut-off of 26 or above indicating normal cognitive function, 25 or below indicating mild cognitive impairment, and 10 or below indicating moderate cognitive impairment.[19] Changes of 1–2 points in the MoCA score have been suggested as a clinically significant threshold.[20,21]

Depression. Depression was assessed using the Short Geriatric Depression Scale-Korea (SGDS-K), a modified Korean version of the original scale developed.[22] The SGDS-K consists of 15 items with a dichotomous response format (1 = yes, 0 = no) and evaluates emotional discomfort, critical thinking, and unhappiness. Scores range from 0 to 15, with higher scores indicating higher levels of depression.

Quality of life. Quality of life was assessed using the Korean version of the World Health Organization Quality of Life Assessment Instrument Abbreviated Version (WHOQOL-BREF), adapted and.[23] The WHOQOL-BREF utilizes a 5-point Likert scale and consists of 24 items covering physical health, psychological well-being, social relationships, and environmental domains. Scores range from 24 to 120, with higher scores indicating better quality of life.

Intervention settings. The intervention in this study was delivered as a digital health program, which comprised the following three main content components:

1. VR-based cognitive rehabilitation and physical enhancement content. <Figure 2>

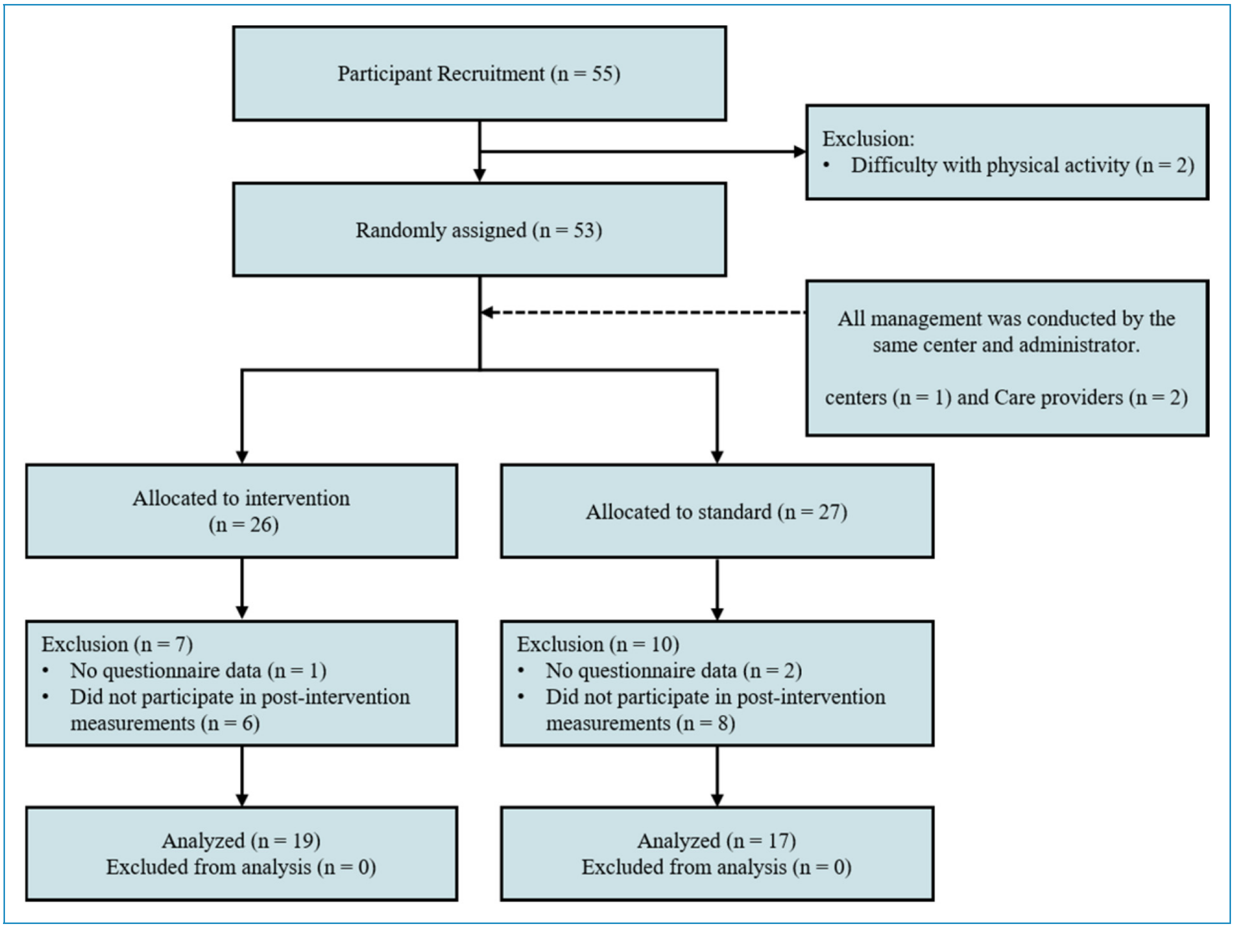

Figure 1. A flowchart of the participants.

