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RESEARCH

Robot-assisted exercise improves gait and physical function in older adults: a usability study

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Abstract

Background With increasing age, individuals are more likely to experience physical disabilities, functional declines, and mobility limitations. Wearable robots or exoskeletons are relatively new technologies that can help address these issues, reduce healthcare costs, and support home healthcare, decreasing the burden of chronic disease. The purpose of this study was to investigate the usability of Bot Fit after task-specific physical activities and functional gait training, as well as to examine the effects of a wearable hip exoskeleton, Bot Fit, on gait, physical function, and muscle strength in older adults living in residential care facilities.

Methods A total of 32 older adults living in residential care facilities were included in this uncontrolled study. All participants performed eight weeks of task-specific physical activities and functional gait training using Bot Fit, with three exercise sessions per week (24 sessions in total). They were assessed at three time points: pre-test (baseline, T0), mid-test (after the 12 exercise sessions, T1), and post-test (after the last exercise session, T2). Each assessment evaluated functional outcomes (10-m walk test [10MWT], timed up-and-go [TUG], 6-min walk test [6MWT], Berg balance scale [BBS], four-square step test [FSST], and geriatric depression scale-short form [GDS-SF]), as well as muscle strength of the lower extremities. After the post-test, the participants completed a questionnaire to evaluate Bot Fit usability.

Results A significant improvement was observed in all physical assessments, including the 10MWT, TUG, 6MWT, BBS, and FSST, from T0 to T2. It is noteworthy that 10MWT, TUG, and BBS also changed significantly from T0 to T1 and from T1 to T2. Muscle strength in hip flexion, hip extension, knee flexion, knee extension, ankle dorsiflexion, and ankle plantar flexion all improved significantly from T0 to T2, with knee flexion, knee extension, ankle dorsiflexion, and ankle plantar flexion showing significant improvements at all time points. Additionally, on the usability questionnaire, most participants provided positive feedback about their experience with Bot Fit.

Conclusion The findings of this study suggest that task-specific physical activity and functional gait training with Bot Fit have several key advantages for improving gait, physical function, and muscle strength in older adults living in

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residential care facilities. The findings support the application of Bot Fit to physical activity and functional gait training to improve age-related declines in physical function and muscle strength and to provide important insights into future robot-assisted exercise devices.

Trial registration URL: https://register.clinicaltrials.gov/. Unique identifier: NCT04610190 (10/26/2020).

Keywords Older adult, Gait, Physical function, Muscle strength, Wearable hip exoskeleton, Usability

Introduction

Improvements in living conditions and advancements in medicine and technology are increasing the life expectancy and proportion of older people worldwide, and a rapidly aging population is being reported [1]. The population of older people is growing by 2% each year, which is considerably faster than the population as a whole. For at least the next 25 years, the population of older persons is expected to continue growing more rapidly than other age group [2–4]. With increasing age, individuals are more likely to experience physical disability, functional decline, and mobility limitations [5]. Reductions in physical function in old age can lead to loss of independence, the need for hospitalization and long-term nursing-home care, and premature death [6].

In this context, the maintenance of mobility is considered fundamental to ensuring high quality of life, social inclusion, and active aging, allowing older adults to continue to lead dynamic and independent lives. Mobility is a key component of good health during a lifetime and is necessary for older adults to retain their independence. Mobility impairment has been shown to be an early predictor of physical disability and is ultimately associated with falling, loss of independence, future institutionalization, and death. For these reasons, researchers and older adults themselves are increasingly interested in ways to maximize mobility during aging [7–9].

Self-reported mobility limitations are common in older adults. Approximately one-third to one-half of persons 65 years of age or older report difficulty in mobility related to walking or climbing stairs [10]. Isolation and loss of social activity resulting from reduced mobility can lead to depression and other adverse mental health outcomes. Individuals with mobility limitations are also at higher risk for reduced access to health services and increased institutionalization. Ultimately, mobility limitations can lead to further frailty and disability and increased risk of premature mortality [7]. For older people with mobility limitations, walking difficulty is a common and costly problem [11, 12]. The altered biomechanics (i.e., decreased range of motion of the ankle, knee, and hip joints, flexed trunk posture, and decreased ankle plantar flexion power at push-off [13–15]), and disrupted movement control (i.e., increase in stride length and time variability, reduced rate of forward momentum, and difficulty transitioning from stance to swing [16, 17]) have been reported to result in gait pattern changes typically associated with increased age. The constellation of deficits that characterize age-related walking problems contribute to an inefficient gait [18, 19].

The World Health Organization (WHO) published guidelines on the importance of regular physical activity in order people [20]. According to these guidelines, exercise is an efficient and cost-effective means of preventing the natural decline of functional capacity with age. Physical activity and exercise can help prevent and manage certain chronic diseases and health conditions. In addition, the positive effects of physical activity include increased independence in self-care activities, improved self-esteem, improved quality of life, longer life expectancy, and decreased mortality. A 42% decrease in the risk of falling is another positive effect for older people [21]. Walking is the most common form of physical activity, and promoting walking is an important part of the drive to improve overall physical activity levels among older adults [22]. Compared to many sports and other recreational activities, walking is a popular, familiar, convenient, and free form of exercise that can be incorporated into daily life and sustained into old age [23]. However, the reduced physical function of many older adults is a major barrier to regular execution of a standard exercise program, including walking. Therefore, alternative exercise programs that include regular physical activity for older people should be developed.

Robotics was first introduced to the healthcare industry in 1985 through robot-assisted surgery [24]. Robotic technology development has continued in surgical and rehabilitation medical fields, is actively used in clinical settings, and its applications are expected to expand in the future [25, 26]. Wearable robots or exoskeletons are a relatively new technology that can address mobility issues, reduce health-care costs, and support home healthcare, thereby preventing chronic disease [27–29]. Several systematic reviews and meta-analyses have suggested the positive effects of robot-assisted exercise [30–34]. Our previous randomized controlled trial results revealed that long-term walking exercise with wearable lower-limb exoskeletons is effective in improving age-related declines in gait, physical function, and cardiopulmonary metabolic efficiency among older adults and stroke patients [35–37]. Additionally, we investigated the immediate effects of Bot Fit on gait performance

