# Clinical effectiveness of a exergame-based exercise via RingFit Adventure to prevent and postpone frailty and sarcopenia among elders in rural long-term care facilities: a randomized controlled trial

Sheng-Hui Tuan, Lin-Hui Chang, Shu-Fen Sun, Chien-Hui Li, Guan-Bo Chen, Yi-Ju Tsai

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Sheng-Hui Tuan[1, 2, 3] MD; Lin-Hui Chang[1, 4] Prof Dr; Shu-Fen Sun[5, 6] MD; Chien-Hui Li[2] MS; Guan-Bo Chen[7] MD; Yi-Ju Tsai[1] Prof Dr

[1]Institute of Allied Health Sciences College of Medicine National Cheng Kung University Tainan TW
[2]Department of Rehabilitation Medicine Cishan Hospital Ministry of Health and Welfare Kaohsiung TW
[3]Department of Physical Medicine and Rehabilitation College of Medicine Kaohsiung Medical University Kaohsiung TW
[4]Department of Occupational Therapy College of Medicine National Cheng Kung University Tainan TW
[5]Department of Physical Medicine and Rehabilitation Kaohsiung Veterans General Hospital Kaohsiung TW
[6]School of Medicine College of Medicine National Yang Ming Chiao Tung University Taipei TW
[7]Department of Internal Medicine Kaohsiung Armed Forces General Hospital National Defense Medical Center Kaohsiung TW

**Corresponding Author:**
Yi-Ju Tsai Prof Dr
Institute of Allied Health Sciences
College of Medicine
National Cheng Kung University
No.1,
University Rd.
Tainan
TW



## *Abstract*

**Background:** Frailty and sarcopenia are more prevalent among LTCF residents than community dwellers, with exercise, especially multicomponent and PRT, being essential for management. However, LTCFs, particularly in rural areas, face challenges in implementing structured exercise programs due to healthcare professional shortages. The Nintendo Switch RingFit Adventure (RFA) exergame (exergame-RFA), which combines resistance, aerobic, and balance exercises, offers a potential solution by boosting motivation and reducing staff intervention needs.

**Objective:** We aimed to evaluate the clinical effectiveness of the exergame-RFA in improving muscle mass and functional performance among elderly LTCF residents.

**Methods:** This was a randomized controlled trial, conducted from August 2022 to September 2023, involved elders ?60 years in rural southern Taiwan LTCFs. Participants were randomized into an intervention group (exergame-RFA plus standard care) or a control group (standard care alone). The intervention, conducted seated with arm fit skills and trunk control exercises via RFA, lasted 30 minutes, twice weekly for 12 weeks. Primary outcomes measured were the study of osteoporotic fracture index, appendicular skeletal muscle mass index, handgrip strength, and gait speed. Secondary outcomes included box and block test, (BBT), maximal voluntary isometric contraction of dominant upper extremity (MVIC), muscle thickness under sonography (sono-thickness), ADLs by the Kihon Checklist, quality of life by the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36), and the cognition by brain health test (BHT). We employed an intention-to-treat analysis, incorporating a simple imputation technique in statistical analysis. A mixed analysis of variance, with time as a within-subject factor and intervention as a between-subject factor, was used to compare the training effects on outcomes.

**Results:** The study recruited 96 individuals, with 60 undergoing randomization and 55 completing the study. Significant group X time interactions were observed in the exergame-RFA group in all primary outcomes (all $p < .01$, except $p = .011$ for HGS) and most secondary outcomes, including MVIC of biceps and triceps muscle, sono-thickness of biceps muscle, BBT, Kihon checklist, and BHT.

**Conclusions:** Exergame-RFA significantly improve muscle mass, strength, and functional performance among elderly residents of rural LTCFs, offering a novel approach to addressing frailty and sarcopenia. Clinical Trial: This trial was registered at

ClinicalTrials.gov (NCT05360667)

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# Original Manuscript

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Sheng-Hui Tuan [1,2,3], M.D.; Ling-Hui Chang[1,4], PhD.; Shu-Fen Sun[5,6], M.D.; Chien-Hui Li [2], M.S; Guan-Bo Chen[7], M.D.; Yi-Ju Tsai[1,8], PhD.

[1] Institute of Allied Health Sciences, College of Medicine, National Cheng Kung University, No.1, University Rd., Tainan City 701, Taiwan (R.O.C)

[2] Department of Rehabilitation Medicine, Cishan Hospital, Ministry of Health and Welfare, No.60, Zhongxue Rd., Kaohsiung City 842, Taiwan (R.O.C.)

[3] Department of Physical Medicine and Rehabilitation, School of Medicine, College of Medicine, Kaohsiung Medical University, No.100, Shih-Chuan 1st Rd, Kaohsiung City, 807, Taiwan (R.O.C.)

[4] Department of Occupational Therapy, College of Medicine, National Cheng Kung University, No.1, University Rd., Tainan City 701, Taiwan (R.O.C)

[5] Department of Physical Medicine and Rehabilitation, Kaohsiung Veterans General Hospital, No.386, Dazhong 1st Rd., Kaohsiung City 813, Taiwan (R.O.C.)

[6] School of Medicine, College of Medicine, National Yang Ming Chiao Tung University, No. 155, Sec. 2, Linong St., Taipei City 112, Taiwan (R.O.C.)

[7] Department of Internal Medicine, Kaohsiung Armed Forces General Hospital, National Defense Medical Center, No.2, Jhongjheng 1st Rd, Kaohsiung City 802, Taiwan (R.O.C)

[8] Department of Physical therapy, College of Medicine, National Cheng Kung University, No.1, University Rd., Tainan City 701, Taiwan (R.O.C)

Corresponding author: Yi-Ju Tsai, Ph.D., Institute of Allied Health Sciences, College of Medicine, National Cheng Kung University, No.1, University Rd., Tainan City 70101, Taiwan (R.O.C.), Phone number: +886-6-2353535 ext 5720, Fax number: +886-6-2367981, e-mail: yjtsaincku2024@gmail.com

## Abstract

*Background:* Frailty and sarcopenia are geriatric syndromes of increasing concern, associated with adverse health outcomes. They are more prevalent among long term care facilities (LTCF) users than community dwellers. Exercise, especially multicomponent and progressive resistance training, is essential for managing these conditions. However, LTCFs, particularly in rural areas, face challenges in implementing structured exercise programs due to healthcare professional shortages. Moreover, elderly individuals often become bored with repetitive exercise training and may lose interest over time. The Nintendo Switch RingFit Adventure (RFA) exergame is a novel exergame, which combines resistance, aerobic, and balance exercises, offers a potential solution by boosting motivation in an immersive manner and reducing staff intervention needs.

*Objective:* We aimed to evaluate the clinical effectiveness of an exergame-based exercise training program delivered via RFA (exergame-RFA) in improving muscle mass and functional performance among elderly LTCF users.

*Methods:* This was a randomized controlled trial, conducted from August 2022 to September 2023, involved elders ≥60 years in rural southern Taiwan LTCFs. Participants were randomized into an intervention group (exergame-RFA plus standard care) or a control group (standard care alone). The intervention, conducted

seated with arm fit skills and trunk control exercises via RFA, lasted 30 minutes, twice weekly for 12 weeks. Primary outcomes measured were the study of osteoporotic fracture index and criteria of sarcopniea including appendicular skeletal muscle mass index, handgrip strength, and gait speed. Secondary outcomes included box and block test, (BBT), maximal voluntary isometric contraction of dominant upper extremity (MVIC), muscle thickness under sonography (sono-thickness), ADLs by the Kihon Checklist, quality of life by the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36), and the cognition by brain health test (BHT). We employed an intention-to-treat analysis, incorporating a simple imputation technique in statistical analysis. A mixed analysis of variance, with time as a within-subject factor and intervention as a between-subject factor, was used to compare the training effects on outcomes.