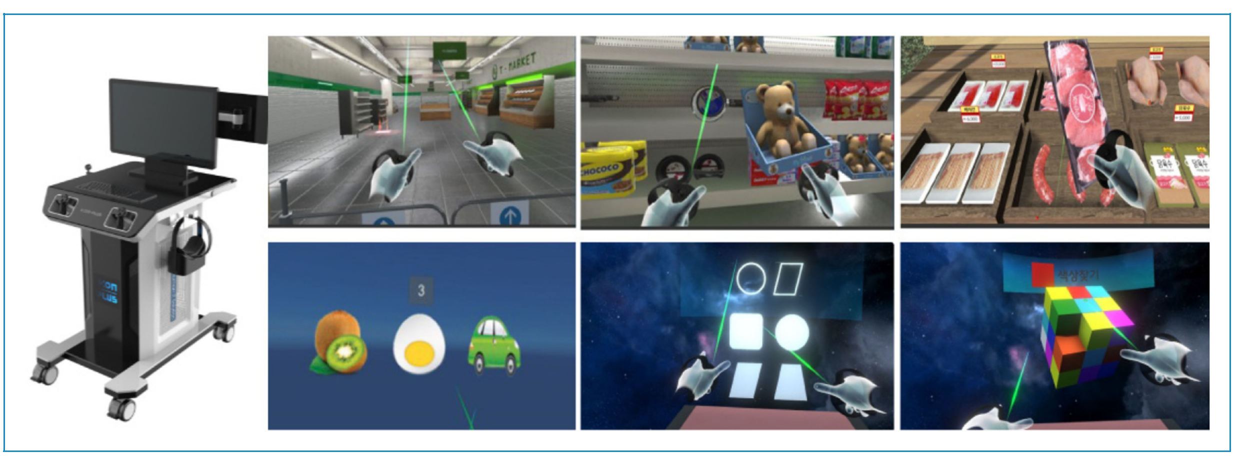

Figure 2. VR-based cognitive healthcare device and contents.

2. Motion tracking-based body activity training. < Figure 3>
3. Touch screen-based cognitive rehabilitation content. < Figure 4>

This program was conducted at a local senior welfare center, targeting women aged 65 and older. The study was carried out over a 12-week period with three sessions per week. Each session lasted 30 minutes and was

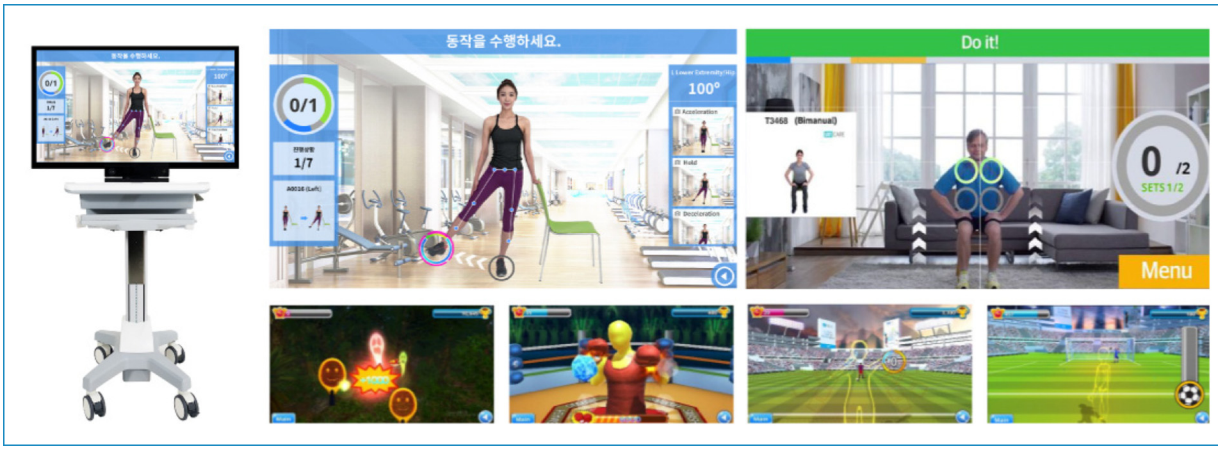

Figure 3. Motion tracking-based healthcare device and contents.

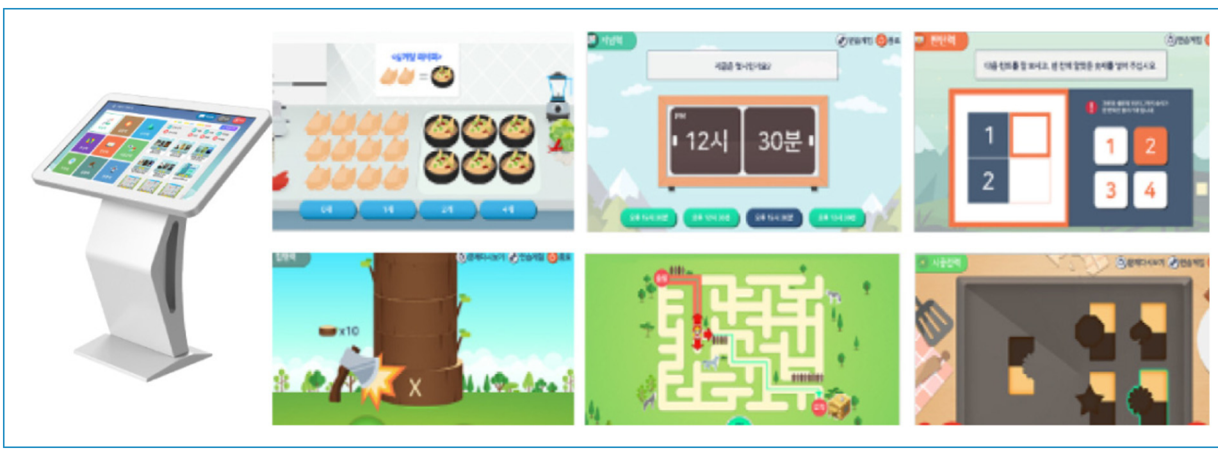

Figure 4. Touch screen-based healthcare device and contents.