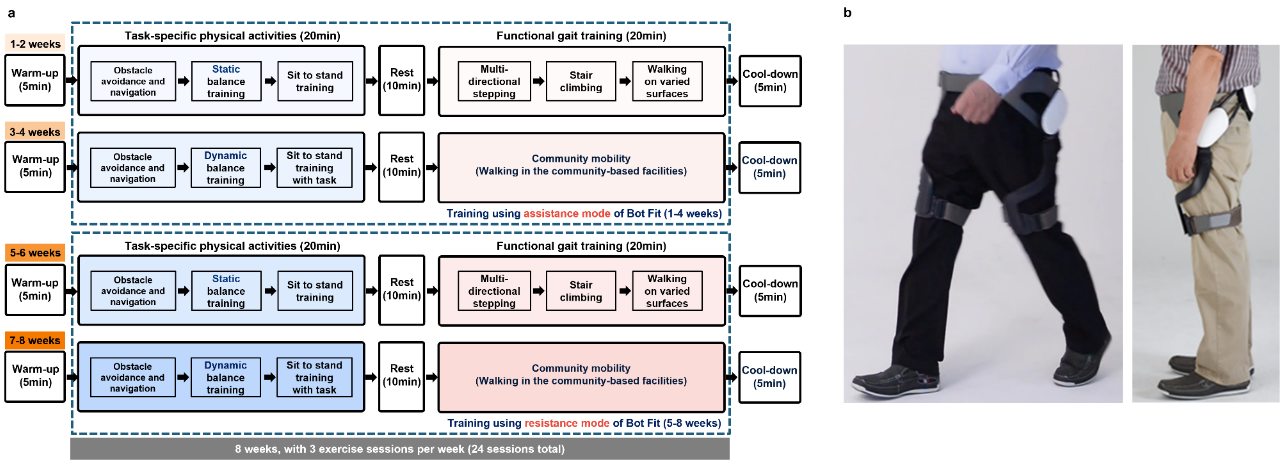

Fig. 1 (**a**) Experimental protocol, (**b**) Appearance of the Bot Fit device

Table 1 Baseline characteristics of participants

Characteristics	All ($n = 32$)	SPPB 8–10 ($n = 18$)	SPPB 11–12 ($n = 14$)
Age, years	79.78 (3.28)	81.78 (2.37)	77.21 (2.39)
Sex (male/female)	10 / 22	7 / 11	3 / 11
Height, cm	157.96 (7.52)	158.71 (8.28)	156.99 (6.58)
Weight, kg	61.20 (8.52)	63.77 (8.94)	57.89 (6.89)
Body mass index, kg/m^2	24.46 (2.17)	25.23 (1.99)	23.46 (2.03)
Short physical performance battery (0–12)	10.41 (1.36)	9.39 (0.85)	11.71 (0.47)**
10-m walk test, m/s	1.30 (0.09)	1.23 (0.17)	1.41 (0.74)**
Timed up-and-go test, sec	9.16 (1.65)	10.02 (1.67)	8.06 (0.74)**
6-min walk test, m	400.43 (58.89)	372.78 (46.64)	435.96 (54.82)**
Berg balance scale (0–56)	47.43 (4.28)	45.00 (4.00)	50.43 (2.21)**
Four-square step test, sec	9.56 (1.96)	10.26 (2.37)	8.68 (0.58)*
Geriatric depression scale-short form (0–15)	2.66 (2.19)	3.50 (2.38)	1.57 (1.34)*

Data are expressed as the mean (standard deviation)

Significant difference compared to SPPB 8–10 group (Mann–Whitney U test, *$P < 0.05$, **$P < 0.01$)

and brain activity modulation in order people and stroke patients, as well as its impact on cardiopulmonary metabolic efficiency during stair ascent in order people [28, 38]. The demand for wearable devices and the development of accompanying technology have been increasing, and research on wearable robotics has grown [39]. However, research on the usability of wearable robots for lower extremities is relatively limited compared to performance studies [40]. To promote the use of exoskeleton devices, usability and acceptability must be evaluated by actual users in terms of wearability.

We developed a wearable robotic hip exoskeleton, Bot Fit, to provide gait assistance in older adults. This device, shown in Fig. 1, can train the wearer's muscles and support their movements by providing controllable assistive and resistive force/torque at the hip joint. In our previous studies, we demonstrated that Bot Fit decreased the metabolic energy cost and improved gait efficiency during walking and stair climbing in community-dwelling older adults [27, 28, 35, 36, 38]. However, the usability of Bot Fit was not adequately assessed in the concept design phase. The primary purpose of this study was to evaluate the usability of a wearable hip exoskeleton, Bot Fit, in older adults living in residential care facilities. Additionally, the study aimed to investigate the effects of Bot Fit on gait, physical function, and muscle strength after task-specific physical activities and functional gait training. Subgroup analysis was also conducted to explore the differential effects of Bot Fit based on functional levels categorized by the Short Physical Performance Battery (SPPB).

Methods

Participants

A total of 32 order people living in residential care facilities (Samsung Novel County, Youngin-si, Gyeonggi-do, Republic of Korea) were included in this study, and their baseline characteristics are shown in Table 1. Based on history taking and functional assessment, we excluded individuals with a history of neurological or musculoskeletal disorders that affect walking capacity, efficiency, or endurance. Inclusion criteria were healthy older adults aged 65 to 85 years without a history of central nervous system disease. Exclusion criteria were individuals with [35] difficulty walking independently owing to problems such as visual field defects or fractures [27], severe arthritis or orthopedic problems that limit the passive range of motion of the lower extremity [28], difficulty understanding the experimental procedure owing to severe cognitive decline (Mini-Mental State Examination– Korean ≤ 10) [36], difficulty participating in exercise programs owing to having a disease such as uncontrolled hypertension or diabetes [25], severe dizziness, or [41] obesity (defined as BMI > 35).

The number of participants was calculated using G*Power software (version 3.1.9.7) with a significance level of 5% and a statistical power of 85%. The change in gait speed following gait training was estimated using a mean difference of 0.08 and a standard deviation of 28.75, resulting in an expected effect size of 0.57 [42]. The calculation indicated that a minimum of 30 participants would be required to detect significant differences. To account for potential dropouts, 32 participants were recruited.

The study procedures were approved by the ethics committee of the Samsung Medical Center Institutional Review Board (approval number: 2020-10-016) and registered with ClinicalTrials.gov (NCT04610190). Written informed consent was obtained from all participants before they entered the study, and all methods were conducted in accordance with the approved study protocol.

