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Feasibility, usability and acceptability of a lifestyle-integrated multicomponent exercise delivered via a mobile health platform in community-dwelling pre-frail older adults: a short-term, mixed-methods, prospective pilot study

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Abstract

Background Pre-frailty is a window of opportunity for frailty reversal and can be enhanced by multicomponent exercise. The Lifestyle-integrated Functional Exercise (LiFE) program may be a promising alternative to overcome traditional exercise barriers. The latest advancements in mobile health (mHealth) technology have enabled individuals to retain the advantages of supervised exercise training within group settings while providing exercise programs that can be accessed and completed at home. This study aims to assess the feasibility, acceptability, and primary efficacy of the *PF-Life* program, which is the Lifestyle-Integrated Functional Exercise program for Pre-Frail supported by an mHealth platform.

Methods Sixteen pre-frail adults aged ≥ 65 years were recruited from five community health centers in Fuzhou, China. All participants were prescribed the *PF-Life* program by geriatricians using the mhealth platform (web-based portal). Participants engaged in the customized exercises program following in-app video instructions and feedback on the mhealth platform (smartphone application). Physical activity (PA) and sedentary behavior (SB) were registered daily through wearable devices. Study endpoints were feasibility (retention rate, compliance rate, adverse events), usability (system usability scale), acceptability (qualitative interviews), changes in physical function (timed up and go (TUG), handgrip strength (HGS), and 30-second chair rise tests), PA and SB.

Results The intervention was feasible, 88% of participants adhered completely to the study protocol, and 95% had completed at least 75% of the prescribed experimental duration. System usability was high (85 out of 100 best imaginable). Changes were observed from baseline to follow-up for total HGS (21.41 ± 6.38 vs. 24.12 ± 6.62 kg, $P < 0.05$,

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d = 0.714), TUG (8.23 ± 1.33 vs. 7.48 ± 2.01 s, $P < 0.01$, d = 1.647) and 30-second chair rise test (17.13 ± 4.3 vs. 20.04 ± 4.54 repetitions, $P < 0.01$, d = 0.94). In addition, SB decreased by a mean of 33 min/day ($P < 0.01$), and low physical activity increased by 31 min/day ($P < 0.01$). No adverse events occurred. The majority of participants found the *PF-Life* program to be straightforward, adaptable, and easily integrable into their daily routines.

Conclusions Preliminary studies have demonstrated that the *PF-life* program exhibits good compliance, safety, and usability for the pre-frail elderly population. Large-scale randomized controlled trials are required to ascertain its long-term effectiveness.

Keywords Lifestyle-integrated exercise, mHealth platform, Pre-frail, Feasibility, Acceptability

Introduction

Frailty is defined as a syndrome characterized by an excessive decline in the function and reserve of multiple physiological systems, resulting in decreased homeostatic tolerance to stressors and increased sensitivity [1, 2]. According to the Fried phenotype, frailty is identified by the presence of at least three out of five criteria: weight loss, exhaustion, physical activity level, walking speed, and handgrip strength [3]. Studies have shown that frailty, typically associated with older age, can manifest in individuals as young as 40 years old [4]. The progression from a state of health to frailty is a critical factor contributing to the decline in independence associated with aging, leading to diminished quality of life, increased hospitalizations, and a greater need for long-term care [5, 6]. Collectively, these factors contribute to an additional €12,000 per person per year in healthcare costs [7]. Importantly, there exists a bidirectional transition between robust health and frailty, prompting a growing interest in focusing on pre-frailty—a high-risk stage between health and frailty that carries significant predictive value for adverse health outcomes [8, 9]. The worldwide incidence rate of pre-frailty has been estimated at approximately 151 new cases per 1,000 person-years [10]. In a pre-frail state, people may still possess self-balancing mechanisms to cope with external stress by modifying risk factors. It is a window of opportunity to reverse frailty, improve long-term health outcomes, and reduce the burden on families and society [11].