conducted individually. There was no fixed sequence for the program, and participants were encouraged to use the available content based on the scheduled time of their visit each week. The amount of content delivered during the program is detailed in Table 1. The VR content provided cognitive stimulation through daily activity-based programs. The motion tracking content combined physical activity and cognitive stimulation, focusing on weight-bearing exercises without using additional weights. It was recommended that all VR and motion tracking sessions be conducted in a standing position. However, for safety reasons, participants who experienced discomfort could perform the sessions seated. The touch screen content, which offered cognitive exercises, was conducted entirely in a seated position for convenience. In the intervention setting, all participants began the program with basic-level exercises. As they consistently demonstrated good form and successfully completed each session, the program gradually increased the difficulty by adjusting the intensity, duration, or complexity of the exercises. This progressive approach allowed the participants to gradually challenge their physical capabilities while maintaining safety and engagement throughout the intervention. The control group was advised to maintain their usual lifestyle habits.

Study procedure

Preintervention measures. To collect participants' current physical information, we used body scales and bioelectrical impedance analysis. Cognitive function, depression status, and quality of life were assessed using validated questionnaires, specifically the MoCA, the Short Geriatric Depression Scale-Korean version (SGDS-K), and the WHOQOL-BREF. Both pre- and postintervention questionnaires were completed by the participants themselves; however, participants who required assistance were aided by a researcher. All researchers conducting the measurements were blinded to the group allocation of the participants.

During intervention measures. Unique identification numbers were generated for participants to manage their progress, which was recorded throughout the intervention. The VR content provided a daily life-based cognitive function enhancement training program, designed to minimize discomfort such as dizziness. The motion recognition-based exercise content recommended personalized exercise amounts, offering integrated training for both upper and lower limbs. The touchscreen-based content provided 12 types of cognitive rehabilitation training, focusing on attention, memory, and other cognitive skills. Each content component monitored user progress to tailor the subsequent sessions accordingly. (Detailed information about the content can be found at http://88care.hmit.kr/)

This study utilized a digital-based exercise program designed for older adults to perform independently. There were no dedicated exercise supervisors or active care providers overseeing the training. However, on-site personnel trained in basic first aid were present solely to ensure participant safety and offer assistance if necessary, without taking part in managing or instructing the exercise sessions. Instead, they assisted with the smooth operation of the digital program and helped coordinate scheduling for subsequent sessions.

To assess and report adherence to the exercise intervention, data was collected by tracking participant engagement throughout all sessions, specifically logging attendance, session completion rates, and any deviations from the exercise plan. Adherence was further evaluated by monitoring the frequency, duration, and intensity of each session compared to the goals set out in the exercise program.

Postintervention measures. After completing the 12-week digital health program, participants' physical information, cognitive function, depression status, and quality of life were reassessed using the same methods as the preintervention measures. Body scales and bioelectrical impedance analysis were used to collect physical information, and the MoCA, SGDS-K, and WHOQOL-BREF questionnaires were administered again. As with the preintervention phase, participants completed the questionnaires themselves, with researcher assistance provided if necessary. All researchers conducting the measurements remained blinded to the participant's group allocation.

Statistical methods

In this study, SPSS PC^{+} for Windows (version 20.0, IBM Corporation, Armonk, NY, USA) was utilized for data analysis. The following statistical methods were employed:

1. Descriptive statistics, including mean (M) and standard deviation (SD), were used to summarize all variables.
2. Two-way ANOVA was conducted to examine the mean differences of dependent variables between the Intervention Group and Control Group.
3. A paired t-test was utilized to evaluate the mean differences of dependent variables between pre- and postintervention time points.
4. A paired t-test was utilized to evaluate the mean differences of dependent variables between pre- and postintervention time points.
5. The assumptions of parametric statistical analyses were verified using the Shapiro-Wilk test to assess the normality of the data and Levene's test to evaluate the homogeneity of variances between groups. The results indicated that all assumptions were satisfied ($P > .05$).

All statistical methods were conducted using a two-sided analysis approach, with the significance level (α) set at .05.

Results

In this study, cognitive function, depression, body composition, and quality of life were measured to assess the effects of the 12-week digital training equipment program on older women.

- Primary outcomes

The primary outcomes of this study were cognitive function and depression, as the digital training intervention primarily aimed to improve these mental health indicators.

Cognitive Function: Participants in the intervention group showed a statistically significant improvement in cognitive function compared to the control group over the 12-week period ($P < .05$).

Depression: There was a significant reduction in depression scores in the intervention group compared to the control group, indicating the positive mental health benefits of the digital training program ($P < .05$).