Exercise intervention

The exercises were designed to improve gait, physical function, and muscle strength in order people. All participants performed task-specific physical activities and functional gait training with Bot Fit, including obstacle avoidance and navigation, static and dynamic balance training, sit to stand exercises, multidirectional stepping, stair climbing, walking on varied surfaces, and community mobility (walking in a community-based facility) [35]. These activities were conducted using various environments and facilities both inside and outside Samsung Noble County. Exercise was structured as an individual program rather than a group program, allowing participants to engage in activities at their own pace under supervision. The exercise intervention was conducted at a perceived exertion between 12 and 16 on Borg's Rating of Perceived Exertion (RPE) scale (somewhat hard–hard) [43] for eight weeks, with three exercise sessions per week (24 sessions in total). The duration of each exercise session was 60 min: 5 min of warm-up, 50 min of exercise with 10 min of rest, and 5 min of cool-down. The exercises in each session were performed in proportional times per station. Each station was allocated an equal duration to ensure a balanced training effect across all modalities. This approach was designed to maintain consistency and allow participants to engage with each exercise type equally within the structured session. The first four weeks of exercise were undertaken using Bot Fit assistance mode. In the next four weeks of exercise, Bot Fit resistance mode was used (Fig. 1a). The criterion for defining 4 weeks for each modality of the Bot Fit (assistance vs. resistance) was based on our previous study [36], which demonstrated that 4 weeks of robot-assisted exercise in both modes effectively improved physical function in older adults. This timeframe was selected to ensure adequate exposure to each modality while maintaining a practical and manageable intervention duration. Exercise intensity was assessed with verbal questions twice during the intervention session based on the Borg RPE scale and was controlled by giving the subject a rest period and adjusting the Bot Fit assistive or resistive torque applied. For subject safety, a physical therapist supervised the intervention. If a participant missed an exercise session during the intervention, an additional session was offered later in the week or at the end of the intervention period. We monitored attendance and tracked dropouts to assess the program's acceptability. All participants successfully completed the 8-week program, with an overall attendance rate of 95%. There were no dropouts during the program.

Wearable hip exoskeleton, bot fit

The wearable hip exoskeleton, Bot Fit, was developed at Samsung Electronics (Suwon, Republic of Korea) to provide gait assistance and resistance using a delayed output feedback control (DOFC) algorithm that we developed for mobility-reduced people and older adults. Bot Fit consists of snap-together components weighing 2.99 kg in total. The waist part houses two actuator modules, a Bluetooth module, and a control module. Each actuator module houses a motor, an embedded angular position sensor, and a controller. The control module contains a central processor, an inertial measurement unit sensor, and a rechargeable battery pack. All components and exterior structures are mass-producible and have a commercially acceptable reliability, weight, and price (Fig. 1b). The specialized DOFC control algorithm for walking exercise noted above is a time-delayed, self-feedback controller for walking exercise with a wearable robot [44]. This time-delayed, self-excited feedback control method does not include a gait phase estimator or reference lookups for generating assistive and resistive torques. Assistive and resistive torques are immediately computed and applied as the user changes joint angles.

The respective torques are updated following hip motion changes at each control period (100 Hz).

Assessment tools and data collection

The participants were assessed at three time points: pre-test (baseline, T0), mid-test (after 12 exercise sessions, T1), and post-test (after the last exercise session, T2). Each assessment measured functional outcomes and muscle strength. To ensure consistency and minimize variability, the same assessor conducted all evaluations. Importantly, the evaluations at T0, T1, and T2 were performed without the Bot Fit on, allowing for accurate assessment of participants' gait performance and physical function. After the post-test, the participants completed a questionnaire to evaluate the usability of Bot Fit.

The functional outcomes were determined via a 10-m walk test (10MWT), timed up-and-go (TUG) test, 6-min walk test (6MWT), Berg balance scale (BBS) assessment, four-square step test (FSST), and geriatric depression scale-short form (GDS-SF) assessment. The 10MWT is a validated and reliable tool for determining walking speed in adults. For 10MWT measurement, the subjects were asked to walk a total of 15 m at a comfortable speed. The time required to walk 10 m was measured, excluding the initial 2.5-m acceleration and the final 2.5-m deceleration. The result in seconds was converted to speed (m/s) [45]. The TUG test is commonly used as a screening tool for risk of falling in a community setting. To perform the TUG test, the subject is timed while they rise from an armchair, walk at a comfortable and safe pace to a line on the floor 3 m away, turn, and walk back to the chair and sit down again [46]. The 6MWT is a widely used tool to measure endurance and aerobic and functional exercise capacity. The distance covered over a time of 6 min is used as the factor by which to compare changes in performance capacity [47]. The BBS is a valid, qualitative, and efficient measure of balance measured through the performance of functional activities that incorporate most components of postural control in older individuals. The tool consists of 14 items scored on an ordinal scale of 0 to 4, with 0 being the worst and 4 being the best performance of independent tasks for a total of 56 points [48]. The FSST assesses dynamic balance and movement ability by measuring the time in which an individual walks forward, backward, and sideways over an obstacle as fast as possible [49]. The GDS-SF consists of 15 questions and is a useful screening tool for monitoring mood status and evaluating depression [50]. All assessments were conducted by an experienced physical therapist.

Muscle strength of lower extremity was measured using a portable digital handheld dynamometer (MicroFET2, Hoggan Health Industries, Salt Lake City, UT, USA), designed specifically for taking objective, reliable, and quantifiable muscle testing measurements. MicroFET2 is approved by the U.S. Food and Drug Administration and has an accuracy of ± 2%, with a sample frequency of 10 samples per second. The averages of three maximal efforts of hip flexion, hip extension, knee flexion, knee extension, ankle dorsiflexion, and ankle plantar flexion were evaluated for each individual. The muscle strength test at each time point was performed by the same physical therapist using the same measurement method [36, 51].

At the end of the study period, to evaluate the usability of Bot Fit, participants were asked to complete a closed-ended usability questionnaire. The questionnaire used a 5-point ordinal scale, 5 being the most favorable and 1 the least favorable score, with answers of "no opinion" scored as 3. As no appropriate usability questionnaire existed for evaluating a wearable hip exoskeleton, the questionnaire was developed and applied according to previous research [25, 52] and consultation with experts. Usability was split into three sub-themes: usability, acceptability, and satisfaction. Questions 1–4 related to the usability theme, questions 5–11 related to the acceptability theme, and the remaining questions [4–8] related to user satisfaction of the Bot Fit exercise program (Table 2).

Statistical analyses

Statistical analyses were performed with SPSS version 22.0 (IBM, Armonk, NY, USA), and the significance level was set to 0.05. The descriptive statistics were expressed as the mean (standard deviation, SD). Previous studies reported that a SPPB score of ≤ 10 indicates one or more mobility limitations and increased risk of a mobility impairment [53, 54]. Accordingly, subgroup analysis was performed to identify Bot Fit effects during exercise in groups divided by functional level (SPPB 8–10 and SPPB 11–12 groups). One-way repeated measures analysis of variance (RM ANOVA) was used to determine statistically significant differences between time points within groups. Post hoc tests were used to determine whether differences existed among the means of each condition, and the significance level of the tests was adjusted using Bonferroni correction. In addition, we performed Spearman's correlation coefficient analysis to examine the relationship between the overall Bot Fit usability score, as rated by the participants, and their age and baseline physical function. Since Q16 is a binary variable (resistance mode or assistance mode), we conducted point-biserial correlation analysis to assess the relationship between this binary variable and continuous or ordinal variables.