*Results:* The study recruited 96 individuals, with 60 undergoing randomization and 55 completing the study. Significant group X time interactions were observed in the intervention group in all primary outcomes (all $p < .01$, except $p = .011$ for HGS) and most secondary outcomes, including MVIC of biceps ($p = .004$) and triceps brachii ($p < .001$) muscle, sono-thickness of biceps muscle ($p < .001$), BBT ($p < .001$), Kihon checklist (physical function $p = .013$, mood status $p = .003$, total $p= .003$), and BHT ($p < .001$ ).

*Conclusions:* Exergame-RFA significantly improve muscle mass, strength, and functional performance among elderly users of rural LTCFs, offering a novel approach to addressing frailty and sarcopenia.

*Trial Registration:* ClinicalTrials.gov NCT05360667; https://clinicaltrials.gov/study/NCT05360667

*Keywords:* exergame; RingFit Adventure; sarcopenia; frailty; long term care; multicomponent training

## Introduction

Global aging is intensifying due to rapid socioeconomic advances and longer lifespans. By 2025, it's predicted that Taiwan will evolve into a super-aged society, with over 20% of its population being 65 or older[1]. This increase in the elderly population brings multiple health challenges, including aging, chronic diseases, cognitive decline, malnutrition, diminished physical fitness, and psychosocial issues. Aging and inactivity lead to decreases in muscle mass, structure, and strength[2], with individuals over the age of 50 losing muscle at a rate of 1 to 2% annually[3]. This contributes to sarcopenia—gradual decline in muscle mass, strength, and physical performance that occurs as individuals age[4]—and frailty, a state of heightened vulnerability due to the decline in multiple physiological systems' reserve and function[4].

Frailty and sarcopenia are significant concerns globally, profoundly influencing older adults' physical capabilities, health risks, quality of life, and longevity[5, 6]. In Taiwan, frailty and sarcopenia affect 17.6 %[7] and 4.1% - 9.3%[8] of community-dwelling elderly, respectively. Notably, these conditions are more prevalent among institutionalized individuals who use long-term care facilities (LTCFs). Frailty rates can reach 79.4% in nursing homes[9]. Sarcopenia rates vary from 17.7% to 73.3% in long-term nursing facilities[10], and from 22% to 87.1% in daycare centers[11]. The

higher prevalence of conditions among older adults in LTCFs is linked to residents' advanced age, more severe health problems, and increased dependence on assistance for daily activities[11].

The current gold standard for managing frailty and sarcopenia focuses on preserving skeletal muscle mass and maintaining muscle strength[12]. Resistance training (RT), particularly progressive resistance training (PRT), combined with multicomponent exercises, is supported by moderate to high-quality evidence[13, 14]. This evidence highlights their effectiveness in increasing muscle mass, strength, and physical performance in older adults with frailty and sarcopenia[14, 15]. When it comes to exercise training, it should be consistently performed at a slightly challenging level of intensity. However, resource limitations, particularly in staffing, present considerable challenges to systematically implementing regular exercise programs in LTCFs[16], especially those in rural areas. Exergames, which are video games necessitating whole-body player engagement, could address the aforementioned issues. They provide real-time interactivity [17] and engaging, multisensory environments, facilitating immersive experiences through extensive body movements[18]. The gamification and enticing environments of exergames motivate older adults, enhancing their engagement to physical exercises[19]. As a result, the incorporation of exergames reduces the necessity for extensive staff involvement in interventions,

motivates patients towards more vigorous activities, and boosts their motivational levels.

While the clinical effectiveness of the allocation of exergames among community-dwelling elders is recognized[20, 21], their efficacy within LTCFs remains underexplored. Most research focuses on improvements in health-related quality of life (HRQoL), cognitive functions, and overall functional status[22, 23]. The literature mainly discusses exergames designed for aerobic and balance training, with limited incorporation of PRT principles. The introduction of Nintendo's Ring Fit Adventure® for the Nintendo Switch® (RFA) marks a significant evolution in exergaming, combining aerobic, strength, and balance training tailored to users' individual needs[24]. Despite its apparent potential, detailed empirical studies to fully ascertain its benefits are still forthcoming. Our team proposed and initiated the EXPPLORE trial[25], aiming to investigate the feasibility and clinical application of RFA for elders in rural LTCFs. This study presents the outcomes of that protocol.

## Methods

### Study design and participants

This study was a prospectively randomized controlled trial conducted from August 2022 to September 2023. Participants were recruited from LTCFs, including daycare

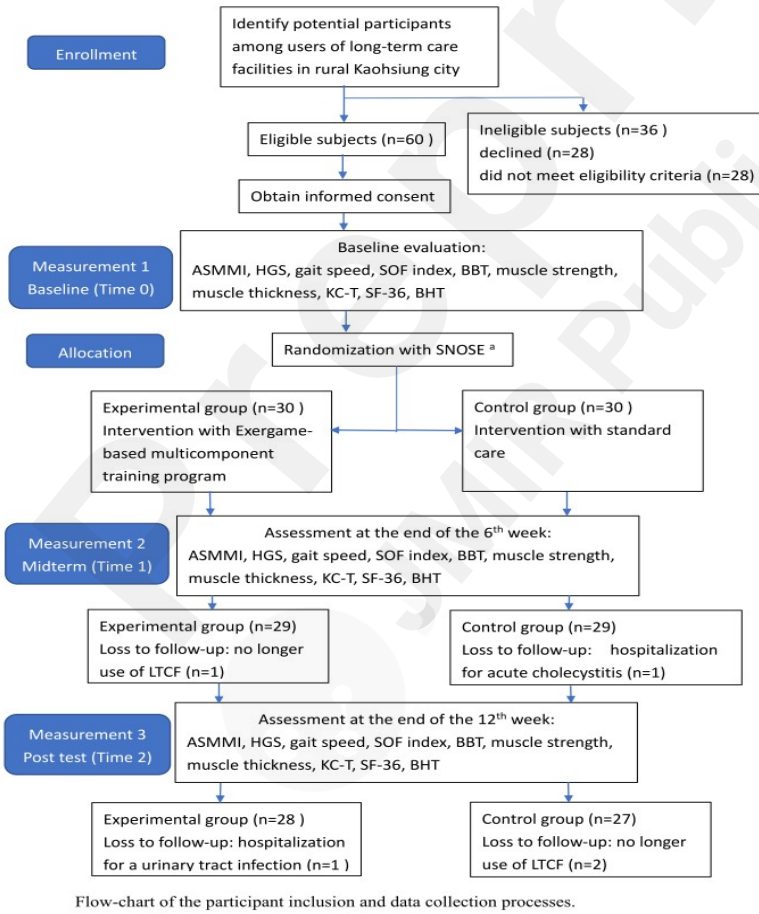
centers and nursing homes, in rural areas of Kaohsiung city, Taiwan. Eligibility criteria included being aged 60 years or above, residing in or attending LTCFs for at least one month, having the ability to understand and communicate in Chinese or Taiwanese, possessing adequate cognitive abilities as determined by the researchers to provide informed consent, and actively participating in the exergame-based exercise and data collection process. Additionally, participants needed to be capable of remaining seated for over 50 minutes during the training session and able to complete the gait speed measurement. Individuals diagnosed with significant cardiopulmonary diseases, on regular oxygen supplementation, with unmanaged hypertension, recent infections, fractures, or other conditions that would contraindicate exercise participation according to the American College of Sports Medicine (ACSM) guidelines[26], were excluded.