- Secondary outcomes

The secondary outcomes included body composition and quality of life.

Body Composition: No significant interaction effects were observed in body composition between the intervention and control groups across the pre- and postintervention periods ($P > .05$).

Quality of Life: Participants in the intervention group demonstrated a significant enhancement in quality of life scores compared to those in the control group after the intervention ($P < .05$).

Demographic characteristics

The analysis of the participants' physical characteristics showed no statistically significant differences between the groups in terms of age, weight, and body composition. The characteristics of the participants in the study are presented in Table 2.

Body composition

The results of the body composition analysis, conducted to examine the intervention effects, are presented in Table 3. A main effect for group was observed in lean body mass ($P = .037$), and interaction effects were found for body fat mass ($P = .011$) and body fat percentage ($P = .010$).

Cognitive function

The results of the cognitive function changes are presented in Table 4. A comparison of pre- and postintervention measurements revealed a significant interaction effect ($P = .017$).

Depression

The interaction effect of the intervention on depression in older adults showed a significant result ($P = .017$). The detailed results are presented in Table 5.

Quality of life

The results of the analysis on the effect of the intervention on quality of life are presented in Table 6. Various outcomes were observed across the eight sub-factors. A significant main effect for the group was found in Limitation of Physical Function ($P = .001$), pain ($P < .001$), general health ($P = .001$), vitality ($P = .013$), social function ($P < .001$), and mental health ($P < .001$). Additionally, significant interaction effects were observed for physical function ($P = .009$), Limitation of Physical Function ($P = .004$), and pain ($P = .002$).

Table 2. Characteristics of the participants.

Variables	Intervention (*n*=19)	Control (*n* = 17)	*P* value
Age (years)	78.47 ± 4.83	78.5 ± 3.85	.947
Height (cm)	154.7 ± 3.86	150.92 ± 4.56	.010*
Weight (kg)	61.22 ± 5.11	58.56 ± 9.14	.283
Lean body mass (kg)	20.99 ± 1.65	19.38 ± 2.16	.017*
Body fat mass (kg)	22.01 ± 4.26	21.90 ± 6.02	.950
Body fat percentage (%)	35.74 ± 4.53	36.63 ± 4.90	.576
Body mass index (kg/m^2)	25.61 ± 2.54	25.61 ± 3.15	.997

*$P < .05$

Table 3. Changes in body composition.

Variables	Group	Pre	Post		Effect Size (95% CI)		*P* value
Weight (kg)	Intervention (*n*=19)	61.22 ± 5.11	61.64 ± 5.35	Time	0.02	(−0.45, 0.48)	.739
				group	0.44	(−0.22, 1.10)	.183
	Control (*n* = 17)	58.56 ± 9.14	57.85 ± 8.70	interactions	0.11	(−0.54, 0.77)	.185
Lean body mass (kg)	Intervention (*n*=19)	20.99 ± 1.65#	20.71 ± 2.03	Time	−0.01	(−0.48, 0.45)	.837
				group	0.69	(0.01, 1.36)	.037*
	Control (*n* = 17)	19.38 ± 2.16	19.75 ± 1.57	interactions	−0.25	(−0.90, 0.41)	.125
Body fat mass (kg)	Intervention (*n*=19)	22.01 ± 4.26	22.96 ± 5.04	Time	0.02	(−0.44, 0.48)	.670
				group	0.22	(−0.43, 0.88)	.496
	Control (*n* = 17)	21.90 ± 6.02	20.60 ± 6.64 +	interactions	0.29	(−0.37, 0.95)	.011*
Body fat percentage (%)	Intervention (*n*=19)	35.74 ± 4.53	36.98 ± 5.76	Time	0.05	(−0.42, 0.51)	.568
				group	0.13	(−0.53, 0.78)	.693
	Control (*n* = 17)	36.63 ± 4.90	34.72 ± 6.50 +	interactions	0.41	−0.25, 1.07)	.010*
Body mass index (kg/m^2)	Intervention (*n*=19)	25.61 ± 2.54	25.78 ± 2.58	Time	0.04	(−0.43, 0.50)	.465
				group	0.10	(−0.55, 0.76)	.758
	Control (*n* = 17)	25.61 ± 3.15	25.20 ± 2.95	interactions	0.15	(−0.51, 0.80)	.075

#$P < .05$: significant difference between group; +$P < .05$: significant difference between time;
*$P < .05$: significant difference main effect or interaction.

Table 4. Changes in cognitive function.

Variables	Group	Pre	Post			Effect Size (95% CI)		P value
MoCA (score)	Intervention (n-=19)	17.88 ± 6.74	19.21 ± 6.44#	+	Time	−0.04	(−0.51, 0.42)	.726
					group	0.58	(−0.09, 1.25)	.085
	Control (n = 17)	15.93 ± 3.56	14.94 ± 3.79		interactions	0.30	(−0.36, 0.96)	.017*

#$P<.05$: significant difference between group; +$P<.05$: significant difference between time;
*$P<.05$: significant difference main effect or interaction.

Table 5. Changes in depression.

