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Research article

# Feasibility of digital technology-supported home exercise intervention for health promotion in community-dwelling older adults: A pilot randomized controlled trial

Ji Young Lim [a], Heeju Yu [b], Yeah Eun Kwon [c], Jong Geol Do [d], Ji Hye Hwang [d,*]

[a] Department of Physical and Rehabilitation Medicine, Sungkyunkwan University School of Medicine, Republic of Korea
[b] Department of Physical Therapy, Graduate School, Sahmyook University, Republic of Korea
[c] Research Institute for Future Medicine, Samsung Medical Center, Republic of Korea
[d] Department of Physical and Rehabilitation Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Republic of Korea

## 1. Introduction

In Korea, 17.5 % (9,018,000) of the population in 2022 are elderly aged >65 years, and the United Nations projects that Korea will advance to be a super-aged society by 2025. This is only 7 years from becoming an aged society (over 20 % of the total population), the fastest aging rate among Organisation for Economic Cooperation and Development countries [1]. Accordingly, the Korean government is moving toward health promotion and disease prevention in older people by formulating the 5th National Health Plan (2021–2030) [2] and guidelines for healthy living for the elderly in Korea have been recently published [3]. These actions infer that attention should be paid to advanced health promotion for older adults' independence and quality of life in conditions where the population aged over 65 years is predicted to account for 16 % of the global population by 2050 [4].

Health promotion targets a wide range of individual, social, and environmental areas. Supporting individuals to manage their health and promote healthy behaviors involves a series of milestones in health promotion [5]. Especially, for healthy and independent life in aging, exercise intervention has been promising [6] in public health, and its implementation is strongly essential for healthy behavior. Exercise is a well-known cost-effective measure for improving physical and socio-psychological health, function, and quality of life, decreasing risk factors of metabolic and cardiovascular diseases, and lowering cancer prevalence [7]. Although the results have varied according to the definition of regular physical activity, studies have established that from 2017 to 2020, only 37.6 % of 10,097 Koreans aged 65 years or older met the recommendation for physical activity (at least 150 min of moderate-intensity aerobic exercise per week) [8]. Despite the importance of regular exercise, less than 1 in 3 (28.7 %) elderly participants performed aerobic exercise, and only 21 % (1 in 5) performed strength exercises (more than twice a week) [9]. In a recent survey that assessed health measures in 600 elderly people aged ≥60 years, only 55.7 % answered that they do regular exercise, which was the lowest among health behavior practices [3].

Many studies have identified multifaceted, complex facilitators and barriers in older adults to their adherence to physical activity, and providers should initially consider such factors for appropriate exercise provision [10]. One systematic review of 34 papers identified perceived physical limitations as key barriers, and improved physical capacity and condition as motivators, including balance, walking, and muscle power [11]. In a systematic analysis of the factors influencing older adult participation in resistance exercises, identifying the crucial benefits for older adults and delivering accurate information should be regarded as a common

* Corresponding author.
*E-mail address:* hwanglee@skku.edu (J.H. Hwang).

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motivating factor [12]. Additionally, one report revealed that older Korean adults prefer to receive more exercise-related information tailored to their health conditions [3]. Consistent with this perspective, Devereux-Fitzgerald et al. (2016) propose that recognizing their distinct wants and requirements is vital for addressing the low engagement in physical activity [13]. Such findings inform us of the significance of safe, correct, and useful exercise prescriptions, considering the broad divergence of individual health, resource conditions, and preferences, among others. Therefore, strategies that design and provide customized exercise for seniors are needed to encourage them to participate in regular physical exercise, ultimately resulting in lasting and optimal outcomes.

Digital technologies that support physical exercise or promote physical activity could be a solution for achieving this goal. This type of intervention has been adapted according to different objectives, levels of maturity, and fundamental properties of the technology. The advantages and effectiveness of digital technology-supported interventions such as virtual reality, augmented reality (AR), and mixed reality have been demonstrated in diverse populations [14–19]. In these interventions, real-time user interaction and goal-directed movement induced better motivation and learn exercise performance effectively [20], resulting in improved health outcomes and regular exercise participation. Furthermore, the digital technology-supported physical exercise system can be used by older adults at home at any time without visiting any exercise facilities [15], as well as reducing access limitations, such as weather effects and lack of exercise trainers specialized for older adults in the community. Given these benefits, older adults are likely to accept and adopt digital health-technology-based exercise programs in home settings, which they usually prefer. They demonstrated better engagement with mobile healthcare services than the general adult population, despite potential barriers related to technology usage [21,22]. According to a systematic review, adherence to digital exercise programs in older adults was greater than adherence to traditional exercise programs [23].