Results

Bot fit usability

The results of the usability questionnaire are presented in Fig. 2. The response rate to the questionnaire was 100%, indicating full and active participation from all

Table 2 Bot fit usability questionnaire

Domain	No.	Questionnaire
Usability	1	Bot Fit was easy to put on/take off.
	2	How much trouble did you have getting started with Bot Fit?
	3	Using Bot Fit on a daily basis was easy.
	4	Do you think Bot Fit helps with your gait and exercises?
Acceptability	5	I felt comfortable wearing Bot Fit.
	6	Bot Fit was bulky or heavy.
	7	Were you satisfied with the material of Bot Fit?
	8	Are you satisfied with the color and design of Bot Fit?
	9	Was there any disturbance caused by noise when using Bot Fit?
	10	Bot Fit interfered with my normal gait/activities.
	11	Would you recommend Bot Fit to people around you?
Satisfaction	12	Was the BOT Fit exercise program more helpful than other programs you previously participated in?
	13	Do you think the total number of program sessions and the time of each session are appropriate?
	14	Would you like to continue participating in an exercise program using Bot Fit?
	15	Would you recommend the Bot Fit exercise program to people around you?
	16	Between the assistance and resistance modes of Bot Fit, which was more helpful? ① Assistance mode ② Resistance mode

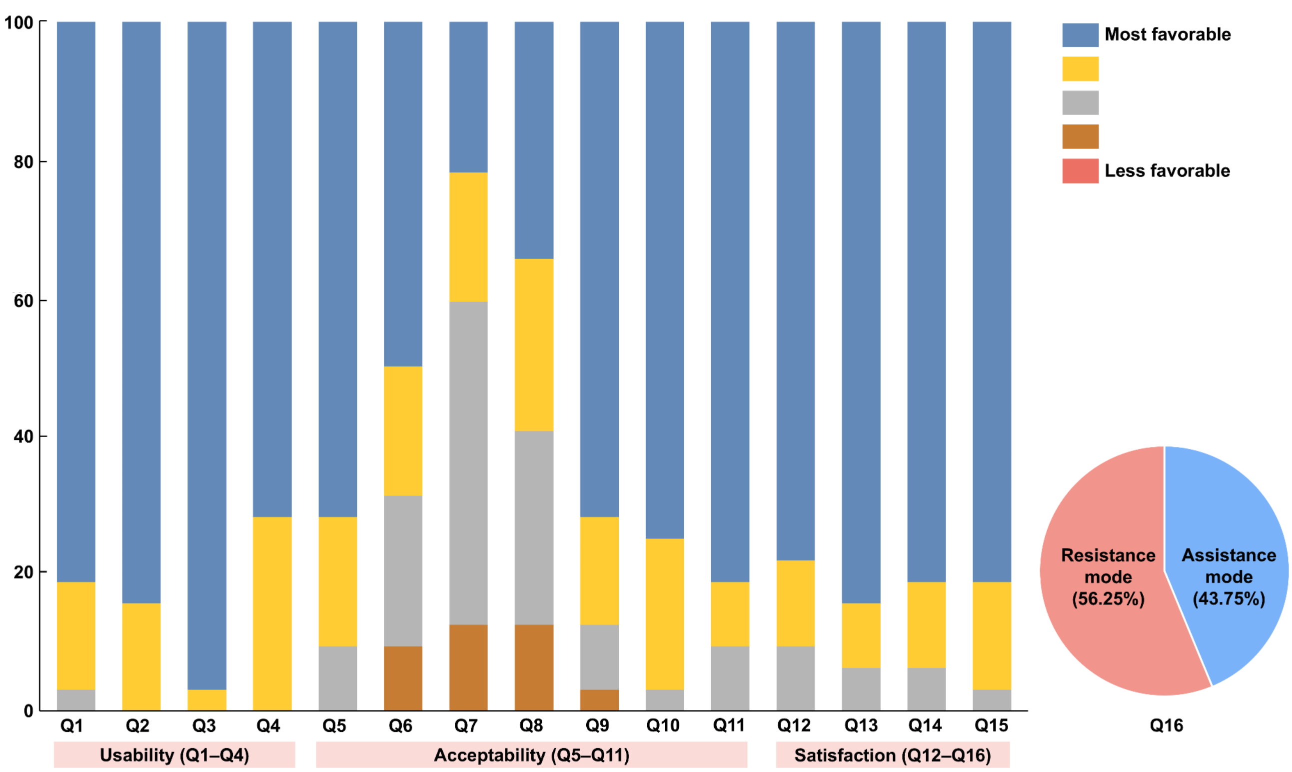

Fig. 2 Reponses to the Bot Fit usability questionnaire: Percentage of responses from the usability questionnaire classified according to usability (Q1–Q4), acceptability (Q5–Q11), and satisfaction (Q12–Q16)

individuals involved in the study. In total, 97% found that Bot Fit was easy to put on and take off (Q1). All subjects had minimal to no trouble initiating use of Bot Fit (Q2), reported that daily use of Bot Fit was easy (Q3), and that Bot Fit helped them with their gait and exercises (Q4). In addition, over 90% of participants felt comfortable wearing Bot Fit (Q5), and 70% reported that Bot Fit was not bulky or heavy (Q6). However, only 40–59% of respondents were satisfied with the Bot Fit material (Q7), color, and design (Q8). According to 87% of participants, Bot Fit was not noisy during use (Q9), and it did not interfere with normal gait or activities in 97% participants (Q10). Over 90% reported that they would recommend Bot Fit to people around them (Q11). For questions 12–15, which related to user satisfaction with the Bot Fit exercise program, over 90% of participants found the

Bot Fit exercise program to be more helpful than other programs in which they previously participated. They reported that they would continue participating in an exercise program using Bot Fit and would recommend the Bot Fit exercise program to people around them. Finally, the responses revealed a tendency to prefer the Bot Fit resistance mode (56%) over assistance mode (44%) (Q16).

Correlation between age, physical function, safety, and satisfaction

Spearman's correlation coefficient and a point-biserial correlation analysis (Table 3) were applied to elucidate the possible relationship between age, physical function/depression (10MWT, SPPB, TUG, 6MWT, BBS, FSST, and GDS-SF), and the Bot Fit usability questionnaire (16 items) completed by participants. A significant correlation existed between Q4, age, 10MWT, SPPB, and BBS ($P<0.05$, $P<0.01$), meaning that the older the user, the slower their walking speed, and the lower their SPPB and BBS scores, the more likely they were to feel that Bot Fit helped with their gait or exercises. In addition, Q12 was significantly correlated with BBS ($P<0.01$), indicating that the lower the user's BBS score, the greater their tendency to find the Bot Fit exercise program to be more helpful than other programs in which they previously participated. Finally, Q16 was significantly correlated with age, all physical assessments, and GDS-SF ($P<0.05$, $P<0.01$), indicating that the younger the user, the better their physical function, and the lower the user's GDS-SF score, the greater was their tendency to prefer resistance mode over assistance.