Variables	Group	Pre	Post			Effect Size (95% CI)		P value
SGDS-K (score)	Intervention (n-=19)	1.61 ± 0.09#	1.56 ± 0.15	+	Time	−0.19	(−0.65, 0.27)	.405
					group	0.07	(−0.58, 0.73)	.839
	Control (n = 17)	1.52 ± 0.17	1.63 ± 0.12	+	interactions	−0.84	(−1.52, −0.15)	.017*

#$P<.05$: significant difference between group; +$P<.05$: significant difference between time;
*$P<.05$: significant difference main effect or interaction.

Discussion

Body composition

After adulthood, muscle mass and strength gradually decline. In women, these changes become particularly pronounced after menopause, where an increase in visceral fat and a decrease in fat-free mass (FFM) can lead to weight gain and an increased body fat percentage.[24] Such changes negatively affect the body composition of older women. However, previous studies have shown that all types of physical activity enhance physical function in older adults, with exercise being particularly effective in increasing muscle mass and strength, boosting metabolism, and reducing body fat.[25]

In this study, no significant changes in body composition were observed in the digital healthcare intervention group. Although a reduction in body fat in the control group suggested a potential interaction effect ($P = .11$), it is difficult to interpret this as a clinically significant change. These results partially align with previous studies. Meta-analyses on combined exercise interventions showed no significant changes in muscle mass or fat percentage. However, studies focusing solely on resistance or aerobic exercises have reported significant improvements in muscle mass and reductions in body fat.[25]

Previous research by Lu et al. (2021) demonstrated that combined exercise had a positive impact on physical function in older adults, including improvements in gait speed.[26] In contrast, Yi et al. (2024) found that while combined exercise could improve cognitive function, balance, and muscle strength in older adults, integrating cognitive activities into the intervention may reduce exercise intensity and limit muscle strength gains.[27] This could explain, in part, the lack of significant body composition changes in the current study.

The digital healthcare intervention in this study combined physical and cognitive activities. The exercises mainly consisted of weight-bearing movements, as well as cognitive tasks necessary for daily life (see Figure 3). The intervention was designed to be safe, engaging, and suitable for independent participation by older adults. However, it is possible that the intensity and frequency of the exercise program were insufficient to elicit significant changes in body composition. Previous studies have reported greater effects with interventions lasting 8–24 weeks, with sessions ranging from 1 to 5 times per week and 30 to 80 minutes per session, suggesting that the relatively lower volume and intensity in this study may have limited its effectiveness.

Furthermore, this study did not assess variables related to physical function in older adults. Future studies on exercise interventions for older adults should consider measuring not only body composition but also a range of physical function variables to better understand the comprehensive effects of the intervention.

Cognitive function

Cognitive decline is a commonly observed change during the normal aging process. These changes can be mitigated by noninvasive strategies such as physical exercise and providing a cognitively stimulating environment, which counteracts various structural and functional alterations associated with aging.[28]

In the preintervention cognitive function measurement, the intervention group (17.88 ± 6.74) and the control group (15.93 ± 3.56) showed no statistically significant

Table 6. Changes in quality of life.

Variables	Group	Pre	Post			Effect Size	(95% CI)	P value
Physical Function	Intervention (n=19)	73.46 ± 18.76	75.56 ± 18.32#		Time	0.21	(−0.25, 0.67)	.061
					group	0.63	(−0.04, 1.30)	.051
	Control (n = 17)	67.33 ± 22.35	55.66 ± 23.38	+	interactions	0.47	(−0.19, 1.13)	.009**
Limitation of Physical Function	Intervention (n=19)	74.54 ± 26.88	91.91 ± 10.97#	+	Time	−0.10	(−0.56, 0.36)	.755
					group	0.93	(0.24, 1.61)	.001**
	Control (n = 17)	67.50 ± 25.78	53.33 ± 30.28		interactions	0.91	(0.23, 1.60)	.004**
Pain	Intervention (n=19)	16.51 ± 16.31#	29.41 ± 27.78#	+	Time	0.02	(−0.44, 0.48)	.776
					group	−1.50	(−2.24, −0.76)	.001***
	Control (n = 17)	62.66 ± 19.51	47.33 ± 20.14	+	interactions	0.93	(0.24, 1.62)	.002**
General health	Intervention (n =19)	50.59 ± 6.42#	49.41 ± 8.80#		Time	0.08	(−0.38, 0.54)	.658
					group	1.02	(0.32, 1.71)	.001***
	Control (n = 17)	38.66 ± 18.74	38.00 ± 7.45		interactions	-0.03	(−0.69, 0.62)	.902
Vitality	Intervention (n=19)	50.28 ± 9.42#	53.67 ± 13.67		Time	-0.03	(−0.49, 0.43)	.936
					group	-0.69	(−1.37, −0.02)	.013*
	Control (n = 17)	63.75 ± 16.26	60.83 ± 18.54		interactions	0.30	(−0.35, 0.96)	.289
Social Function	Intervention (n=19)	37.03 ± 7.27#	40.58 ± 5.23#		Time	-0.02	(−0.48, 0.44)	.969
					group	-2.06	(−2.87, −1.25)	.001***
	Control (n = 17)	68.66 ± 14.08	65.33 ± 21.75	+	interactions	0.36	(−0.30, 1.02)	.222
Limitation of Emotional Function	Intervention (n-=19)	80.26 ± 28.32	92.15 ± 11.93		Time	-0.18	(−0.64, 0.29)	.470
					group	0.07	(−0.59, 0.72)	.798
	Control (n = 17)	87.22 ± 21.62	82.22 ± 24.27	+	interactions	0.53	(−0.13, 1.20)	.083
Mental Health	Intervention (n=19)	80.33 ± 16.62#	80.33 ± 9.24#		Time	<0.01	(−0.46, 0.46)	.994
					group	1.49	(0.75, 2.23)	.001***
	Control (n = 17)	60.92 ± 7.31	60.88 ± 16.34		interactions	<0.01	(−0.65, 0.66)	.994