A systematic review of 21 studies on mixed-reality technologies for the prevention of falls in older adults revealed a common finding. Several studies lacked clarity on the involvement of healthcare professionals in exercise sessions, and details on their role were often missing; in particular, insufficient information was provided on the resources required for administering interventions, including support for older participants. Furthermore, usability issues crucial for the effectiveness of AR-based interventions among older users have not been adequately reported. As a new strategy for older adults, this study introduced an AR-based physical exercise system combined with older and modern technologies such as 3D Kinect cameras, desktop computers, and inertial measurement unit (IMU) sensors, to provide targeted movement and more accurate visual feedback on exercise performance. We adjusted for older people by selecting a display larger than a mobile phone and prescribed a detailed evidence-based structured exercise program. It is provided by healthcare professionals using a web-based system that includes a battery of exercises suitable for older adults, setting each separate movement time and holding time as the target benchmarks. This pilot randomized controlled trial primarily aimed to provide useful information on feasibility, including intervention usability issues. Additionally, we sought to examine the potential benefits of an AR-based home exercise intervention (named "OASIS Pro") on health outcomes in community-dwelling older adults of 65 years and over compared with a real-world community-level control group (without any intervention who maintained routine physical activity).

## 2. Material and methods

### 2.1. Study design and setting

This study was a parallel-group, open (without blinding), exploratory, randomized clinical trial with block sizes of 3, 6, and 9 and a 1-month intervention with a 1-month follow-up. This study followed the Consolidated Standards of Reporting Trials (CONSORT) statement: extension to randomized pilot and feasibility trials [24].

### 2.2. Participants

Fifty participants were enrolled in the Research Registry of our department between July 2022 and February 2023. All participants were screened for eligibility by phone and in person. They were randomly allocated in a 2:1 ratio to the intervention or control group. Unequal allocation was implemented because it might have potential advantages, such as gaining experience with the digital exercise intervention and its probable effects. Additional analysis of the intervention group can be performed, particularly exploring dimensions of digital home exercise intervention for older adults, including delivery, safety, cost, and target population [25–27].

Participants were asked to report their characteristics through face-to-face interviews to examine their eligibility. The inclusion criterion was community-dwelling older adults aged ≥65 years. The following individuals deemed unsafe to participate in testing or exercise intervention were excluded: 1) taking physical therapy for medical care or participating in a regular exercise program (more than two times per week); 2) severe visual impairment or neurological disorder; 3) dizziness when exercising; 4) having an acute illness or medical condition that physician considered to be unsafe to exercise, including uncontrolled cardiovascular disease such as unstable angina, aneurysm, and congestive heart failure; and 5) inability to communicate education and follow-up required for the study procedure.

### 2.3. Interventions

The primary goal of the intervention was for participants to experience regular exercise practice at home through a digital technology-supported intervention for one month. To accomplish this goal, the exercise program referred to the guidelines of the American College of Sports Medicine (frequency, intensity, type, and time principles) for older adults. Additionally, strategies that increased self-efficacy, which is included as a core component in most theories of behavioral change, were utilized [28].

Exercise type focused on balance and lower extremity strengthening exercises was developed based on the Otago Exercise Program [29] and Balance Berg Scale [30]. The exercise type was adjusted to minimize potential discomfort or unintended injuries from an unsupervised setting as well as potential implementation challenges due to digital technology connection, management of the system, and individual capacities of digital technologies. Participants were advised to exercise at least three times per week. The exercise intensity for each level is described in detail in the Supplementary Material 1. All sessions consisted of warm-up, main, and cool-down exercises with exercise intensity progressively increasing. The duration of the main part of the session ranged from eight to 15 min. The exercise time during the warm-up and cool-down was approximately 7 min. This session was prescribed twice daily to meet the exercise prescription guidelines as closely as possible, reducing the burden of exercise participation. To increase the intensity of the strengthening exercises, the participants were asked to wear two sandbags (each 1 kg) on their ankle joints in the third week. In cases where the participants thought the intensity was low after the exercise, they were allowed to wear two sandbags before the planned week.

The OASIS Pro system (RBIOTECH Corp., Seoul, Korea) was used for the exercise program provision. The digital exercise intervention consisted of the following steps.

(1) Hardware settings for running OASIS Pro: personal computers (installed software), monitors, 3D Kinect camera sensors, IMU wearable sensors, and portable Wi-Fi
(2) Software-OASIS-Rehab (for users): an application for patients that allows them to perform rehabilitation exercises prescribed by healthcare professionals
(3) Software-OASIS Manager (for healthcare professionals): an application for healthcare professionals that allows staff to prescribe and update individual rehabilitation exercises and view individual data (performance and accuracy of exercises)

A total of 25 joints were calibrated using infrared and motion capture technology with a 3D camera (Kinect v2 for Windows®, Microsoft, USA) to track lower extremity movements in real time. The screen showed virtual information in a real home environment. During the exercise, the participant enabled to check virtual information, such as the exercise guide image, joint position, target point for each exercise, time taken to reach the target point, holding on the point, returning counted by voice, number and sets of exercises, and encouraging messages in real time. This function provided visual and auditory feedback to the participants.