Physical inactivity is a significant risk predictor for frailty and other conditions associated with aging [12, 13], while an excessively sedentary lifestyle accelerates the deterioration of functional trajectories [14, 15]. Several randomized controlled trials (RCTs) have provided compelling evidence to support multicomponent exercise as a single intervention to prevent pre-frailty [16–18]. Despite these positive findings, the practical implementation of supervised, community-based multicomponent exercise in pre-frail persons remains challenging due to extrinsic or intrinsic barriers, such as time constraints, lack of transportation, limited opportunities, and reluctance to participate in group activities [19, 20]. This highlights the need to identify more innovative yet feasible exercise modalities. Incorporating exercise into daily activities presents a promising solution to overcome conventional barriers to physical activity [21]. By merging low to moderate-intensity exercise with regular daily routines, this approach fosters the establishment of new exercise habits, promoting long-term adherence through habit formation and empowerment [22, 23]. Clemson developed the original Lifestyle-integrated Functional Exercise (LiFE), which has been demonstrated to be highly adherent and motivating for the elderly at high risk of falls [24]. Nevertheless, the implementation of LiFE among pre-frail individuals is not extensive.

As a home-based exercise program, LiFE can enhance the accessibility and sustainability of exercise; however, it does not provide the supervision, feedback, and individualized coaching available in group training settings [25, 26]. The development of mobile health (mHealth) technologies has proven to be an effective strategy for delivering healthcare to promote behavior change [27]. In the frail elderly, previous research has found that objective physical activity (PA) data collected by wearable devices can be used to develop motivational strategies to reinforce daily PA [28, 29]. Mobile applications (APPs) incorporating behavioral change techniques (BCTs), such as feedback and reminders, can provide richer content through multiple delivery methods and thus encourage exercise [30, 31]. However, at present, no mHealth platform exists that amalgamates smartphone applications with wearable devices and web-based portals. This integration would facilitate the accessibility of lifestyle-integrated exercise whilst concurrently providing the supervision of health professionals via remotely guided exercise programs. Consequently, grounded on an exhaustive literature review and consultations with experts, we have designed a Lifestyle-Integrated Functional Exercise program for Pre-Frail known as the *PF-Life* program. This program is specifically tailored for frail older adults and is delivered via a mobile health platform, referred to as the *PF-Life* platform.

Before undertaking a definitive RCT, it is crucial to perform a feasibility study to assess pre-established progression criteria pertinent to either the evaluation design or the intervention itself. We hypothesized that the novel

PF-Life program is feasible, user-friendly, and acceptable. Moreover, we anticipate that the *PF-Life* program will yield enhancements in physical function and escalate the levels of daily physical activity among pre-frail older adults residing in the community.

Methods

Study design

An 8-week, community-based, prospective, single-cohort, mixed methods feasibility study was designed to evaluate the *PF-Life* program. Pre-frail elderly were prescribed a personalized exercise program by geriatricians using the *PF-Life* platform (web-based portal). Participants completed a customized exercise program following in-app video instructions and feedback on the *PF-Life* platform (smartphone APP). PA was recorded daily through ActiGraph wGT3X-BT wearable devices. The trial was managed at the Institute for Fujian Geriatrics Center, Fuzhou, China, and was approved by the Ethics Committee of Fujian Provincial Hospital (K2022-09-001).

Participants and recruitment

From September to November 2022, a systematic recruitment strategy employing posters, leaflets, and health lectures was utilized to recruit 16 pre-frail elderly individuals at community health centers (CHCs) where the *Fujian Prospective Ageing Cohort* was conducted. The cohort study was conducted in five CHCs in Fuzhou, China, where the prevalence of pre-frailty was 44% [32]. Geriatricians were responsible for recruiting participants and conducting frailty assessments on all elderly individuals aged 65 and above using the frailty phenotype scale [1]. Based on this frailty screening tool, participants were classified as normal (score of 0), pre-frail (score of 1–2), or frail (score of 3–5) [33]. In this study, we specifically invited elderly individuals in the pre-frail stage to participate. However, participants were excluded if they had conditions that impeded the safe execution of the exercise program, moderate-to-severe cognitive impairment (MMSE score ≤ 20 points) [34], or psychiatric disorders that prevented cooperation. For more information on the screening procedures and inclusion/exclusion criteria, please refer to the study by Li N et al. [35].