Participants were divided equally into the intervention and control groups with allocation ratio 1:1. The intervention group underwent standard care combined with RFA for 12 weeks, whereas the control group continued with the usual care typically provided in LTCFs. In the control group, traditional sedentary activities common in LTCFs, like singing, table games, and gardening, were replaced with RFA training sessions. The duration allocated for activities was kept consistent across both groups.

A flowchart detailing the study is presented in Figure 1. This current study was

conducted under the published protocol of the EXPPLORE (using **EX**ergame to **P**revent and **P**ostpone the **LO**ss of muscle mass, muscle strength, and functional performance in **R**ural **E**lders) EXPPLORE trial (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9792490/; DOI: 10.3389/fmed.2022.1071409)[25].

*Figure1. Flow-chart of the participant inclusion and data collection processes of this study*




Flow-chart of the participant inclusion and data collection processes.
[a] sequentially numbered, opaque, sealed envelopes

ASMMI, appendicular skeletal muscle mass index; HGS, handgrip strength; SOF index, study of osteoporosis index; BBT, box and block test; KC-T, Kihon checklist Taiwan version; SF-36, short form 36 questionnaire; BHT, brain health test

## Randomization and Blinding

Randomization was achieved using sequentially numbered, opaque, sealed envelopes (SNOSE) that contained the group assignment numbers. These envelopes were prepared by an independent individual and numbers of the envelopes were generated by the other individual who was not involved in the clinical aspects of the study to ensure blinding to the research proceedings. After verifying eligibility based on the inclusion and exclusion criteria, participants were randomized equally between the intervention and control groups. Given the nature of the study and the distinct characteristics of the interventions, blinding health professionals in and participants of the LTCFs to the treatment conditions was not possible. However, to maintain an objective evaluation and minimize bias, both the assessors conducting the outcome measurements and the data analyst interpreting the results were blinded throughout the duration of the study.

## Contents of the training program in the intervention group

The training program focused on PRT and functional movements, primarily targeting the upper extremities, using the "RFA" for delivery (exergame-RFA). The RFA system requires a Nintendo Switch console, a Ring-Con (a Pilates ring held by the user), a Joy-Con wireless controller (attached to both the Ring-Con and a leg strap worn by the player), and a display screen, as shown in Figure 2.

*Figure 2. Components of Nitendo Switch RingFit (which included Ring-Con, a Pilates ring the user holds(A); Joy-Con, a wireless controller, which should be placed on the Ring-Con and affixed into a Leg Strap (C) on the thigh of the player)*


In RFA's Adventure Mode, players moved through the game by performing physical activities like jogging or squatting. Given the increased fall risk among LTFC residents[27], we utilized RFA's knee assist mode, making the game more accessible. The knee assist is a virtual support built-in the RFA. It provides support during exercises requiring stepping, kneeling or squatting, making them more manageable for players with physical limitations. By adjusting exercise intensity and providing support to the knees, it enhances accessibility and inclusivity, allowing a wider range of players to enjoy the game's fitness benefits. In RFA's battle mode, players engaged in aerobic, resistance training, and yoga exercises involving the full body to advance.

Players were rewarded based on exercise volume, encouraging skill improvement.

The exergame-RFA regimen was scheduled twice weekly, with sessions 48 hours apart, lasting 50 minutes: 10 minutes for warm-up and cool-down each, and 30 minutes for the main exercise. This was maintained over a 12-week period, with each session overseen by a qualified therapist. Six "fit skills", deriving from the game's built-in movement dataset, focused on upper extremity and trunk training were included, with participants using three skills during battle mode to defeat opponents. A detailed table illustrates the exergame-based exercises, highlighting targeted muscle groups and joint movements was provided in the Table 1 in the multimedia appendix 1. Target intensity of the training was set at a level of 13 (somewhat hard) on the Borg Rating of Perceived Exertion scale (RPE), with progression automatically adjusted by RFA based on each player's performance (details on RFA content, gameplay steps, and auto-adjustment mechanisms are in the supplementary file). Table 2 in the multimedia appendix 1 outlines the RFA-exergame exercise prescription using the FITT-VP principle by ACSM[26].

## Contents of the standard care in the control group

For the control group, standard was provided in accordance with the routine practices of the LTCFs. This included group-based activities like calisthenics

(modified for seated positions), horticultural therapy, and sedentary group activities such as tabletop games. These sessions, led by a therapist, occurred twice a week, with each session lasting from 30 to 60 minutes, depending on the activity.

## Outcomes measured

All participants underwent three distinct assessments. The initial assessment was conducted at baseline (referred to as Time 0) prior to randomization. Subsequent evaluations took place at the end of the 6th (Time 1) and 12th (Time 2) weeks post-intervention, respectively. The selected primary outcomes for this study were based on the diagnostic criteria for sarcopenia as proposed by the the Asian Working Group for Sarcopenia (AWGS). These included the appendicular skeletal muscle mass index (ASMMI), dominant hand grip strength (HGS), and customary gait speed. Additionally, the study of osteoporotic fractures index (SOF index), serving as an indicator of frailty status, was also designated as a primary outcome.

The secondary outcomes for this study encompassed several dimensions, including the muscle strength [indicated by the maximal voluntary isometric contraction (MVIC) of the biceps brachii and triceps brachii muscles, measured by microFET® 3 (Hoggan Health Industries, West Jordan, UT, USA)] of the dominant side, muscle morphology [indicated by the sonographic thickness of the biceps brachii, quadriceps,

and gastrocnemius muscles, operated and measured by the same operator with gentle pressure in standard positions by a portable LOGIQ e-ultrasound device (General Electric Company, USA, 2010)], manual dexterity of the dominant hand [indicated by the box and block test (BBT)], activities of daily living (ADL, indicated by the Kihon checklist), health-related quality of life [HRQoL, indicated by the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36)], and cognitive function [indicated by the brain health test (BHT)]. For details of the details and process of RFA training and each outcome measured, please refer to the published protocol of the EXPPLORE trial[25], and Table 3 in the multimedia appendix 1 summarizes the instruments and measures implemented for data collection of this study.

## Statistical analysis

### Quantitative data

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) for Windows (version 21.0; Released 2010; IBM Corp., Armonk, NY, USA). Continuous variables were represented as means accompanied by their standard deviations, while categorical data were denoted in either absolute numbers or percentages. Preliminary checks for data normality and homoscedasticity were performed prior to executing each specific analysis. For demographic data comparisons between the experimental and control cohorts, appropriate statistical

tests, including the chi-square test, independent t-test, and Mann–Whitney U-test, were employed, depending on the data distribution characteristics.

To address potential attrition, an intention-to-treat analysis was employed, incorporating a simple imputation technique. Specifically, for any missing data, the last observation carried forward method was utilized[28]. To assess the effects of the intervention on outcomes over time, a mixed analysis of variance was employed, designating time as a within-subject variable and the nature of the intervention as a between-subject variable. For any significant interactions or main effects, post hoc assessments were carried out utilizing the Bonferroni test.

## Sample size estimation

Given the absence of a high-quality study evaluating the effects of a comparable intervention of using RFA on muscle strength, physical activity, and functionality at the time our manuscript was drafted, we based our primary outcome measure (ASMMI) on the findings from a single study that utilized an augmented reality (AR)-based exercise. The effect size observed in that study for the AR-based intervention was notably substantial, with a magnitude of 0.71[29]. Using the G*Power software (version 3.1.9.2, for Windows), calculations indicated a requirement for a minimum of 18 participants in each group to detect a difference of two standard deviations (SD) in

the ASMMI between the groups, assuming a power of 80% and an alpha level of 5%. The effect size, situated within the F-test family, was set at 0.4[30]. Anticipating a potential 20% dropout rate, especially considering that many LTCF participants often have multiple comorbidities, it was deemed prudent to increase the number of participants in each group to 22. Consequently, the target recruitment for the study was set at a minimum of 44 participants.