Effects of bot fit exercise on physical function

The changes in physical function at the T0, T1, and T2 time points are shown in Fig. 3. A significant improvement was seen in all physical assessments (10MWT, TUG, 6MWT, BBS, and FSST) from T0 to T2 ($P<0.05$). It is noteworthy that 10MWT, TUG, and BBS also changed significantly from T0 to T1 and from T1 to T2 ($P<0.05$). The 10MWT showed a significant walking speed improvement of 0.12 m/s after Bot Fit training, exceeding the MCID of 0.05 m/s. Similarly, the 6MWT improvement exceeded the MCID range of 14.0–30.5 m, reflecting clinically meaningful enhancements in functional mobility and endurance. In subgroup analysis, the SPPB 8–10 group showed significant changes in all physical assessments and GDS-SF from T0 to T2 ($P<0.05$). However, the SPPB 11–12 group showed significant changes only in 10MWT, BBS, and FSST from T0 to T2 ($P<0.05$). The T2-T0 difference values for the physical assessments of the SPPB 8–10 and SPPB 11–12 groups are presented in Table 4. The SPPB 8–10 group exhibited significantly greater improvements in BBS T2–T0 compared to the SPPB 11–12 group ($P<0.05$).

Effects of bot fit exercise on muscle strength

Figure 4 illustrates the progression of muscle strength at the T0, T1, and T2 time points. The muscle strength of hip flexion, hip extension, knee flexion, knee extension, ankle dorsiflexion, and ankle plantar flexion all changed significantly from T0 to T2 ($P<0.05$). The muscle strength of knee flexion, knee extension, ankle dorsiflexion, and ankle plantar flexion also improved significantly from T0 to T1 and from T1 to T2 ($P<0.05$); however, the strength of hip flexion and extension changed only from

Table 3 Spearman's correlation coefficient and point-biserial correlation between age, physical function, safety, and satisfaction

	Age	10MWT	SPPB	TUG	6MWT	BBS	FSST	GDS-SF
Q1	0.109	0.226	−0.103	0.149	0.292	−0.344	0.007	−0.034
Q2	0.379	−0.065	−0.257	0.140	−0.228	−0.333	0.284	0.293
Q3	−0.117	0.224	0.283	−0.185	0.302	0.020	−0.302	−0.148
Q4	**0.480****	**−0.396***	**−0.497****	0.337	−0.275	**−0.731****	0.297	0.160
Q5	0.087	−0.084	−0.081	0.086	−0.036	−0.057	−0.106	−0.228
Q6	0.092	−0.182	−0.311	0.117	0.036	−0.140	0.284	0.112
Q7	0.149	−0.167	−0.163	0.041	0.118	−0.319	−0.190	−0.129
Q8	−0.018	−0.026	0.090	0.061	0.120	−0.188	−0.040	−0.155
Q9	0.205	−0.047	−0.094	−0.002	−0.095	−0.344	−0.059	−0.006
Q10	0.061	−0.117	−0.316	0.227	−0.129	−0.178	0.284	0.119
Q11	−0.097	−0.101	−0.268	0.329	−0.070	−0.195	0.127	−0.220
Q12	0.154	−0.274	−0.321	0.276	−0.070	**−0.457***	−0.068	0.061
Q13	0.247	−0.129	−0.304	0.299	−0.353	−0.282	0.064	0.158
Q14	−0.076	0.089	0.017	−0.058	0.138	−0.202	−0.196	−0.176
Q15	−0.187	0.069	0.106	0.131	0.084	−0.150	−0.226	−0.310
Q16	**−0.606****	**0.382***	**0.783****	**−0.560****	**0.487****	**0.542****	**−0.448***	**−0.374***

Statistical significant in analysis of Spearman's correlation and point-biserial correlation (*$P<0.05$, **$P<0.01$)

10MWT: 10-m walk test, SPPB: short physical performance battery, TUG: timed up-and-go test, 6MWT: 6-min walking test, BBS: Berg balance scale, FSST: four-square step test, GDS-SF: geriatric depression scale-short form