For a more accurate movement evaluation of the two exercises (knee extension while sitting and mini squat), the participants wore four IMU sensors embedded with three-axis gyro and accelerometer sensors. The IMU sensors were connected via Wi-Fi, and the raw data extracted from the sensors were transmitted to personal computers. After the data were analyzed, whether the movement was performed within the specified range in real time was presented as a score (0–100 %) on a monitor display. For correct attachment of IMU sensors at both thighs and shanks with Velcro straps, participants were asked to wear comfortable shorts, if possible. In addition, the total performance and accuracy scores (0–100 %) of the exercises analyzed by the Kinect camera and IMU sensors were provided upon completion of each session. The OASIS Pro system automatically saved individual engagement in the intervention, including the time and data when participants completed the exercise session or stopped; if completed, the system provided the results of the performance and accuracy score. Participants could also check their daily progress rate for the week at the end of the exercise routine.

At the initial evaluation, the participants were informed, with brochures, of the precautions to be taken when exercising. After baseline assessment, the OASIS Pro and sandbags were delivered to individual homes by the company that developed the system. The employee delivered and installed the system in the participant's home and educated them on the operation of OASIS Pro. Before the intervention began, a research assistant with a physical therapist license contacted the participants to confirm whether the system was installed at home, informed them of the start of the exercise, and confirmed the use of sandbags from the third week. They were also contacted to retrieve the system after the completion of the intervention. If the participants had problems during the intervention, the research assistant and a company employee dealt with it remotely or visited their homes. In addition, the research assistant recorded any adverse events and modified the use of sandbags according to each individual's needs.

### *2.4. Measures*

All outcome measures were assessed by an unblinded research assistant at baseline and at the 1- and 2-month follow-up and were completed face-to-face. At baseline, the characteristics of all the participants were collected, including sex, age, height, weight, comorbidities, number of medications, smoking, drinking, living status, educational level, employment, and history of falls. The Mini-Nutrition Assessment (full form) was used to assess nutritional status (range, 0–30; scores, 24–30 points, normal; 17–23.5 points, risk of malnutrition; and less than 17 points, malnutrition). In addition, the use of the internet and digital devices was examined [31].

All participants' physical performance, exercise self-efficiency, level of physical activity, and depression were evaluated at baseline and after 1 month (completion of intervention) and 2 months (1 month follow-up). For the intervention group, exercise program engagement was assessed, and additional questionnaires, such as usability, acceptance, and overall satisfaction with the AR-based exercise intervention and technology aspects were administered at the end of the intervention.

### *2.5. Feasibility: retention, engagement, usability, satisfaction, and acceptance*

Retention was calculated as the number of participants in both groups who completed the 1-, and 2 months assessments. Engagement in the exercise intervention was defined as the average number of participants who completed the exercise regimen more than three days per week. The perceived usability of the OASIS Pro system was evaluated using the qualitative System Usability Scale

(SUS), which was composed of 10 items rated on a 5-point Likert scale [32]. The total score ranged from 0 to 100, with higher scores indicating better usability. Additionally, a non-standardized (semi-structured) questionnaire on satisfaction and usability was employed, including five close-ended questions (5-point Likert scale) and four open-ended questions for feedback and requirements about the overall service and technology, function, design, and exercise program. A questionnaire based on the Senior Technology Acceptance Model (STAM) was used to determine the acceptance of the OASIS Pro system by older adults [33].

### *2.6. Potential benefits*

Outcomes were collected and evaluated to assess the potential benefits of the intervention. Changes in the Short Physical Performance Battery (SPPB) scores were examined over time. Briefly, the SPPB is useful and easy to apply for assessing lower extremity function and is a quality indicator of the risk of incident disability in non-disabled community-dwelling older adults [34,35]. The SPPB was administered using a validated multi-sensor-based kiosk (AndanteFit, Dyphi, Daejeon, South Korea), which had been described in detail in a previous study [36]. The multisensor-based kiosk was connected to a mobile application using Bluetooth. Using a mobile application that provided graphical and audio instructions, the research assistant performed the test according to the standard SPPB protocol. Three subsets of the SPPB were estimated. For the standing balance test, the participants were asked to maintain each posture of the side-by-side stand, semi-tandem stand, and tandem stand for 10 s while standing on a load cell array. For the gait speed test, the time spent walking 4 m was measured twice consecutively using a light detection and ranging sensor (LiDAR). The higher value was used for the analysis. For the ability to rise from a chair, the chair sit-to-stand time was recorded five times using a load cell array fitting the chair seat and a LiDAR sensor, which was used to determine the total standing up and sitting positions. During the assessment, all the data were recorded every 10 ms. The application automatically indicated the sum of the scores based on the cut-off points. Summary scores ranged from 0 to 12 points, and higher indicated better performance. Assessment of changes in physical activity, exercise self-efficacy, and depression were included. For older adults' physical activity, the widely used Physical Activity Scale for the Elderly (PASE) was applied. Briefly, PASE is composed of 10 items and produces total scores according to each weight (leisure, housework, and work-related activity) and activity frequency. Achievable scores range from 0 to 360, with higher scores indicating higher levels of physical activity. We used the validated Korean version of the PASE (test-retest reliability = 0.75) [37]. The validated Korean version of the Self-Efficacy for Exercise scale was used to measure how confident older adults were in exercising for 20 min 3 times a week in each of the 9 conditions [38]. The total score was 90 points, with a higher score indicating a higher confidence in exercise. The Korean version of the Short Geriatric Depression Scale, with a total of 15 questions, was used to assess changes in the severity of depressive symptoms. The score ranged from 0 to 15, and scores of 0–4 indicated no depression; 5–9, mild depression; and 10–15, moderate to severe depression [39–41].