## Ethical Considerations

The trial was designed in compliance with the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines for randomized controlled trials and the Consolidated Standards of Reporting Trials (CONSORT) guidelines. Conducted in accordance with the Declaration of Helsinki, this study received approval from the Institutional Review Board of National Cheng Kung University Hospital (approval number: B-ER-111-058) and was registered at www.ClinicalTrials.gov (ClinicalTrials.gov NCT05360667; https://clinicaltrials.gov/study/NCT05360667)[31]. Written informed consent was obtained from all participants in this study. The study data were anonymized and deidentified. No compensation was provided to participants.

# Results

## Baseline characteristics and adherence to the study protocol

From August 2022 to September 2023, 96 older adults from nursing homes and

daycare centers in rural Kaohsiung city, were recruited. Of these, 28 declined and 8 did not meet eligibility criteria. Sixty consented and were randomized: 30 to the intervention and 30 to the control group. Fifty-five of the total 60 participants (92%) completed the study. In the RFA group, two dropped out due to leaving LTCFs (n=1, before the Time 1) and hospitalization for a urinary tract infection (n=1, before the Time 2). In the control group, three withdrawals occurred because of hospitalization for acute cholecystitis (n=1, before the Time 1) and leaving LTCFs (n=2, before the Time 2). Dropout rates were not significantly different between groups (p = .640).

Table 1 demonstrated the baseline characteristics of participants. In the intervention group, the frailty and sarcopenia status distribution included 4 pre-frail, 13 frail, 16 with possible sarcopenia, 2 with confirmed sarcopenia, and 3 with severe sarcopenia. The control group consisted of 8 pre-frail, 7 frail, 24 with possible sarcopenia, 1 with confirmed sarcopenia, and 2 with severe sarcopenia. The average long-term care case-mix system(CMS) level was 4.20 ± 0.79 for the intervention group and 4.40 ± 0.82 for the control group. CMS level categorizes individuals based on their requirements for assistance with ADLs. These levels play a crucial role in determining the suitable level of care and support needed by individuals in long-term care facilities, ranging from minimal assistance to intensive nursing care[32]. This result indicatedthat both groups required moderate daily activity assistance. There

were no significant baseline differences between the groups, except the RFA group had a lower average grip strength.

**Table 1: Demographic characteristics of the participants at baseline evaluation**

| | | Experimental group (n=30) | Control group (n=30) | P value [b] |
|---|---|---|---|---|
| **Gender (M:F)** | | 10:20 | 11:19 | .787 |
| **Age (yr)** | | 78.83 ± 7.71 | 78.73 ± 6.82 | .958 |
| **Height (cm)** | | 152.89 ± 7.99 | 153.88 ± 8.84 | .673 |
| **Weight (kg)** | | 57.00 ± 10.05 | 61.44 ± 11.07 | .136 |
| **BMI (kg/m$^2$)** | | 24.33 ± 3.57 | 25.86± 3.47 | .123 |
| **Percentage of body fat** | | 29.16 ± 7.82 | 32.86 ± 6.92 | .078 |
| **BMI group** | underweight | 1 | 1 | .771 |
| | normal | 13 | 10 | |
| | overweight | 13 | 16 | |
| | obese | 3 | 2 | |
| **CMS** | | 4.20 ± 0.79 | 4.40 ± 0.82 | .529 |
| **No. below cut-off** | **ASMMI** | 5 | 4 | .718 |
| | **DHS** | 21 | 28 | .020[a] |
| | **Gait speed** | 28 | 29 | .554 |
| **Degree of frailty** | **Robust** | 13 | 15 | .194 |
| | **Pre-frail** | 4 | 8 | |
| | **Frail** | 13 | 7 | |
| **Degree of sarcopenia** | **No** | 9 | 3 | .162[c] |
| | **Probable** | 16 | 24 | |
| | **Definite** | 2 | 1 | |
| | **Severe** | 3 | 2 | |

Data are the mean ± standard deviation or numbers

BMI, body mass index; CMS, Long-Term Care Case-Mix System; ASMMI, appendicular skeletal muscle mass index; DHS, dominant handgrip strength

[a] $p < 0.05$

[b] Refers to the p value of a Mann-Whitney U test (continuous variables) or chi square test (categorical variables) except that [c] was done by Fisher's exact test between participants in the two groups

## Comparisons of primary outcomes between the intervention group and the control group (Table 2)

A significant group and time interaction effect was observed in frailty status as measured by the SOF index ($F = 5.594$, $p = .007$), with a small-medium effect size ($\eta^2 = 0.088$)[33], indicating the RFA group saw a more significant reduction in frailty scores over time. In sarcopenia diagnostic criteria, (1) body components showed notable improvements in ASMM over time ($F = 7.934$, $p = .005$), with a significant group and time interaction ($F = 9.895$, $p = .002$), indicating larger gains in the intervention group. This trend was reflected in ASMMI, revealing significant time ($F = 7.339$, $p = .005$) and group x time effects ($F = 8.408$, $p = .003$). Post-hoc analysis indicated significant improvements from baseline to post-study and from mid-term to post-test in both ASMM and ASMMI; (2) Dominant HGS saw a significant increase in the intervention group, with a notable interaction effect ($F = 5.326$, $p = .011$) and a small-medium effect size ($\eta^2 = 0.087$). Post-hoc analysis revealed significant improvements from baseline to post-study and from mid-term to post-test, exceeding the minimal clinically important difference (MCID); (3) Functional performance exhibited significant time effects in gait speed (m/s) ($F = 6.664$, $p = .005$), with a large effect size for the group x time interaction ($\eta^2 = 0.314$), indicating that the intervention group experienced significantly greater improvements in walking speed. Post-hoc analysis showed significant improvements from baseline to post-study,

surpassing the MCID. The MCID signifies the smallest change in a clinical outcome measure perceived as meaningful by patients or clinicians[34]. Both the improvement in HGS and walking speed exceeding the MCID indicates not only statistical significance but also clinical relevance following RFA training.

Table 2: Data of primary outcomes at baseline (week 0), mid-term evaluation (week 6th), and the post-test evaluation (week 12th)

| | | | Baseline | Mid-term | Post-test |
|---|---|---|---|---|---|
| | Exp. | | 1.07 ± 1.05 | 1.00 ± 1.01 | 0.80 ± 0.85 |
| | Con. | | 0.73 ± 0.83 | 0.80 ± 0.85 | 0.80 ± 0.81 |
| | Two-way ANOVA | | | | |
| **SOF index** | **Time** | | | **Group X Time** | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 2.650 | .083 | 5.594 | .007[a,b] | 0.088 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 17.29 ± 3.81 | 18.63 ± 4.31 | 19.13 ± 4.58 |
| | Con. | | 17.05 ± 2.95 | 16.94 ± 2.81 | 16.96 ± 2.40 |
| | Two-way ANOVA | | | | |
| **Appendicular skeletal muscle mass (kg)** | **Time** | | | **Group X Time** | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 7.934 | .005[a] | 9.895 | .002 [a,b] c (.008) e(.019) | 0.165 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 7.37 ± 1.25 | 7.92 ± 1.72 | 8.15 ± 1.77 |
| | Con. | | 7.17 ± 0.82 | 7.12 ± 0.86 | 7.15 ± 0.84 |
| | Two-way ANOVA | | | | |
| **Appendicular skeletal muscle mass index (kg/m$^2$)** | **Time** | | | **Group X Time** | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 7.339 | .005 [a] | 8.408 | .003 [a,b] c (.009) e(.034) | 0.144 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 7.41 ± 2.73 | 6.98 ± 2.71 | 6.62 ± 2.60 |
| | Con. | | 9.00 ± 2.94 | 8.71 ± 3.03 | 8.38 ± 2.95 |
| | Two-way ANOVA | | | | |
| **Fat mass index (kg/m$^2$)** | **Time** | | | **Group X Time** | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 16.233 | <.001 [a] | 0.241 | .714 | 0.005 |