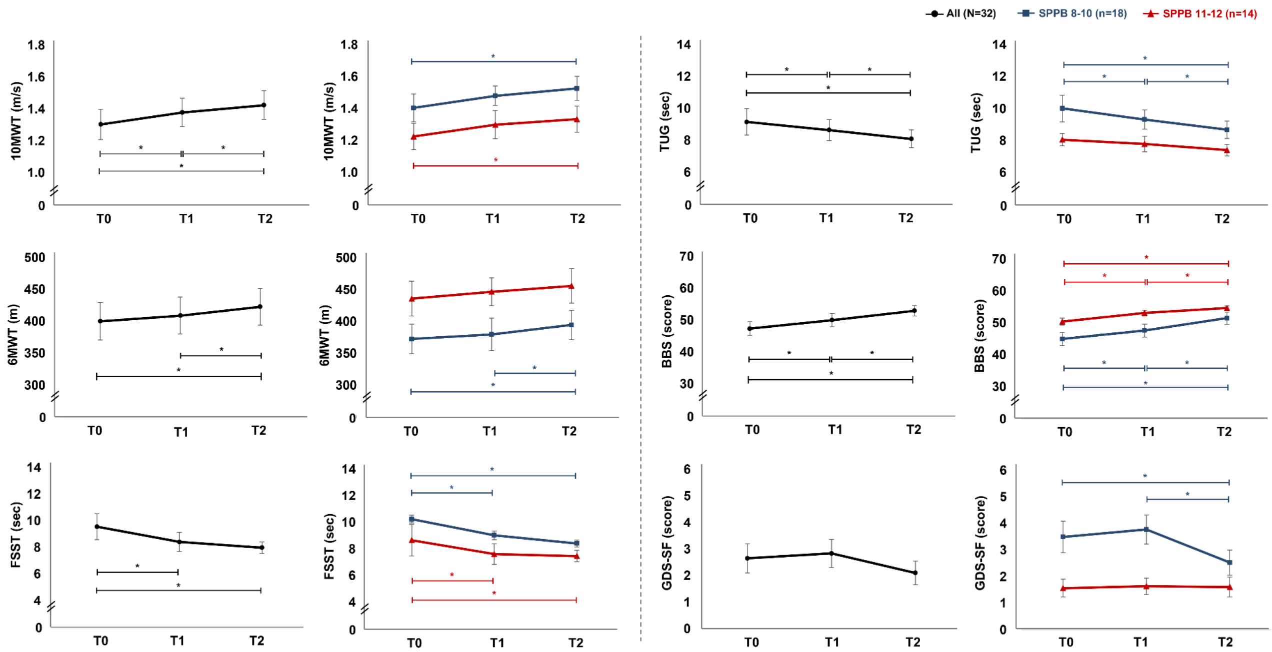

Fig. 3 Physical assessments: Changes in physical assessments at T0, T1 and T2 (*$P<0.05$)
T0: baseline, T1: after the 12 exercise sessions, T2: after the last exercise session
10MWT: 10-m walk test, TUG: timed up-and-go, 6MWT: 6-min walk test, BBS: Berg balance scale, FSST: four-square step test, GDS-SF: geriatric depression scale-short form, SPPB: short physical performance battery

Table 4 Changes in physical assessments and muscle strength in the Sub-group (ΔT2-T0)

Characteristics	SPPB 8–10		SPPB 11–12		
	Mean (SD)	95% CI	Mean (SD)	95% CI	*P*
Physical assessments					
10-m walk test, m/s	0.09 (0.11)	[0.03, 0.15]	0.12 (0.14)	[0.03, 0.20]	0.539
Timed up-and-go test, sec	-1.30 (1.21)	[-1.97, -0.63]	-0.77 (0.90)	[-1.31, -0.23]	0.209
6-min walk test, m	17.77 (23.40)	[4.81, 30.72]	14.70 (58.79)	[-20.83, 50.23]	0.854
Berg balance scale (0–56)	6.60 (2.82)	[5.04, 8.17]	4.23 (2.20)	[2.90, 5.56]	**0.022***
Four-square step test, sec	-1.63 (2.45)	[-2.77, -0.48]	-1.21 (0.72)	[-1.64, -0.77]	0.282
Geriatric depression scale-short form (0–15)	-0.53 (1.13)	[-1.16, 0.09]	0.08 (1.80)	[-1.01, 1.17]	0.285
Muscle strength (kg)					
Hip flexion	7.84 (8.30)	[3.24, 12.43]	9.75 (10.53)	[3.39, 16.11]	0.594
Hip extension	10.03 (8.29)	[5.44, 14.62]	8.45 (9.08)	[2.97, 13.94]	0.635
Knee flexion	11.73 (8.60)	[6.97, 16.50]	10.37 (5.73)	[6.91, 13.83]	0.631
Knee extension	15.34 (8.32)	[10.73, 19.94]	12.04 (9.79)	[6.13, 17.96]	0.344
Ankle flexion	14.45 (13.15)	[7.17, 21.74]	9.18 (7.05)	[4.91, 13.44]	0.208
Ankle extension	12.09 (13.60)	[4.56, 19.62]	23.48 (24.36)	[8.76, 38.20]	0.132

Data are expressed as the mean (standard deviation)

Significant difference compared to SPPB 8–10 group (Mann–Whitney U test, *$P<0.05$)

SD: standard deviation, CI: confidence interval

T1 to T2 ($P<0.05$). In subgroup analysis, both the SPPB 8–10 and SPPB 11–12 groups showed significant changes in all muscle strength categories after Bot Fit training ($P<0.05$). The T2-T0 difference values for muscle strength in the SPPB 8–10 and SPPB 11–12 groups are presented in Table 4, and no significant difference was found.

Discussion

The findings of this study highlight the usability of Bot Fit as the primary outcome, emphasizing its effectiveness and participant satisfaction. The results of the usability questionnaire revealed that most participants felt positively about their experience using the Bot Fit, indicating its feasibility and acceptability in older adults living in residential care facilities. Additionally, task-specific

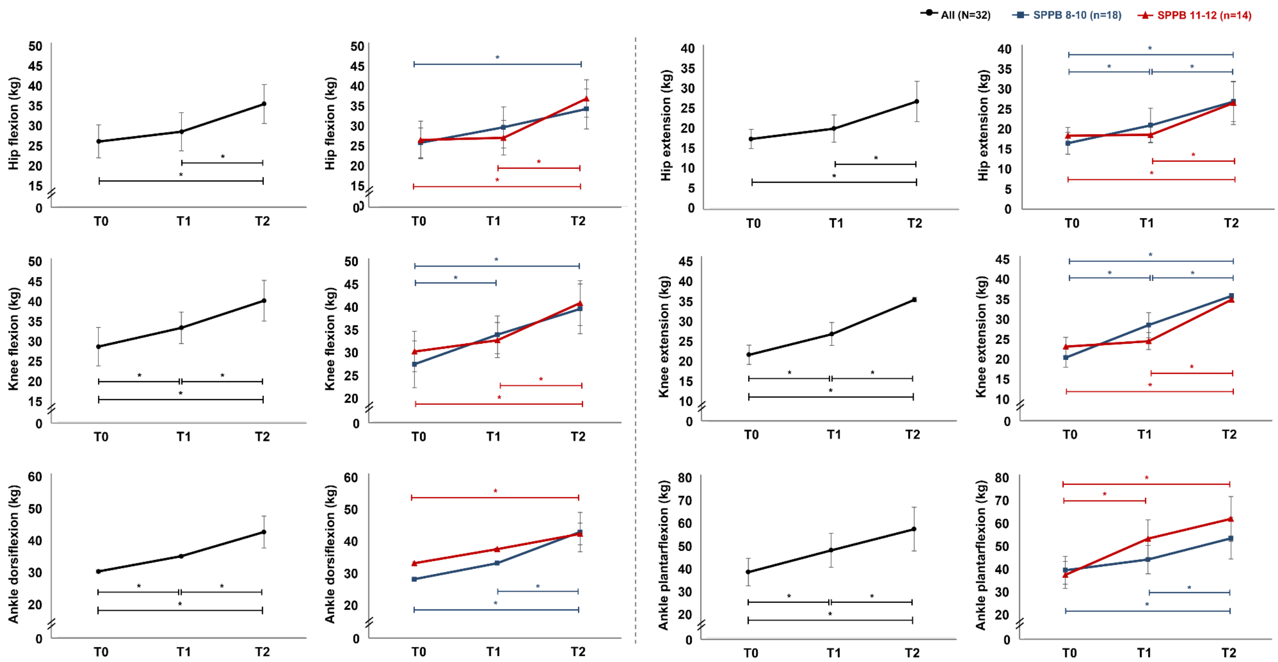

Fig. 4 Muscle strength: Changes in muscle strength of lower extremities at T0, T1 and T2 (* $P < 0.05$)
T0: baseline, T1: after the 12 exercise sessions, T2: after the last exercise session

physical activity and functional gait training with Bot Fit demonstrated several key advantages, including significant improvements in gait, physical function, and muscle strength. Physical assessments (10MWT, TUG, 6MWT, BBS, and FSST) and muscle strength of hip flexion, hip extension, knee flexion, knee extension, ankle dorsiflexion, and ankle plantarflexion all showed significant improvements after Bot Fit training, further supporting its potential for practical application.