### *2.7. Sample size*

Sample size calculation was not essential for this randomized controlled pilot trial [42]. However, we estimated to recruit a minimal number of participants in each of the two groups with unequal allocation ratios according to the CONSORT 2010 checklist of information to be included when reporting a pilot or feasibility trial.

In a previous work [43], the average SPPB score of community-dwelling older adults aged 65 years was 8.3 (SD 2.7). A 30 % improvement in the SPPB score (greater than 10, meaning no sarcopenia and no mobility disability) is desired in a future full-scale randomized controlled trial (RCT). When calculated with a 1:2 (control group: intervention group) enrollment ratio, alpha level of 0.05, and power of 80 %, a total of 14 participants in the control group and 28 participants in the intervention group (total of 42) were needed. Considering a dropout rate of approximately 15 %, 51 individuals were recruited, 17 in the control group and 34 in the intervention group.

### *2.8. Data analysis*

Data were presented as the mean (SD) or number (%). Independent samples *t*-test and Fisher's exact test (or Pearson Chi-square test) were used to compare the characteristics and baseline clinical parameters between the groups. Retention, engagement, satisfaction, usability, and acceptance as primary outcome were evaluated using descriptive statistics and a frequency analysis.

Additionally, we explored the potential benefits in the intervention group compared with the control group using a Generalized Estimating Equation (GEE). The GEE was performed with the change from baseline in each outcome measure as the dependent variable, two groups and two time points as fixed effects, and the baseline value of each continuous outcome as a covariate. Intention-to-treat principle was applied for data analysis. To analyze changes in all outcomes within each group, the Wilcoxon signed-rank test and paired sample *t*-test were conducted. All data were analyzed using IBM SPSS version 28.0 (SPSS Inc., Armonk, NY, USA), and statistical significance was set at a two-sided p-value of $<0.05$.

## 3. Results

### *3.1. Participants*

Among the older adults screened, 50 older adults were enrolled. Fig. 1 shows the flow of participant enrollment, allocation, follow-up, and analysis. In total, 55 participants were originally eligible, but 5 of them declined. Owing to the limited space for the setup of the system at home, one participant could not receive the allocated intervention and withdrew. Three participants were lost to follow-up after 1-, and 2 months in the intervention group.

Among them, 37 (74 %) were female, and the mean (SD) age was 70.6 (5.3). The number of medications, falls, smoking, alcohol consumption, education level, living status, employment status, and comorbidities were similar between the groups (Table 1). There were 4 and 5 participants in the control and intervention groups, respectively, who were at risk of malnutrition (score <24). As shown in Table 2, the use of the internet and digital devices was similar between the groups. All participants could use a smartphone, 42 (84 %) participants could access the internet using digital devices, almost all had a television at home, and 35 (70 %) had personal computers available at home. Approximately half of the participants had exercised at least once using a digital device.

### 3.2. Retention, engagement, usability, satisfaction, and acceptance

Study retention rate was 87.9 and 100 % in the intervention and the control groups, respectively. Participants performed exercise for a mean of 3.4 days (SD 1.2) per week. In total, 20 (68.9 %) participants performed exercise more than 3 days per week. No adverse events were observed during the intervention period.

The mean SUS score of the OASIS system was 69.3 (SD = 11.1), an acceptable value [44]. The results of the self-developed satisfaction questionnaires showed that the participants were fairly satisfied with the overall service and system (mean [SD]:3.6 [0.8]). In terms of usability, the common issues that participants experienced over the four weeks were connection stability (17/29, 58.6 %) and administration of IMU sensors or discomfort in straps (20/29, 69.0 %). Network instability or software disconnection occurred despite portable Wi-Fi being provided.