| | | | | | |
|---|---|---|---|---|---|
| **Fat-free mass index ($kg/m^2$)** | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 16.96 ± 1.76 | 17.10 ± 2.00 | 17.67 ± 1.99 |
| | Con. | | 16.85 ± 1.00 | 16.86 ± 1.52 | 17.26 ± 1.80 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 7.583 | .002 [a] | 0.480 | .573 | 0.010 |
| **Dominant handgrip strength (kg)** *[MCID: 2.44-2.69kg]* | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp.[f] | | 14.51 ± 6.42 | 17.60 ± 6.49 | 20.80 ± 7.59 |
| | Con. | | 13.40 ± 5.51 | 15.16 ± 5.73 | 16.20 ± 6.04 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 35.698 | <.001 [a] | 5.326 | .011 [a,b] c ,d(<.001) e(.001) | 0.087 |
| **Walking speed (m/s)** *[MCID: 0.1-0.2 m/s]* | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp.[f] | | 0.47 ± 0.25 | 0.51 ± 0.31 | 0.53 ± 0.33 |
| | Con. | | 0.48 ± 0.23 | 0.58 ± 0.30 | 0.53 ± 0.27 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 6.664 | .005 [a] | 25.173 | <.001 c (.009) | 0.314 |

All data represent mean ± standard deviation.

Exp.—experimental group; Con.—control group; M—mean; SD—standard deviation

SOF index, Study of Osteoporotic Fractures index; MCID, minimal clinically important difference

[a] $p < 0.05$ were analyzed by mixed repeated measures ANOVA with time as within-subjects factor and group as between-subjects factor

[b] post hoc Bonferroni test was performed to compare baseline, mid-term evaluation, and the post-test scores in the experimental group

Post-hoc analysis showed significantly different data between [c] baseline and the post-test, [d] baseline and the mid-term, and [e] the mid-term and post-test

[f] The change of data between the third month and the baseline was beyond the

minimal clinically important difference.

## Comparisons of secondary outcomes between the intervention group and the control group (Table 3)

Secondary outcomes included muscle strength, morphology, hand dexterity, ADLs, HRQoL, and cognition. The intervention group saw significant increases in biceps and triceps brachii muscles MVIC, with time effects (biceps: $F = 12.879$, $p < .001$; triceps: $F = 32.684$, $p < .001$) and group x time interactions (biceps: $F = 6.532$, $p = .004$; triceps: $F = 11.797$, $p < .001$). Sonographic muscle thickness in the biceps brachii also increased ($F = 10.520$, $p < .001$), with significant group x time interaction ($F = 10.029$, $p < .001$) in the intervention group. Hand dexterity improvements in the intervention group were significant over time ($F = 16.848$, $p < .001$) with a notable group x time interaction ($F = 12.374$, $p < .001$). ADLs, as measured by the Kihon Checklist, showed no significant changes over time within groups for physical function ($F = 1.005$, $p = .343$) but significant group x time interactions for both physical ($F = 5.599$, $p = .013$) and mood functions ($F = 7.376$, $p = .003$), indicating impactful intervention on daily activities. HRQoL, as assessed by SF-36 scores, demonstrated no significant changes over time in physical function ($F = 0.667$, $p = .466$) or in the interaction effect between group and time ($F = 0.516$, $p = .536$). However, improvements in mental function were observed ($F = 6.571$, $p = .009$) without significant differences between groups.

Table 3: Data of secondary outcomes at baseline (week 0), mid-term evaluation (week 6th), and the post-test evaluation (week 12th)

| | | | | | |
|---|---|---|---|---|---|
| **Maximal voluntary isometric contraction** | | | | | |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Biceps brachii muscle (kg)** | Exp. | | 2.89 ± 0.52 | 3.14 ± 0.64 | 3.62 ± 0.73 |
| | Con. | | 2.92 ± 0.83 | 2.95 ± 0.83 | 3.04 ± 0.82 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 12.879 | <.001[a] | 6.532 | .004[a,b] c (<.001) e(<.001) | 0.108 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Triceps brachii muscle (kg)** | Exp. | | 3.00 ± 0.68 | 3.24 ± 0.61 | 3.96 ± 0.63 |
| | Con. | | 3.03 ± 0.69 | 2.93 ± 0.56 | 3.23 ± 0.87 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 32.684 | <.001[a] | 11.797 | < .001[a,b] c(<.001) e(<.001) | 0.179 |
| **Sonographic thickness** | | | | | |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Biceps brachii muscle (cm)** | Exp. | | 2.02 ± 0.59 | 2.13 ± 0.55 | 2.41 ± 0.70 |
| | Con. | | 2.27 ± 0.44 | 2.34 ± 0.37 | 2.29 ± 0.36 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 10.520 | <.001 | 10.029 | <.001[a,b] c (.001) d(.019)e(.043) | 0.167 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Quadriceps muscle (cm)** | Exp. | | 2.36 ± 0.67 | 2.51 ± 0.68 | 2.64 ± 0.71 |
| | Con. | | 2.32 ± 0.48 | 2.38 ± 0.57 | 2.47 ± 0.55 |
| | **Two-way ANOVA** | | | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 16.710 | <.001 | 1.760 | .186 | 0.034 |
| **Gastrocnemius muscle** | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 1.12 ± 0.46 | 1.26 ± 0.45 | 1.34 ± 0.49 |

| | | | | | |
|---|---|---|---|---|---|
| | Con. | | 1.06 ± 0.34 | 1.14 ± 0.39 | 1.11 ± 0.40 |
| | | | **Two-way ANOVA** | | |
| **(cm)** | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 9.580 | .001 [a] | 3.211 | .057 | 0.060 |
| **Hand dexterity** | | | | | |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp.[f] | | 49.82 ± 13.21 | 54.55±13.86 | 56.96 ± 12.77 |
| **Box and Block test** | Con. | | 43.21 ± 14.98 | 44.29±14.71 | 43.60 ± 14.52 |
| | | | **Two-way ANOVA** | | |
| [*MCID: 5.5 cubes/min*] | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 16.848 | <.001 [a] | 12.374 | <.001 [a,b] c (<.001) d(<.001) | 0.186 |
| **Activity of Daily living** | | | | | |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Kihon checklist Score (No.1 to No. 20)** | Exp. | | 8.80 ± 4.29 | 8.70 ± 4.19 | 8.46 ± 4.03 |
| | Con. | | 10.57 ± 3.82 | 10.60 ± 3.88 | 10.70 ± 3.82 |
| | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 1.005 | .343 | 5.599 | .013 [a] | 0.088 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Kihon checklist Score (No.21 to No. 20)** | Exp. | | 1.50 ± 1.00 | 1.33 ± 1.09 | 1.20 ± 1.06 |
| | Con. | | 1.43 ± 1.19 | 1.60 ± 1.22 | 1.63 ± 1.22 |
| | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 0.379 | .628 | 7.376 | .003 [a] | 0.113 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| **Kihon checklist Score (total)** | Exp. | | 10.30 ± 4.89 | 10.03 ± 4.70 | 9.67 ± 4.43 |
| | Con. | | 12.00 ± 4.70 | 12.20 ± 4.76 | 12.33 ± 4.64 |
| | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 0.859 | .381 | 8.093 | .003 [a] | 0.122 |
| **Health-related Quality of Life** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 65.23 ±30.83 | 67.20±30.36 | 67.80 ±30.58 |
| **SF-36 Physical function** | Con. | | 60.86 ±28.00 | 40.66±29.66 | 61.17 ± 29.41 |
| | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 0.667 | .466 | 0.516 | .536 | 0.009 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 64.47 ±25.87 | 70.60±24.72 | 72.50 ± 25.51 |
| **SF-36 Mental function** | Con. | | 69.79 ±25.51 | 73.34±22.52 | 74.21 ± 22.68 |
| | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 6.571 | .009 [a] | 0.534 | .495 | 0.009 |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 64.87 ±26.35 | 68.90±26.30 | 70.15 ±26.85 |
| | Con. | | 65.33 ±26.10 | 67.00±25.23 | 67.69 ±25.15 |
| **SF-36 Total** | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 4.481 | .034 [a] | 0.682 | .430 | 0.012 |
| **Cognition** | | | | | |
| | | | **Baseline** | **Mid-term** | **Post-test** |
| | Exp. | | 9.17 ± 4.22 | 10.17 ± 4.14 | 10.90 ± 3.96 |
| **Brain health test score** | Con. | | 10.02 ± 4.56 | 9.60 ± 4.43 | 9.33 ± 4.65 |
| | | | **Two-way ANOVA** | | |
| | **Time** | | **Group X Time** | | |
| | F-value | *p*-value | F-value | *p*-value | Effect size $\eta^2$ |
| | 2.824 | .085 | 15.285 | <.001 [a] | 0.211 |