Intervention

The *PF-Life* program utilized its cloud-based digital health platform to deliver exercise prescriptions, monitor progress, and provide coaching. The *PF-Life* platform grounded on behavior change strategies such as goal setting, action planning, feedback, and incentives, includes a smartphone app that syncs with wearable devices and a web-based portal. Geriatricians could remotely assign exercise, track progress, offer immediate feedback, and send reminders. Participant's smartphones, synced with their wearable device, allowed them to access exercise tasks, track workouts, view exercise reports, and communicate with their healthcare team. Prior to the intervention, participants completed the initial assessment at the CHC to determine frailty and physical function. They were guided to download the app, with geriatricians demonstrating its use. Each participant received an ActiGraphw GT3X-BT to record baseline PA data. Tailored exercises were then assigned via the app based on their physical function. Participants could view examples of how to integrate exercise into their daily lives and were guided through the exercise tasks by the exercise videos in the APP. The exercise videos, recorded by sports coaches, are uploaded separately for participants to click and follow (see Supplement File 1 for video illustrations). The platform automatically logged completed exercises, and upload daily PA data through the ActiGraph wGT3X-BT wearable devices. Researchers set daily reminders and motivational messages through the platform to keep participants on track toward their personal goals (Fig. 1). Throughout the intervention, participants could contact geriatricians online for advice on exercises or the app. Additionally, a video conference was specially scheduled in the third week to discuss incorporating exercise into daily routines. More details on behavior change strategies and mHealth platform-based exercise management can be found elsewhere [35].

The lifestyle-integrated multicomponent exercise program augmented the original LiFE program by integrating aerobic and flexibility training with existing strength and balance exercises, resulting in a multicomponent exercise program. This program was refined by 15 experts in geriatrics, sports medicine, and rehabilitation medicine to more effectively meet the needs of seniors who are in a state of pre-frailty [24]. Personalized exercises are tailored based on the participants' initial functional fitness levels, divided into three difficulty levels: beginner, intermediate, and advanced. Specifically, participants were instructed to complete 16 targeted exercises of low-to-moderate intensity (3–6 on a 10-point modified rate of perceived exertion [RPE] scale) targeted exercise (2–3 sets of 5–8 repetitions) each day for any 5 days throughout the week. The cumulative time of these 16 exercise sets amounted to 30 min. Following the principle of progressive overload, the exercise programs were designed to enhance the exercise load by incrementing the number of repetitions and extending the training duration. Additionally, at more advanced levels, ankle weights were incorporated to further intensify the workouts. All exercise equipment (objects of equal weight, chairs, towels, etc.) was derived from life scenarios. The program consists of four aerobic exercises (e.g. march on the spot, elbow-knee collision, etc.), four challenging balance