In the self-developed questionnaire for satisfaction, overall satisfaction was assigned a mean score of 3.6 (SD 0.8). 55.2 % of the participants (n = 16) responded that they were mostly satisfied with the digital exercise intervention because of no constraints on time, environment, and motivation towards daily exercise. Three participants were not satisfied with the intervention because of the inconvenience of use, disconnection issues, or device malfunction. 75.9 % of the participants (n = 22) responded that they exercised more consistently than they did before the intervention (mean 3.7 [SD 1.0]) and 20 participants (69.0 %) became more interested in managing their health (mean 3.7 [SD 0.8]). In addition, 21 participants (72.4 %) thought that this was an effective way to improve

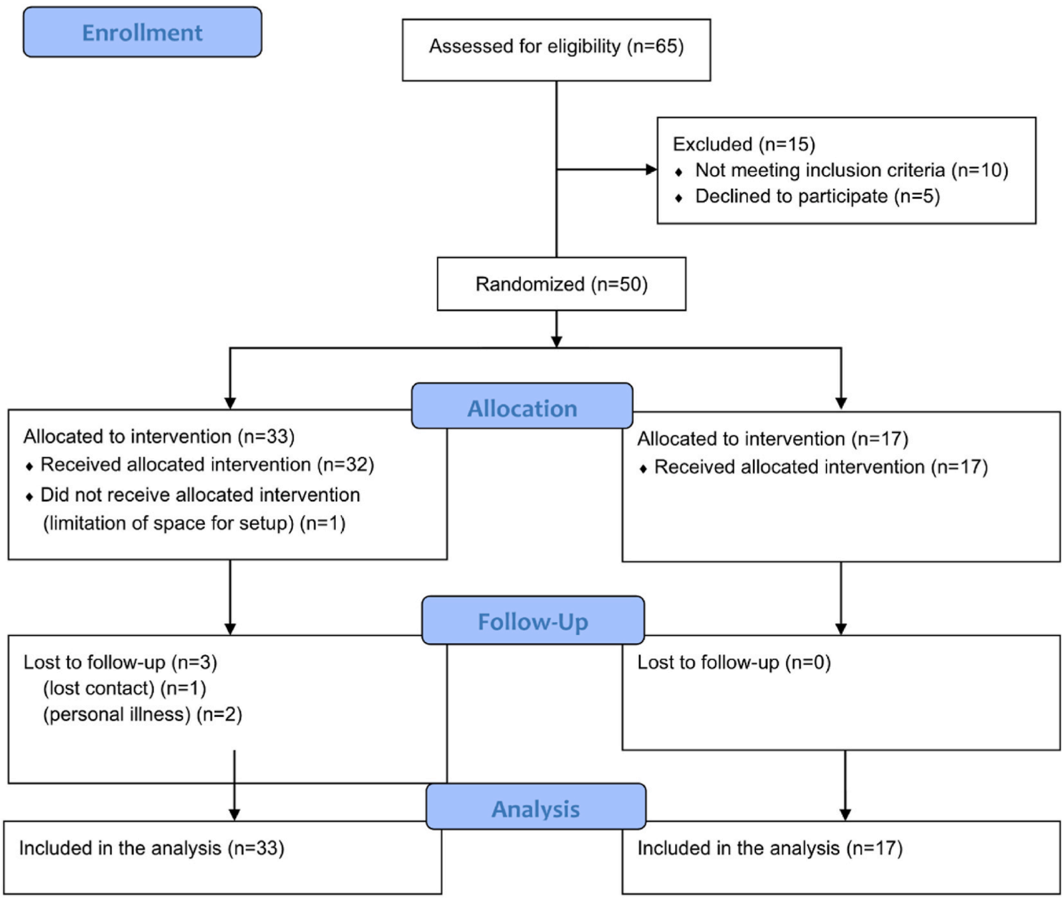


**Fig. 1.** Flowchart of participant enrollment, allocation, follow-up, and analysis.

**Table 1**
Participant characteristics.

| Variables | Intervention group (n = 33) | Control group (n = 17) |
|---|---|---|
| Sex, n (%) | | |
| Female | 27 (81.8) | 10 (58.8) |
| Male | 6 (18.2) | 7 (41.2) |
| Age (y), mean (SD) | 70.9 (5.8) | 69.9 (4.5) |
| Height (cm), mean (SD) | 159.2 (6.5) | 161.9 (7.9) |
| Weight (kg), mean (SD) | 60.3 (11.9) | 63.3 (11.1) |
| Living status, n (%) | | |
| Home alone | 5 (15.2) | 1 (5.9) |
| Home with others | 28 (84.8) | 16 (94.1) |
| Education level, n (%) | | |
| Elementary school graduation or less | 5 (15.2) | 5 (29.4) |
| Middle school | 3 (9.1) | 2 (11.8) |
| High school | 14 (42.4) | 4 (23.5) |
| Junior college | 1 (3.0) | 1 (5.9) |
| University or above | 10 (30.3) | 5 (29.4) |
| Currently employment, n (%) | | |
| Yes | 10 (30.3) | 6 (35.3) |
| Alcohol consumption in 1 mo prior to study, n (%) | | |
| ≥1 | 4 (12.1) | 6 (35.3) |
| Smoking, n (%) | | |
| Never | 29 (87.9) | 12 (70.6) |
| Former | 4 (12.1) | 4 (23.5) |
| Current | 0 (0.0) | 1 (5.9) |
| More than 1 fall prior to year, n (%) | 3 (9.1) | 1 (5.9) |
| No. Of comorbidity diseases, mean (SD) | 0.8 (0.6) | 1.1 (1.0) |
| No. Of medication, mean (SD) | 1.5 (0.9) | 1.8 (1.4) |
| Mini Nutrition Assessment score, mean (SD) | 26.3 (2.3) | 25.7 (2.9) |
| Short Physical Performance Battery score, mean (SD) | 11.52 (1.06) | 11.24 (0.97) |
| Physical Activity Scale for Elderly score, mean (SD) | 130.58 (63.64) | 139.35 (38.14) |
| Self-Efficiency for Exercise score, mean (SD) | 50.09 (22.55) | 49.76 (24.12) |
| Short Geriatric Depression Scale score, mean (SD) | 1.24 (2.56) | 1.53 (2.79) |