All data represent mean ± standard deviation.

Exp.—experimental group; Con.—control group; M—mean; SD—standard deviation

MCID, minimal clinically important difference; SF-36, Short Form 36 Health Survey

[a] $p < 0.05$ were analyzed by mixed repeated measures ANOVA with time as within-subjects factor and group as between-subjects factor

[b] post hoc Bonferroni test was performed to compare baseline, mid-term evaluation, and the post-test scores in the experimental group

Post-hoc analysis showed significantly different data between [c] baseline and the post-

test, [d] baseline and the mid-term, and [e] the mid-term and post-test

[f] The change of data between the third month and the baseline was beyond the minimal clinically important difference.

In summary, the RFA intervention resulted in significant improvements in muscle strength (medium-large effect size), hand dexterity (large effect size), ADLs (medium effect size), and cognition (large effect) compared to the control group. However, the RFA intervention did not significantly enhance ADL or the sonographic thickness of the quadriceps and gastrocnemius muscles compared to the control group. We have compiled the above findings in the table in Multimedia Appendix 2.

## Discussion

To our knowledge, this was the first study to evaluate the clinical effectiveness of RFA, an exergame that uniquely integrates aerobic and resistance training with real-time feedback in an engaging manner. Considering the multifaceted nature of frailty and sarcopenia and their varied definitions[12], our focus was on muscle and functional performance parameters. Our findings revealed that exergame-based exercise via RFA significantly improved muscle mass, strength, and functional performance among elderly LTCF residents, in comparison to standard care. This underscores its potential as a novel therapeutic strategy to partially prevent and address frailty and sarcopenia.

This project stands out as it delivered exergame-based exercise via RFA system. Like other exergames, RFA employs a gamified approach and immersive scenarios for player motivation through role-playing.[35]. It offers visual and sensory feedback

from the screen and the Ring-Con, respectively. Unlike other exergames that mostly require fingertip operation, RFA, with its unique Ring-Con, demands significantly higher energy consumption[36] and encompasses a multicomponent exercise regimen, blending PRT with aerobic activities for enhanced strength, balance, and muscle flexibility. Previous studies have confirmed the efficacy of PRT in improving physical function and strength among community-dwelling older adults due to its accessibility, low cost, and effectiveness.[37, 38]. Consistent with these findings, our results demonstrate that RFA can significantly enhance ASMMI, handgrip strength, MVIC of the dominant upper extremity, and overall functional performance.

Another distinctive aspect of delivering exergames through RFA is its capability to establish the initial volume of exercise required at each stage, adjusting it progressively and automatically based on the player's performance. At the start of the RFA training, participants were allowed to select their exercise intensity based on age, physical fitness, and preferred exercise intensity. This intensity setting in RFA is determined by a manufacturer-developed algorithm and follows a specific procedure: initially, users input their age and sex (Step 1), followed by their exercise habits and desired exercise intensity (load) (Step 2). From these inputs, the load level (1-30) was automatically set on a scale from 1 (weakest) to 30 (strongest). As the load level increases, users need to apply more force on the Ring-Con to defeat enemies,

facilitating personalized exercise progression. This feature saves time and manpower by being machine-adjustable[39]. However, for older adults (≥65 years old), the intensity options are limited, with the system defaulting to a maximum load setting of 15 or lower. While a preliminary study on older adults suggests they can generally achieve moderate or greater intensity levels in RFA as assessed by the Karvonen heart rate reserve formula, it also recommended employing established and validated exercise intensity indices (e.g., HR and RPE) alongside considering RFA's intensity settings[39]. Furthermore, the ACSM recommends increasing intensity over time to maintain exercises at moderate levels (41–60% of 1 RM for resistance exercise and Borg RPE 12–14 for aerobic exercise)[40]. Consequently, we set our exergame-based exercise's target intensity at Borg RPE 13, leaving the weight intensity to the discretion of the Nintendo Switch. Although this approach is practical in real-world settings and safer for the elderly to perform PRT by squeezing or stretching the Ring-Con, a limitation remains in not being able to verify if the Ring-Con's weight intensity aligns with moderate levels.

Considering the reliance on wheelchairs for mobility among many elderly individuals in LTCFs, attributed to poor muscle endurance, yet with the capacity to walk short distances for gait assessments[27], our RFA program incorporated a knee assist mode directly within the RFA system. This feature allowed us to focus on

strengthening the upper extremities and trunk. This approach enabled participants to train in a seated position, thereby minimizing the risk of falls. Indeed, no participants in the intervention group experienced serious adverse effects. Consequently, it was logical that most outcomes of this study, including HGS, MVIC of the biceps and triceps brachii muscles, sonographic thickness of the biceps muscle, and the BBT, demonstrated significant group x time training effects.

In this study, we assessed both MVIC and sonographic thickness to determine if early morphological changes in the trained muscles could be detected prematurely. This approach was taken because aging can dampen the hypertrophic response of muscle groups to resistance training[41]. Unlike in healthy young adults, whereas neural factors play a significant role in the initial increase in strength and muscle hypertrophy becomes predominant after the first 3–5 weeks, the effects of muscle training in older adults may rely entirely on neuromuscular adaptation after an 8-week training course[42]. Interestingly, we observed significant improvements in the sonographic thickness, rather than MVIC, of the biceps brachii muscle at the mid-term assessment. By the end of the intervention, both MVIC and sonographic thickness of the biceps brachii muscle showed significant enhancements. No improvement in the sonographic thickness of lower leg muscles was observed, however, despite a significant increase in walking speed post-intervention. This

suggests that improvements in muscle parameters do not directly translate into functional performance enhancements. The relationship between muscle parameters and functional performance is complex and likely influenced by multiple factors.