#$P<.05$: significant difference between group; +$P<.05$: significant difference between time;
*$P<.05$, **$P<.01$, ***$P<.001$: significant difference main effect or interaction.

differences. However, after the exercise intervention, there were slight changes in the intervention group (19.21 ± 6.44) and the control group (14.94 ± 3.79). The results revealed a significant interaction effect ($P = 0.017$), suggesting that the 12-week digital healthcare intervention had a positive impact on cognitive function.

However, MoCA's use in intervention studies requires consideration of its responsiveness. Responsiveness refers to the tool's ability to detect clinically meaningful changes over time, particularly in response to an intervention. While MoCA has been validated for screening, evidence on its responsiveness to intervention-related cognitive changes is still being developed. Some studies suggest that MoCA is effective in detecting cognitive changes in various neurological conditions and following interventions, but further research is needed to establish consistent thresholds for clinically relevant changes.[29]

Although initial differences in cognitive function scores may have influenced the results, both groups were classified within the same MoCA scoring category, and preintervention measurement differences were not statistically significant. Therefore, these initial differences are unlikely to have significantly impacted the overall findings. However, it is essential for researchers to carefully consider this criterion depending on the specific population and the type of intervention being studied. The responsiveness of MoCA should be further supported by longitudinal data and clinical trials, particularly those focused on detecting subtle cognitive changes over time.

Previous research indicates that cognitive activities, including problem-solving programs like games, can significantly improve cognitive abilities.[30] In interventions that combine cognitive and physical exercises through exergames, activities that involve standing position focusing on stepping movements are more effective for improving cognitive function than seated activities. It is recommended to use a combination of home and field settings, group training, and fully supervised training methods. Additionally, to stimulate the 'facilitation effect,' it is suggested that exercise intensity should be at a moderate level or higher, as this plays a crucial role in the effectiveness of the intervention.[9] In this study, three types of digital healthcare programs (VR, motion tracking, and touch screen) were utilized in the intervention. Excluding the touch screen content, both the VR and motion tracking content encouraged users to maintain a standing posture, similar to previous research. However, the intervention setting (see Figure 5) had a limited space of approximately $1\ m^2$ per content, which restricted the range of activities. Additionally, to promote independent engagement, the intervention was conducted without the direct involvement of an instructor. The combination of these factors may have impacted the effectiveness of the intervention.

The digital healthcare intervention in this study integrated both cognitive training and physical activity components. Previous research has proposed certain recommendations for exergame interventions, including an exercise frequency of three sessions per week, a duration of 15–30 minutes, a training volume of approximately 150 minutes per week,

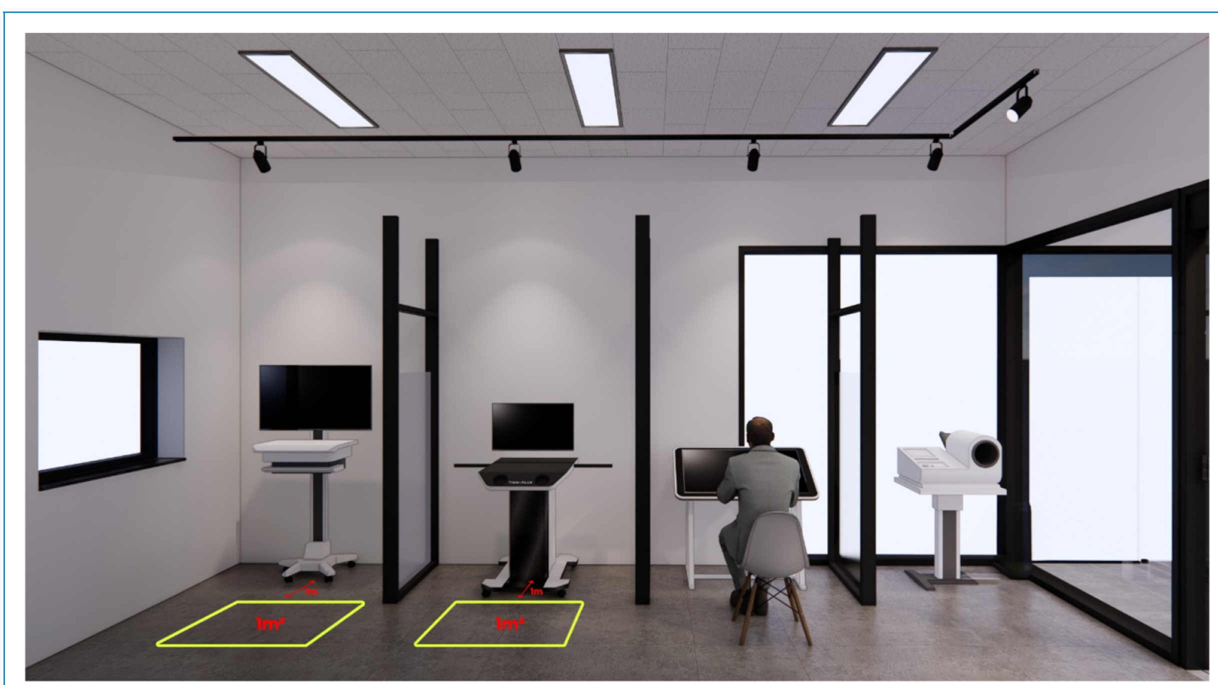

Figure 5. Digital healthcare zone.