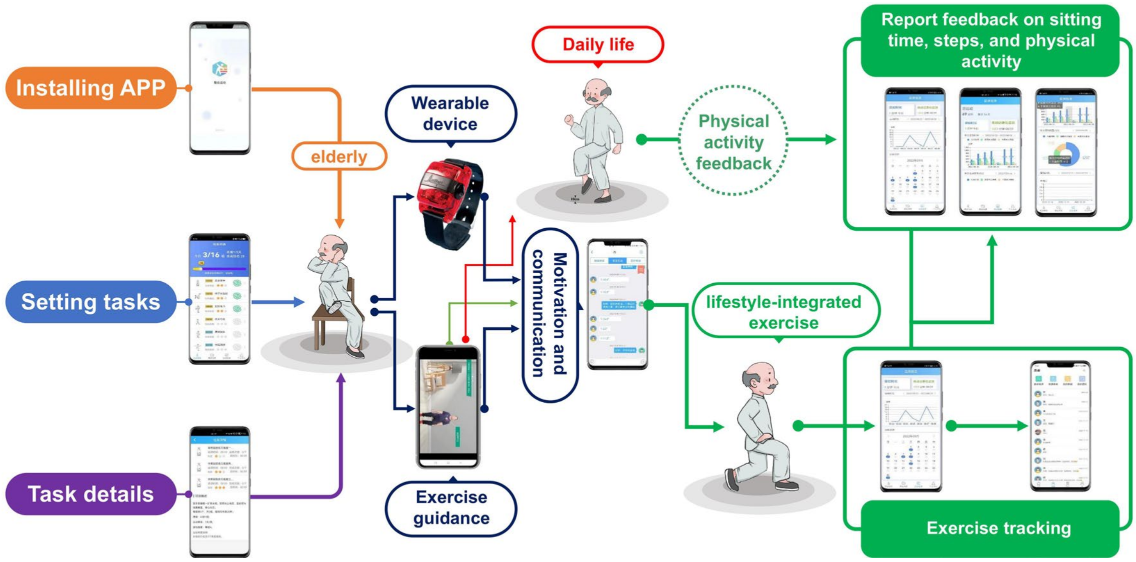

Fig. 1 Overview of the developed *PF-Life* platform

exercises (e.g. flamingo, 8-shaped winding pile, etc.), four resistance exercises (e.g. arm curl, chair-sit-stand-up, etc.) and four flexibility exercises (e.g. chest stretching, grab from behind feet, etc.). These exercises are designed around functions that are important for independent living in daily life and can be integrated into or mimic life (Fig. 2).

Measures

Feasibility

Feasibility was assessed in terms of retention, compliance, and safety. Retention was recorded as the number (proportion) of participants who completed the 8-week intervention. The *PF-Life* platform automatically documents compliance rates, which are determined by the frequency of exercise sessions per week, the number of exercise sets executed per day, and the overall adherence to the prescribed program. Safety was determined based on the incidence of adverse events (AEs). AEs were defined as intervention-related events such as falls, low back pain, leg pain, etc. that led to discontinuation or modification of the exercise intervention. Study procedures that would support a future adequately powered randomized trial were retention of ≥90%; compliance to prescribed exercises of ≥66%; and no major AEs related to the study [30].

PA and sedentary behavior (SB)

PA and SB were measured objectively using an ActiGraph wGT3X-BT accelerometer (ActiGraph, USA). Accelerometry is a valid and reliable indicator of PA and SB in the elderly [36]. Participants were instructed to wear the device on the wrist 24 h a day for at least 7 days during baseline and the last week of the intervention period. The device was worn as much as possible for ≥10 h per day at all other intervention times. Participants were also instructed to complete a daily wear time log to confirm wear time. The sampling rate of the ActiGraph wGT3X-BT was set to 100 Hz, and activity intensity was determined using counts per minute (CPM) thresholds derived from 60-second epochs (SB: <100 CPM, low-intensity physical activity [LPA]: 100–1941 CPM, and MVPA: ≥1952CPM) [37]. Data were processed using ActiLife 6 software [38]. The wearable device automatically transmits the data in real-time to the web-based portal of the geriatricians during data collection, thus validating the accuracy of the data.

Physical function

Physical function was measured by the 30-second chair rise test, handgrip strength (HGS) test, and timed up and go (TUG) test. The lower limb strength was assessed using the 30-second chair rise test, which counts how many times a participant can stand up from a 43 cm high chair and sit back down within 30 s without using their hands [39]. Upper-extremity muscle strength was evaluated using the HGS test. The left and right HGS were measured alternately three times each using a Jamar® Hydraulic Hand Dynamo meter (USA), and the maximum left/right HGS measurement was recorded [40]. The TUG test was used to measure mobility and dynamic balance. The participant was instructed to sit in a standard 43-cm high chair, rise from the chair walk forward as quickly as possible for 3 m, and then return to a seated position. The time taken to complete the task was recorded [41].