Even though the exergame-RFA was focused on the training of upper extremities and trunk, we found significant improvement in gait speed, one of the diagnostic criteria of sarcopenia. Walking encompasses complex movements requiring several functional tasks[43]. Participants had to maintain balance in various positions, such as leaning forward, reaching forward, and lateral shifting, to perform the RFA. Despite our protocol not permitting the performance of training on the lower extremities, movements in arm fit skills likely engaged the trunk, hips, and knees. Granacher et al. demonstrated that the ability of older adults to rise from a chair, ambulate, and make turns improved after 9 weeks of core muscle strength training[44]. Park et al. observed an increase in walking speed after a sitting boxing program for 6 weeks[45]. Both studies have shown that strengthening programs can induce adaptive processes, particularly in the neuromuscular system. These processes, in turn, enhance balance performance and functional mobility. Given these reasons, observing an increase in gait speed in our study was reasonable.

We observed significant improvements in ADLs, both in physical (Kihon checklist No. 1 to No. 20) and mood aspects (Kihon checklist No. 21 to No. 25). Nevertheless,

after the exergame-RFA, we only noted a significant improvement in mental function, not in physical function, as measured by the SF-36. A systematic review involving 15 eligible RCTs indicated that exercise positively affects physical outcomes and enhances QoL and ADLs in elderly individuals[46]. A large cohort study showed that community-dwelling elders engaging in moderate to vigorous intensity physical activity had a lower risk of ADL dependence.[47]. Another study found a significant association between better physical function and higher levels of physical function in the SF-36[48]. Our results align with these findings to some extent. However, whether there is a strong correlation between muscle strength, muscle mass, functional performance, and those questionnaires still requires larger studies with longer follow-up periods to elucidate the association and even the causal relationship.

Exergames have been shown to have therapeutic effects on cognition among older adults[49, 50]. Exergame environments enhance spatial awareness, challenging players with tasks that involve visual and auditory stimuli, cues, and feedback. Immersion into these virtual environments aids in attention restoration, stress reduction, and cognitive rehabilitation[50]. Additionally, exergames necessitate decision-making during gameplay[49]. Therefore, it was not surprising to observe significant improvements in the BHT score following the exergame-RFA intervention. Identifying a cutoff value for cognitive measurements to determine suitability for

exergame participation among LTCF residents would enhance the application of these findings.

Our study encountered several limitations. Firstly, while the sample size exceeded the minimum requirements for statistical analysis, it remained relatively small. Secondly, participants were recruited from nursing homes and day-care centers in rural Southern Taiwan, leading to a lower attrition rate than anticipated[51], potentially due to the unique characteristics of rural regions where elders have limited healthcare options and may value services more highly. As a result, our findings may only be generalizable to similar populations. Thirdly, the exergame-RFA intervention and evaluation period spanned only 3 months. Although improvements in muscle mass, strength, muscle thickness under sonography, and certain questionnaire aspects were observed, this duration may have been too brief to detect significant increases in functional performance, particularly among older adults. Fourthly, there was no established protocol for training with RFA. Despite basing the exercise prescription on ACSM guidelines for older adults, we cannot confirm the idealness of the current exergame-based exercise protocol. The individualized setting and progression of exercises, a hallmark of using RFA for elderly training, were assessed solely through RPE, leaving uncertainties about the precise resistance offered by the Ring-Con during each session. Furthermore, although the ability to automatically customize

exercise settings and progression is a key feature of utilizing RFA for training elderly individuals. However, in this project, exercise intensity was only measured using RPE. The investigators were unable to verify the precise resistance provided by the Ring-Con during each training session. Lastly, due to the small sample size, we did not perform a subgroup analysis to determine if specific subgroups would benefit more from exergame-RFA. Future studies should aim to recruit larger samples to explore how elders with varying degrees of frailty and sarcopenia respond to exergame-RFA. We also recommend further investigation into the optimal volume and long-term effects of exergame-RFA on older adults through larger randomized trials with control groups and extended follow-up periods, drawing from this study as a reference.

In summary, our study contributes valuable insights into the practical application of exergame-based exercises within LTCF settings, affirming the potential of such interventions to improve muscle parameters, functional performance, and, by extension, the quality of life among the elderly. These findings not only echo the sentiments expressed in the pre-study expectations but also pave the way for future research to refine and expand upon these interventions, ensuring they meet the holistic needs of the aging population. Further studies could explore the integration of lower extremity exercises and more personalized exergame programs, aiming to encompass

the full spectrum of sarcopenia criteria and ADL requirements.

## Declarations

*Acknowledgements*

Not applicable.

*Ethics approval and consent to participate*

The study was conducted according to the Declaration of Helsinki and was approved by the Institutional Review Board of National Cheng Kung University Hospital, Taiwan in May 2022 (number: B-ER-111-058). The trial has been registered on the clinicaltrials.org website under the identification number NCT05360667 (https://clinicaltrials.gov/ct2/show/NCT05360667). All participants had signed an informed consent form.

*Consent for publication*

Not applicable.

*Availability of data and materials*

Individual participant data that underlie the results reported in this article, after deidentification might be shared. Proposals should be directed to

n118029@mail.hosp.ncku.edu.tw for application.

*Competing interests*

The results of the present study do not constitute endorsement. All authors declared that there is no conflict of interest.

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*Authors' contributions*

SHT planned the project, developed the research design, measured the outcomes, applied for funding, and wrote the first draft.

LHC was responsible for literature reviewing, evaluating the appropriate measurement tools, and the revisions of the manuscript.

SFS calculated the sample size and was responsible for the revisions of the manuscript.

CHL was responsible for literature reviewing and evaluating the appropriate measurement tools.

GBC measured the outcomes and did the statistical analysis.

YJT planned the project, developed the research design and revised the manuscript.

All authors read and approved the final manuscript.

## Multimedia Appendix 1

Table 1. Flowchart of Exergame-based multicomponent training program

Table 2. Exercise prescription of exergame via Ring Fit Adventure using the FITT-VP principle