and moderate-intensity exercise.[31] However, this study only met some of these conditions, excluding the specified training volume and intensity. To achieve the recommended 30 minutes of exercise per session, participants would have needed to visit the exercise location daily. Considering the study's attrition rate of 32%, this presents challenges for older adults to balance their personal lives with more than three visits per week. Additionally, to ensure appropriate exercise intensity, the use of additional weights or an increase in the number of repetitions would have been necessary. However, these were not included in the study due to safety considerations for the older participants, which may contribute to the limited outcomes observed.

Heisz et al. (2017) demonstrated that combining physical exercise with cognitive training resulted in more significant improvements in memory performance compared to either intervention alone. Their findings highlight that the synergistic effects of combined training approaches offer substantial cognitive benefits.[32] Additionally, evidence supports the bidirectional relationship between physical activity and cognitive function, suggesting that physical exercise can improve cognitive decline in older adults.[33,34] This suggests that for individuals with mild cognitive impairment, a combined approach of physical exercise and cognitive training may be a more effective strategy for enhancing cognitive abilities compared to isolated interventions. Consequently, participation in the 12-week digital healthcare intervention combining cognitive training and physical activity led to cognitive improvements in older adults; however, the results were modest. It is believed that greater effects could have been observed had the intervention been more rigorously implemented, as suggested by previous studies. While the MoCA has proven to be a reliable and valid tool for cognitive screening, additional research and references regarding its responsiveness to intervention-related changes are needed to fully justify its use in interventional research.

Depression

The decline in cognitive and physical functions associated with aging often leads to restrictions in social activities, which negatively impacts the psychological well-being of older adults. Depression, in particular, is a significant concern in the psychological state of older adults and has been widely recognized as a social issue requiring various interventions.[35]

The study observed a statistically significant interaction effect in the depression indicators between the intervention and control groups ($P = 0.017$). Prior to the intervention, the intervention group had higher depression scores compared to the control group. However, postintervention measurements showed that the intervention group had lower depression scores than the control group, demonstrating a statistically significant difference.

This study combined cognitive training with physical activity. Physical activity interventions are known to have positive effects on improving physical fitness and reducing feelings of depression. Previous research inverse correlation between exercise levels and depression symptoms, suggesting that exercise can positively affect depression through neurophysiological mechanisms.[36] Additionally, a study on camera-sensing exercise programs for individuals with depression reported that such programs alleviated depression and improved physical health, leading to a positive shift in attitudes towards regular physical activity and exercise participation, ultimately contributing to the prevention of depression in older adults.[37] The results of this study align with these previous findings, indicating that the camera-sensing-based exercise program likely contributed to the alleviation of participants' depression.

Similarly, cognitive activities using touchscreens have shown improvements in cognitive and daily functioning, which in turn reduced symptoms of depression.[38] Research also highlights that immersive experiences provided through VR can expose older adults to new environments, enhancing life satisfaction and reducing depressive symptoms.[39]

The digital healthcare program used in this study integrated tools that have shown positive effects in previous research. Participants had the opportunity to engage in cognitive training using VR and touchscreens and to promote physical activity through motion tracking. The intervention effectively enhanced various physical and mental functions of the participants, suggesting potential positive applications beyond the primary goals of the study.

Additionally, the intervention program was conducted individually with scheduled visit times. Conversations among participants during center visits and waiting times facilitated social interactions, which have been shown to positively affect emotional stability and well-being in older adults.[40] Digital healthcare served as both an intervention tool and a platform for older adults to engage in social communication networks, potentially contributing to the improvement of participants' depression.

Therefore, the digital healthcare program could be seen as a social device capable of providing cognitive and physical activity training along with social interaction opportunities.

Quality of life

This study demonstrated that participants in the digital healthcare program showed statistically significant differences in several subdomains (Physical Function = 0.009, Limitation of Physical Function = 0.004, Pain = 0.002) of quality of life. Prior research indicates that physical activity and cognitive are crucial factors influencing the quality of life in older adults, particularly emphasizing the importance of the health status of older adults.[41]

Health status, as a factor reflecting overall well-being, is effectively managed and improved through regular physical activity or exercise programs.[42]

Blumenthal et al. (2017) reported that regular physical activity not only enhances physical health but also positively improves mental factors such as depression and anxiety. These results were shown to have a positive impact on mental health through opportunities for social participation.[43]

Bott et al. (2018) reported that interventions combining exercise and cognitive training are effective in preventing or delaying cognitive impairment in older adults, as well as managing physical health conditions such as diabetes, reducing cardiovascular risk, and alleviating pain. These digital lifestyle interventions have been shown to be effective tools for improving the mental and physical health of participants and are suitable for continuous monitoring. Furthermore, the study suggested that interventions delivered via mobile phones and internet access devices are not only effective but can also be utilized in community centers.[11] Such physical and cognitive enhancements can serve as significant factors in improving the overall quality of life for older adults.