Age-related decline in functional status is a common health problem among older adults. Common manifestations of physical degradation include, but are not limited to, changes in skeletal muscle mass and metabolism, postural instability, and increased sensory deficits, which lead to slower walking speed, higher fall risk, disability, and even death among the older adult population [55, 56]. Walking speed has been shown to be correlated with survival in older people, reflecting their overall health and functional status. Walking requires demands on multiple organ systems, including the heart, lungs, circulatory system, nervous system, and musculoskeletal system. Walking speed can be considered a summary indicator of vitality because it integrates known and unrecognized disturbances on multiple organ systems, many of which affect survival [57]. It is also a sensitive predictor of future dependence during daily living activities of people aged 75 years and older [58].

In this study, we evaluated 10MWT to examine changes in walking speed after training with Bot Fit and found a statistically significant improvement (an increase of 0.12 m/s). Moreover, we identified significantly greater changes compared with the MCID (small meaningful change = 0.05 m/s), which refers to the smallest change in an outcome that represents a meaningful health change [59]. Bot Fit supports repetitive, high-frequency, and task-specific training by providing assistive or resistive force at the hip joint, which helps either reduce or increase the physical effort required for walking, depending on the training needs. Both assistance and resistance modes were applied to all participants, regardless of their functional level. By targeting specific gait deficits such as stride length, foot clearance, and postural control, Bot Fit promotes better alignment and more efficient movement patterns. This helps participants maintain or improve gait quality and speed, reduce fall risk, and prolong functional independence [25, 27, 28, 35, 36]. The combination of assistance and resistance optimizes training effects, ensuring that even high-functioning individuals can improve gait mechanics and resilience to age-related decline. The assistance mode reduces the energy cost of walking, enabling greater endurance, while the resistance mode increases muscle workload, promoting strength development and neuromuscular coordination. Together, these complementary modalities enhance gait mechanics, improve gait speed, and support resilience to age-related decline. Our results demonstrate that Bot Fit interventions can improve the overall health status of users by providing an adaptable and effective training experience tailored to individual needs.

Gait and balance disorders are common causes of falls in older adults and often lead to injury, disability, loss of independence, and diminished quality of life [60]. Approximately 30% of community-dwelling people aged 65 years and over experience falls each year. Falls account for 40% of all injury-related deaths and lead to 20–30% of mild to severe injuries in older people, ranging from soft tissue injuries to fractures [61]. Early identification of gait and balance disorders through standardized assessment and appropriate intervention may prevent functional disability and loss of independence.

In this study, TUG, 6MWT, BBS, and FSST were assessed to investigate changes in gait and balance function. Participants completed GDS-SF to evaluate the psychological well-being of older adults, as mental health can significantly influence physical performance, motivation, and engagement in rehabilitation activities. All physical assessments demonstrated significant changes following Bot Fit training, including a decrease of 1.07 s in TUG, an increase of 22.75 m in 6MWT, an increase of 5.63 points in BBS, and a decrease of 1.58 s in FSST. However, improvements in TUG, BBS, and FSST did not reach the threshold for clinical significance, as they fell below the established MCID or minimal detectable change (MDC) values. This suggests that while changes were observed, they may still contribute to functional improvements for the user, even if they do not fully meet the thresholds for clinical significance. In contrast, 6MWT improvement exceeded the MCID range of 14.0 to 30.5 m [62], indicating a clinically meaningful enhancement in functional mobility, which could contribute to better real-world walking capacity and endurance for users. The MCID and MDC values reported in the literature are as follows: TUG (MCID = 2.9 to 4.9 s) [63], BBS (MDC = 8 points) [64], and FSST (MDC = 1.8 s) [65]. In subgroup analysis, the SPPB 8–10 group showed significant changes in all physical assessment categories and GDS-SF; however, the SPPB 11–12 group showed significant changes only in BBS and FSST after Bot Fit training. Improvements in health and functional level are generally associated with a lower incidence of depressive symptoms and improved mood status among older adults. Physical improvements are also related to superior mental health, well-being, and quality of life [36]. Improved physical functioning in the SPPB 8–10 group after Bot Fit training may therefore have had a positive effect on mood status. Older people with relatively low physical function have the potential to dramatically increase functional levels through Bot Fit training. This study offers encouraging data to suggest that improvements in functional status are possible with Bot Fit training in both fit and frail older people.

Loss of muscle strength is a critical element to consider in the detection of important age-related conditions [66]. Systematic reviews and meta-analyses have indicated that lower extremity weakness is a clinically important and statistically significant risk factor for falls and a potentially important factor in balance and postural control [67]. Therefore, muscle strength (especially that of lower extremities) should be a factor that is evaluated and treated in older adults at risk for falls and decline in physical performance. This study showed a significant increase in lower extremity strength after Bot Fit training. In subgroup analysis, both the SPPB 8–10 and SPPB 11–12 groups showed significant changes in muscle strength of all types. Measures of lower-extremity strength (force-generating capacity) may be strongly related to other variables, such as balance and physical performance [68]. Maintaining a high muscle force–generating capacity into older age is related to beneficial effects on functional performance, which might not be otherwise achieved through recreational activities. The importance of strength training in healthy aging is therefore underscored [69].

In this study, increased muscle strength of the lower extremities after Bot Fit training may have been related to improved physical function (10MWT, TUG, 6MWT, BBS, and FSST).

Performing walking exercises using the Bot Fit in resistance mode appeared to increase muscle workload, stimulating greater strength development. The resistance modality likely provided a higher mechanical load, effectively challenging the muscles and contributing to significant improvements in lower extremity strength. By simultaneously offering the benefits of both resistance and aerobic exercise, the resistance mode may serve as an essential component of multicomponent training programs designed to enhance strength, endurance, and overall mobility in older adults. Additionally, the Bot Fit enables users to engage in more physical activity with reduced effort by lowering the energy cost of walking. This efficiency allows participants to perform a greater volume of exercise, leading to improvements not only in endurance and muscle strength at the hip joint but also in the knee and ankle, ultimately enhancing overall mobility and physical function. These features make Bot Fit an effective and practical tool for improving physical activity and addressing age-related declines in mobility. Subgroup analysis revealed that improvements in muscle strength were observed across both functional-level groups, regardless of baseline physical function. This suggests that Bot Fit training is beneficial for enhancing muscle strength in older adults with varying levels of physical capability. This was evidenced by the successful completion of an 8-week exercise program by all participants, with a high attendance rate of 95% and no dropouts, suggesting that the device supports sustained physical activity. This study demonstrated that Bot Fit can have a positive effect on muscle strength as well as physical function when used as a training tool during endurance, resistance, and multicomponent exercises in older people.