Table 3. Instruments and measures implemented for data collection of this study

## Multimedia Appendix 2

Summary of Significant Time X Group Effects on Outcome Measures

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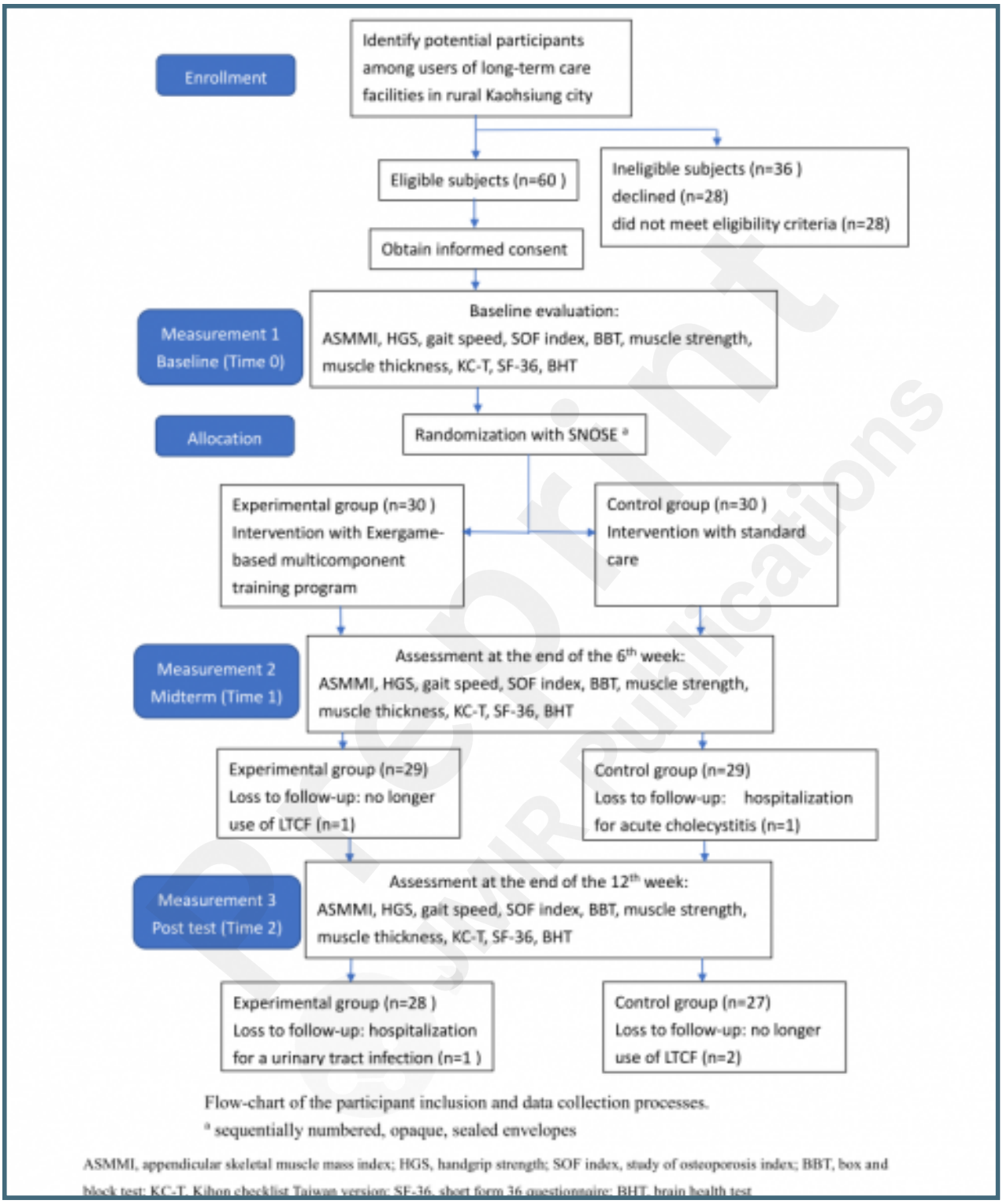
## List of abbreviations

LTCF, long-term care facility; RT, resistance training; PRT, progressive resistance training; HRQoL, health-related quality of life; RFA, Ring Fit Adventure® for the Nintendo Switch®; ACSM, American College of Sports Medicine; AWGS, the Asian Working Group for Sarcopenia; ASMMI, appendicular skeletal muscle mass index; HGS, dominant Hand Grip Strength; SOF index, the study of osteoporotic fractures index; MVIC, maximal voluntary isometric contraction; BBT, box and block test；SF-36, the Medical Outcomes Study 36-Item Short-Form Health Survey; BHT, brain health test

# Supplementary Files

# Figures

Flow-chart of the participant inclusion and data collection processes.

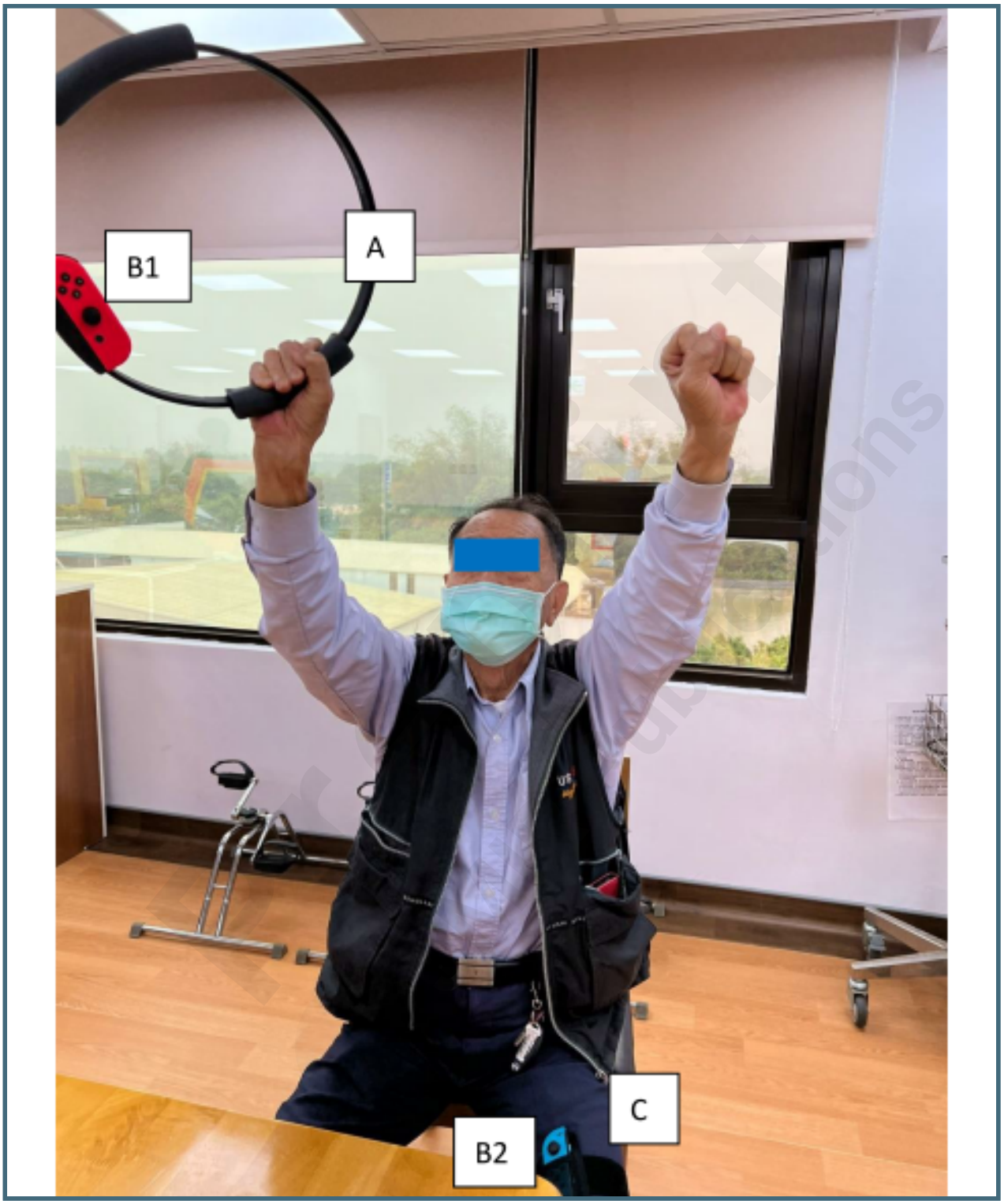



Flow-chart of the participant inclusion and data collection processes.

[a] sequentially numbered, opaque, sealed envelopes

ASMMI, appendicular skeletal muscle mass index; HGS, handgrip strength; SOF index, study of osteoporosis index; BBT, box and block test; KC-T, Kihon checklist Taiwan version; SF-36, short form 36 questionnaire; BHT, brain health test

components of RingFit Adventure.



# Multimedia Appendixes

File for 1. Flowchart of Exergame-based multicomponent training program; 2.Exercise prescription of exergame via Ring Fit Adventure using the FITT-VP principle; 3.Instruments and measures implemented for data collection of this study.
URL: http://asset.jmir.pub/assets/e447112527683ecf18a4fc4558eafe17.docx

Summary of Significant Time X Group Effects on Outcome Measures.
URL: http://asset.jmir.pub/assets/264ffcaf380b3fe91394e85bfb5e6f24.docx

# CONSORT (or other) checklists

CONSORT checklist.
URL: http://asset.jmir.pub/assets/66450234601f92933af688aeadef2d2b.pdf