Previous research has provided evidence that combined interventions (cognitive and physical) are more effective than single interventions (cognitive or physical) for older adults without cognitive impairments.[44] Exergaming, which combines physical and cognitive activities, has been shown to provide overall cognitive benefits for older adults with mild cognitive impairment.[45] Additionally, training that integrates physical exercise with cognitive stimulation is considered more effective than either activity alone and has been proposed as a successful intervention strategy.[46] However, Cacciata et al. (2019) found that while exergaming is an engaging intervention, it was difficult to obtain conclusive results on its positive impact on the quality of life of older adults, highlighting the need for further research.[47]

However, in this study, no significant changes were observed in several subdomains of quality of life. While combining physical activity with cognitive training is generally recommended to enhance the quality of life in older adults, there is a need for programs that offer personalized coping strategies.

As suggested by previous research, utilizing digital-based cognitive and physical exercise tools that reduce social opportunity costs could be valuable. Future studies should focus on analyzing the broad effects of these digital interventions on cognitive function, physical abilities, and social activities in older adults with dementia. This approach could help in developing more effective, individualized interventions that address the specific needs of this population and ultimately improve their overall quality of life.

Limitation

This study has several limitations that should be considered when interpreting the results. Firstly, the focus on female older adults aged 65 and above may limit the generalizability of the findings to other demographic groups, such as older men or younger older adults.[48]

Moreover, the relatively small sample size and the high attrition rate of 32% may impact the reliability and generalizability of the results, as these factors can introduce biases and reduce statistical power. The high attrition rate can be attributed to various health-related challenges faced by older adults, such as physical ailments, cognitive decline, or hospitalization, which could lead to dropout.

In this study, participants were required to meet specific health standards, including the absence of significant cognitive disorders and only minor musculoskeletal or cardiovascular issues. The exclusion of those with more severe impairments means these findings may not be fully applicable to older adults with more advanced health conditions. Broader studies that include participants across a wider range of health statuses could provide more widely applicable insights.[49]

Furthermore, the intervention, which combined physical and cognitive activities, may have been challenging for some participants, potentially leading to fatigue or diminishing motivation over time. For participants with mild cognitive impairment, motivation levels might fluctuate, which could further affect their consistent commitment to the program. Addressing these limitations could enhance the applicability and robustness of future interventions targeting older adults.

Previous research has reported similar attrition rates (approximately 20%) and participation levels (70–80%) due to factors such as mortality, hospitalizations, fractures, falls, and other nonserious or serious events. It has been suggested that offering home-based program environments, along with involvement from caregivers, family members, or home-based instructors, could reduce attrition rates in studies involving older adults, including those with mild cognitive impairment.[50]

To address these issues in future research, several strategies are recommended. Enhancing participant support through ongoing communication, encouragement, and assistance can help maintain engagement. Implementing a buddy system or establishing peer support groups may also foster motivation and accountability among participants. Furthermore, offering flexible scheduling for sessions or incorporating virtual participation options can accommodate the varying needs and schedules of older adults, potentially reducing dropout rates.

Lastly, the study specifically included female older adults with mild cognitive impairment who were mobile, capable of communication, and motivated to participate. This limitation restricts the applicability of the findings to other populations with differing levels of cognitive impairment, mobility, or motivation. Additionally, the 12-week intervention period and the subjective measures of intervention intensity may have been insufficient to produce significant effects. Therefore, longer-term studies with objectively measured intervention intensity are needed to better understand the impact of such programs.

Conclusions

Regular participation in exercise is known to increase muscle mass and reduce body fat. The appropriate intensity and volume of exercise are crucial for enhancing muscle mass and achieving proper fat reduction in older adults. However, in this study, a reduction in body fat was observed without a corresponding increase in muscle mass. This discrepancy might be attributed to the lack of muscle activity and energy expenditure due to insufficient exercise, which could be influenced by age-related metabolic changes affecting muscle mass and body fat.

Additionally, the virtual reality and touchscreen activities provided not only increased physical activity but also offered cognitive stimulation. Cognitive stimulation can be effective in preventing depression and improving mental health in older adults.

Although the digital healthcare program used in this study was designed as an individualized activity program, it was found to increase opportunities for social interaction among older adults. These physical and social activities were associated with emotional interactions and closely linked to improvements in cognitive function. The health status and cognitive function of older adults significantly impact their quality of life, and participation in regular physical activity and cognitive training programs has been shown to be effective in enhancing quality of life. Digital healthcare plays a crucial role in maintaining and improving the health of older adults by providing regular programs that address both physical activity and cognitive function.

However, when implementing digital-based interventions for older adults, several challenges need to be considered, including physical discomfort, technology acceptance, safety concerns, and cost. To understand the long-term effects of such digital interventions, optimize intervention design, and identify the specific populations that would benefit the most, further research is required.

These findings highlight that while the digital training program did not significantly affect body composition, it had a notable impact on improving cognitive function and reducing depression, along with enhancing quality of life.

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