SD, Standard deviation.

**Table 2**
Participant use of internet and digital devices.

| Use of internet and digital devices | Intervention group (n = 33) | Control group (n = 17) |
|---|---|---|
| Digital devices available at home, n (%) | | |
| Personal computers | 23 (69.7) | 12 (70.6) |
| Laptops | 13 (39.4) | 4 (23.5) |
| Smartphone | 33 (100.0) | 17 (100.0) |
| Television | 32 (97.0) | 17 (100.0) |
| Digital tablet | 6 (18.2) | 1 (5.9) |
| Smart peripherals | 8 (24.2) | 3 (17.6) |
| Accessing internet using digital devices, n (%) | | |
| Yes | 28 (84.8) | 14 (82.4) |
| Experienced ≥1 exercise using digital devices, n (%) | | |
| Yes | 17 (51.5) | 7 (41.2) |
| No | 16 (48.5) | 10 (58.8) |
| Digital devices used during exercise, n (%) | | |
| Desktop computers or laptops | 3 (14.3) | 0 (0.0) |
| Smartphone or digital tablet | 11 (52.4) | 2 (25.0) |
| Television | 7 (33.3) | 6 (75.0) |
| Game consoles | 0 (0.0) | 0 (0.0) |
| Usefulness of exercise using digital devices, n (%) | | |
| Very helpful | 6 (35.3) | 1 (14.3) |
| Little helpful | 11 (64.7) | 5 (71.4) |
| Non-helpful | 0 (0.0) | 1 (14.3) |

physical function and manage health (mean 3.9 [SD 0.7]). However, the degree of willingness to recommend the OASIS Pro to others was low (mean [SD]: 3.3 [1.0]). The participants' remarks on satisfaction and requirements regarding the intervention are summarized in Supplementary Material 2. In addition, other uncommon, usability issues worthy of attention are explained in the discussion.

The results of the STAM questionnaire, which were rated on a 5-point Likert scale, are shown in Table 3. The participants reported a positive experience overall and that the tool was very easy to use (mean score for both: 3.9). Perceived enjoyment and usefulness showed fair levels, with average scores of 3.5 and 3.6, respectively. The score for intention to use was relatively low (mean [SD]: 3.3

[1.1]).

### 3.3. Potential benefits

In the intervention group, the mean (SD) SPPB score improvement was 0.138 (0.639) at 1 month and 0.172 (0.658) at 2 months. In the control group, the mean (SD) SPPB score improvement was 0.471 (0.717) at 1 month and 0.706 (0.985) at 2 months. There were no significant differences between the two groups (Table 4). The intervention group showed significant improvements in self-reported physical activity (adjusted difference [SE], – 16.930 [7.013]; p = 0.016) and a significant change in the PASE score at 1 month. There were no between-group differences in self-efficacy for exercise and depression at any time point, and there were no significant improvements in either group (Table 4).

## 4. Discussion

This randomized controlled pilot study evaluated the feasibility and potential benefits of a digital technology-supported home exercise intervention in older adults within 1 and 2 months of follow-up. Good engagement with acceptable satisfaction with the intervention was indicated. In addition, the intervention group reported that a digital technology-supported exercise intervention was effective in preventing the worsening of health. Although there were no sustainable health benefits in the outcome measures, compared to the control group, the intervention group exhibited significantly higher improvement after 1-month self-reported physical activity. Nevertheless, it is important to interpret these findings cautiously, taking into account the study's design, the substantial variation between the SPPB scores used for sample size calculation, and those of the study participants, as well as the brief duration of the intervention.

Interestingly, our feasibility results supported the acceptance of digital healthcare by older adults. Most participants completed the new digital technology-supported exercise intervention 3 times a week, on average, for 1 month. In line with the results of other studies on access to digital health in older people [21,45], participants in our study had a high level of digital competence and experienced digital health services; as much as half of them had exercised using a digital device at least once. In addition, all participants were living in Korea, where digital devices and services are widespread and available enough to be called an IT powerhouse [46]. Further, with respect to mobile phone use, the participants might have had more interest in or a positive attitude toward these digital technology-based interventions, as reported in previous studies [45,47,48]. When designing this intervention, human support for sufficient training in digital technology was considered an element of trust [49]. These characteristics of the participants and interventions could explain the high engagement in digital technology-based exercise interventions among older adults.