Usability testing of the Bot Fit system is crucial for ensuring its effectiveness and practicality in real-world applications, particularly for older adults. While physical performance improvements are important, the true success of the device depends on how easily users can integrate it into their daily lives. Factors such as comfort, ease of use, and the intuitive nature of the device significantly influence long-term adoption and adherence. A study exploring the usability of the wearable robot Myosuit for older adults revealed positive user experiences, but many participants did not feel a personal need for the device. Key barriers included the perception of usefulness, technological attitudes, ease of use, and external support [41]. Our previous study [25] included a usability test after a single session of Bot Fit which provided initial insights into user interaction, usability related to long-term use should be obtained separately. By conducting comprehensive usability testing, which includes gathering feedback on user experiences, interface design, and overall satisfaction, we can identify potential barriers to regular use. This feedback is essential not only for improving the current version of Bot Fit but also for tailoring the system to meet the specific needs of older adults with varying levels of mobility. Ultimately, optimizing usability will ensure that the device is not only effective in improving physical outcomes but also practical and accessible to the target population [70].

In this study, we investigated Bot Fit usability during task-specific physical activities and functional gait training. The results provide vital insights for future Bot Fit development. Most participants expressed positive feedback on the usability questionnaire about their experience with Bot Fit. Nevertheless, the Bot Fit exterior (material, color, and design) requires improvement. In the future, these aspects will be addressed to improve user satisfaction. For example, in terms of potential design improvements, consideration will be given to enhancing user interface simplicity and ensuring intuitive operation, as older adults may have varying levels of technological literacy. Features such as adaptive interfaces, which adjust based on user feedback and capabilities, or voice-guided instructions, could greatly improve ease of use and engagement. Older adults often face cognitive, sensory, and physical limitations that affect their interaction with assistive technologies. Usability testing should focus on these groups to assess how well the system accommodates such challenges. For further research, factors such as comfort during extended use, portability, and safety mechanisms will be carefully evaluated. The question on Bot Fit assistance versus resistance mode showed the users' tendency to prefer the latter. The correlation analysis results showed that the younger the user, the better their physical function, and the higher their mood status, the more they tended to prefer resistance mode. Although exercise recommendations for both young and older people include aerobic, resistance, and stretching exercise, generally it has been suggested that older people begin exercise training at a lower intensity than young people [71]. Based on the same exercise duration, the intensity of exercise is higher when exercising in resistance mode versus in assistance mode. Thus, older people with relatively higher physical function may prefer high-intensity exercise through the Bot Fit resistance mode. In addition, the result of the exercise mode preference (resistance mode over assistance mode) may be owing to the significant improvement in physical function after Bot Fit exercise compared to physical function before Bot Fit exercise. These results can be used as supporting data to suggest customized exercise protocols according to physical function and condition.

While many existing strength, balance, and cardiovascular programs rely on minimal or no equipment and are both cost-effective and widely accepted, the introduction of advanced equipment like Bot Fit may offer specific benefits that justify the increased cost. Bot Fit devices provide individualized and adaptive assistance and resistance, potentially targeting specific muscle groups or addressing unique physical limitations in older adults, thereby enhancing the overall effectiveness of workouts. The ability to precisely control resistance and assistance levels in Bot Fit may lead to significant improvements in strength, mobility, and balance, particularly for individuals requiring more advanced support than what bodyweight exercises or basic equipment can provide. Additionally, real-time feedback and monitoring systems are currently being developed for Bot Fit that will allow users to track their progress more accurately and adjust their training based on objective data. This feature can improve motivation and adherence, as users can observe measurable improvements in performance. Moreover, the device will provide trainers and healthcare providers with detailed data to better assess the intervention's effectiveness, enabling more tailored exercise programs suited to individual needs. By integrating these advanced features, Bot Fit has the potential to enhance not only physical outcomes but also user engagement, making it a practical and valuable addition to exercise regimens for older adults.

This study had several limitations. The main limitation was its use of an open-label trial, and no control condition was used with conventional training for comparison with the effect of Bot Fit training. Second, because the statistical power of this study was relatively low due to the small sample size, the ability to detect true changes in outcomes is limited. This lack of power reduces the generalizability of the results, as any observed improvements in physical performance may be due to random variation or measurement errors rather than the true effect of the intervention. Future studies should include a formal sample size calculation to ensure adequate power, allowing for more reliable and valid conclusions that can be generalized to the broader older adult population. Another limitation is the inadequate control of the daily activity levels of the participants beyond the experimental sessions. During the long-term intervention period, other factors that might have affected the study outcome, such as an individual's overall amount of physical activity, were not controlled or monitored. Therefore, our data showing gait and physical functional changes induced by Bot Fit training in older adults warrant future studies with a larger sample and randomized controlled trials. The final limitation of this study is the lack of detailed usability assessments, such as user feedback on device comfort, interface, and ease of use. This limits our ability to fully evaluate the practicality and feasibility of implementing the Bot Fit system in everyday settings. Future studies should incorporate comprehensive usability testing, including qualitative data from participant interviews and questionnaires, to better understand user experiences and potential challenges that may impact long-term use and compliance.

Conclusions

This study was a long-term, longitudinal open-label observation primarily focused on evaluating the usability of Bot Fit in older adults residing in care facilities. The usability evaluation, conducted after an extended period of Bot Fit training, provided valuable insights into the device's practicality, acceptability, and effectiveness for this population. The findings emphasize the feasibility of Bot Fit as a user-friendly and beneficial tool for addressing age-related declines in mobility and physical function. Additionally, the results highlight the potential of Bot Fit to enhance physical activity in older adults while offering critical guidance for further refinement and optimization to improve its usability and application in this population.

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Author contributions
S.H.L. and Y.H.K. designed the overall approach to the research, and H.J.L. developed Bot Fit. S.H.L., J.K., and E.K. conducted the experiments, and S.H.L. and H.J.L. analyzed the data. S.H.L., H.J.L., E.K., J.K., and Y.H.K. prepared the manuscript. All authors revised and approved the final manuscript.

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Data availability
The datasets collected and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the ethics committee of the Samsung Medical Center Institutional Review Board (approval number: 2020-10-016). All procedures for this study were conducted by the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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