The STAM and usability scores indicated mostly positive results. Some participants recognized the benefits and importance of regular exercise and thus performed it by themselves after completion of the intervention, similar results to previous studies [16,50]. However, scores of perceived enjoyment, usefulness, and intention to use were lower than those of other items. Studies have shown that older adults with higher levels of perceived enjoyment, usefulness, and ease of use are more likely to use digital health technologies [51–53]. The enjoyment of using the system, which is related to higher engagement rates [23], may not have been met because there are fewer gamification elements than other exergames. During the intervention, participants experienced exercise discontinuation due to disruptions in internet connection or program errors and the inconvenience of wearing the IMU sensors. It might be difficult to perceive usefulness, such as positive lifestyle changes and the promotion of social participation, owing to the short intervention period and the participants' good mobility or physical functioning. This may have influenced the low score for intention

**Table 3**
Descriptive results of each construct and corresponding items in STAM (n = 29).

| STAM construct and corresponding items | Mean (SD) |
|---|---|
| **User experience** | **3.9 (0.5)** |
| This device gave me a new experience. | 4.1 (0.7) |
| This device was easy to use. | 3.8 (0.8) |
| Overall, this device gave me a positive experience. | 3.9 (0.5) |
| **Perceived enjoyment** | **3.5 (0.7)** |
| It was very attractive to use this device. | 3.5 (0.7) |
| It was a pleasure to use this device. | 3.5 (0.8) |
| It was fun to use this device. | 3.5 (0.9) |
| **Perceived usefulness** | **3.6 (0.7)** |
| Using this device has made my life easier. | 3.3 (0.8) |
| Using this device was useful for increasing daily activities or social engagement. | 3.6 (0.8) |
| Using this device was more effective in maintaining health. | 3.9 (0.7) |
| **Perceived ease of use** | **3.9 (0.6)** |
| Overall, it was easy to use this device. | 3.9 (0.7) |
| Learning how to operate this instrument was easy for me. | 4.0 (0.7) |
| I had no problems using this machine proficiently. | 3.8 (0.9) |
| **Intention to use** | **3.3 (1.1)** |
| In the future, I intend to use this home digital exercise device for physical health management. | 3.4 (1.1) |
| In the future, I intend to continue to use this home digital exercise device for physical health management. | 3.2 (1.1) |

STAM, Senior Technology Acceptance Model; SD, Standard deviation.

**Table 4**
Intervention effects on outcome measures.

| Variables | Intervention group (n = 29) | | Control group (n = 17) | | Adjusted difference (SE) | P-value[b] |
|---|---|---|---|---|---|---|
| | Mean (SD) | P-value[a] | Mean (SD) | P-value[a] | | |
| SPPB change, score | | | | | | |
| 1 month | 0.138 (0.639) | .234 | 0.471 (0.717) | .023 | 0.092 (0.114) | .417 |
| 2 months | 0.172 (0.658) | .160 | 0.706 (0.985) | .016 | −0.108 (0.091) | .235 |
| PASE change, score | | | | | | |
| 1 month | 17.069 (29.187) | .002 | −2.529 (23.402) | .510 | 16.930 (7.013) | .016* |
| 2 months | 7.483 (38.742) | .149 | −8.471 (30.463) | .196 | 13.285 (9.440) | .159 |
| SEE change, score | | | | | | |
| 1 month | 7.379 (18.978) | .045 | 1.647 (14.418) | .644 | 6.809 (4.936) | .168 |
| 2 months | 4.690 (20.352) | .225 | −1.824 (16.106) | .647 | 7.590 (4.145) | .067 |
| SGDS change, score | | | | | | |
| 1 month | −0.276 (1.032) | .174 | 0.059 (0.827) | .763 | −0.408 (0.232) | .079 |
| 2 months | −0.172 (1.649) | .750 | −0.118 (1.054) | .483 | −0.128 (0.392) | .745 |

*$p < 0.05$.
SD, Standard deviation; SE, Standard error; SPPB, Short Physical Performance Battery; PASE, Physical Activity Scale for Elderly; SEE, Self-Efficiency for Exercise; SGDS, Short Geriatric Depression Scale.
[a] Using Wilcoxon-signed rank test or paired sample *t*-test.
[b] Using a linear mixed model with no imputation.

to use as one of indicators of adoption. Although we applied a more accurate exercise intervention using IMU sensors and 3D Kinect cameras, the participants needed not only scores, but also more personalized and detailed real-time feedback, for example, descriptions of incorrect poses, such as direction and movement speed. Besides, one participant said that he felt neck discomfort while looking at the screen during exercising while standing sideways because of the properties of the 3D Kinect camera. The use of IMU sensors in this study helped solve the problem of sensing by limiting postural change (i.e., the supine position, which is not considered in this study) and occlusion by someone or something [54,55]. However, IMU sensors provide the load of wearing and administration [56,57]. Advanced 3D human pose estimation techniques without wearable sensors may be suitable for addressing these usability issues or customizing the feedback, especially in confined spaces. To improve physical function effectively, efficiently, and comfortably through exercise, comprehensive usability must be improved through relevant discussions among researchers.

With respect to the health outcome, we attempted to objectively measure it using a validated multi-sensor-based kiosk to decrease the risk of internal bias. There was no meaningful difference in the SPPB scores by intervention. This result may be explained by the fact that most participants enrolled in our study had good physical performance and were community-dwelling older adults living in urban areas who were able to engage in daily activities or social activities. Particularly, because 76 % of the participants in the intervention group already had an initial score of 12, there was little room for improvement. A previous study reported that in well-functioning older adults, a ceiling effect may occur, and the SPPB may have limitations in discriminating physical performance [58]. During the assessment, research assistants observed that both groups performed better over time, especially in the five-repetition sit-to-stand test. The control group showed better static balance over time, but there were no statistically significant differences in the sub-tests between the groups. In the control group, it may be the result of learning effects from study participation [59].

Focusing on mobility among health target areas, this AR-based home intervention provided evidence-based, well-documented, practical exercises for balance and lower-extremity strengthening to prevent falls and sarcopenia. We identified the benefits of physical activity and trends in improved exercise self-efficacy and depressed mood in older adults with comorbidities but without mobility impairment and depression. Notably, the intervention groups reached the MCID of the PASE (i.e., between 17- and 25 points) post-intervention [60]. In similar implementations, Otago and balance training-based mixed reality technologies showed positive effects on physical function among older adults [50]. A recent systematic review [19] reported that AR technology-supported rehabilitation and training of older adults have mainly been leveraged for one's physical (i.e., balance and mobility) and cognitive (i.e., attention) well-being and recommended exploring the effects in a clinical setting rather than a research setting. Our exploration extrapolates the types of digital home exercise intervention towards health promotion and maintaining independence in older adults, especially in a domestic setting real-home setting and in the context of public health.

Considering environmental factors, such as limited resources, diverse needs for healthcare, and advances and demands in digital technology, the Korean government is operating a healthcare service model using artificial intelligence and Internet of Things technology for the elderly with poor access to healthcare. In addition, the digital information levels of Korean older adults over the age of 55 years have been increasing over the past 3 years [61] due to the creation of an environment for digital information utilization for the elderly population and the influx of digital generations; thus, it is cautiously expected that it is cautiously expected that the digital health literacy of the elderly will be better. For the diffusion of digital healthcare services, further investigations should conduct a full-scale RCT by specifying the targeted older population, such as the types of digital information levels [62], frailty status, and settings, after delicate usability correction.

The current study not only reported the delivery, resources, and administration of digital home exercise intervention in community-dwelling older adults but also crucial usability issues and requirements for better intervention. Nevertheless, this study has some limitations. First, although we adjusted for digital offers for older adults, the participants still exhibited diverse usability issues and conflicting responses. Usability issues may occur because of diverse technology capabilities and technological properties.

Secondly, volunteers from our department's Research Registry might have represented older individuals who were already active, potentially limiting the generalization of the study findings to the entire older population. Thirdly, it may be significantly challenging to generalize this method and its results in the context of older adults with a digital divide or to those living in rural settings. Individual subjective factors (i.e., age, education level, and technology usage capabilities) remain diverse among older people [48,63]. However, strong social and environmental support from government agencies, research, and stakeholders will allow the adoption of digital healthcare tailored to the elderly to alleviate inequities in the future. Fourth, we did not address the concrete progress and outcomes regarding individual needs and healthcare system challenges. Future research should focus on such practical implications.

## 5. Conclusions

This pilot randomized controlled study suggests that evidence-based digital exercise interventions can be feasible in real-world home settings for health promotion in community-dwelling older adults, as evidenced by the good engagement and enhanced physical activity found in this study. In the future, an in-depth approach may be required that addresses various aspects related to older adults, including individual factors, available resources, environmental changes, healthcare system challenges, and advancements in age-friendly technology.

## Ethics statement

The study was approved by the Institutional Review Board of the Samsung Medical Center (IRB No. 2021-10-142). All participants were provided a sufficient description of the study procedure and provided written informed consent.

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## Data availability

If a reasonable request, after the approval by the Data Review Board, the datasets used in the current study are available.

## CRediT authorship contribution statement

**Ji Young Lim:** Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis. **Heeju Yu:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Yeah Eun Kwon:** Writing – review & editing, Investigation. **Jong Geol Do:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Ji Hye Hwang:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interestsOASIS Pro used in the study was supported by the RBIOTECH corp.

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none.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24933.

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