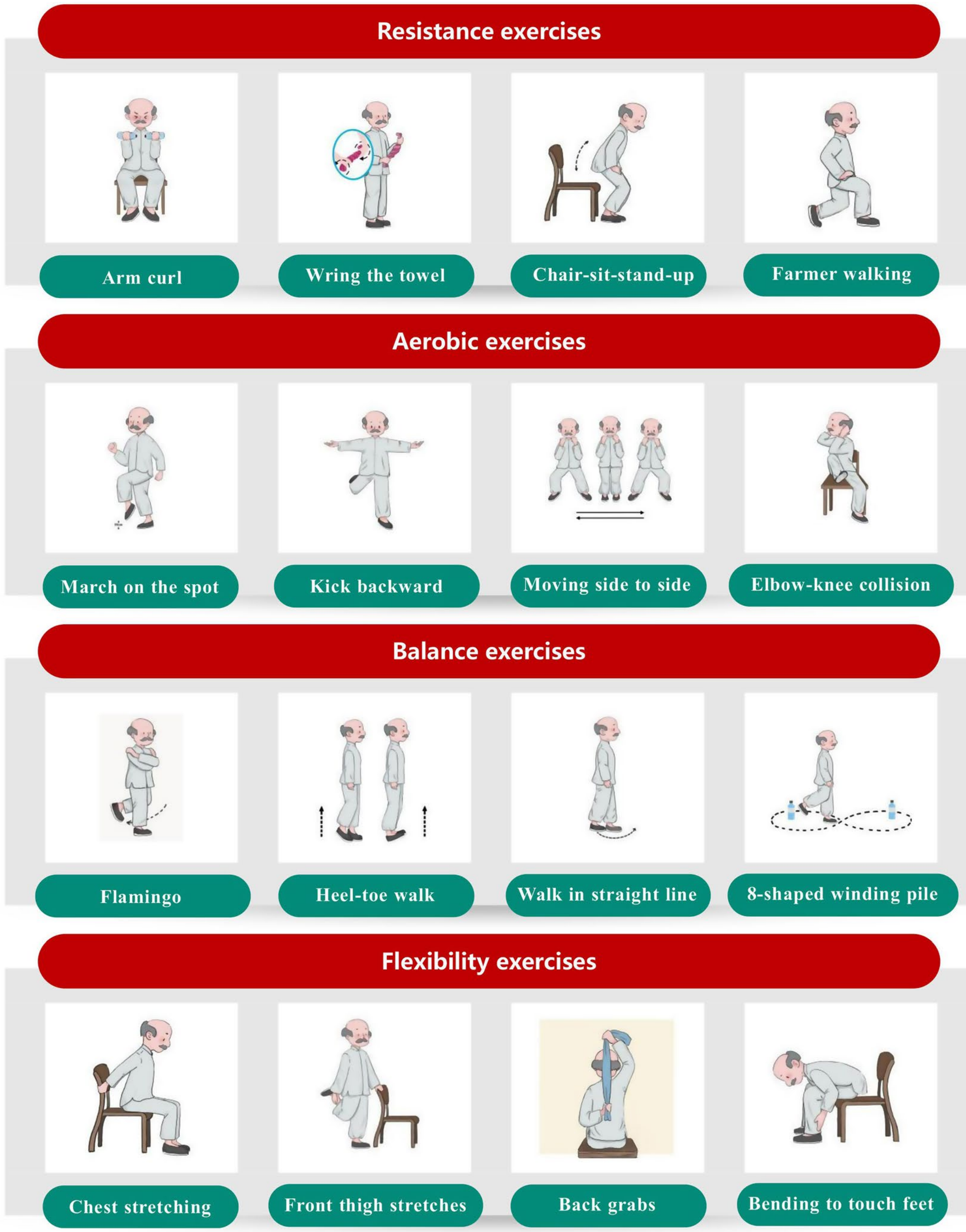

Fig. 2 Lifestyle-integrated multicomponent exercise content

System usability

The System Usability Scale (SUS) was used to assess the subjective usability of the *PF-Life* platform, as it is a valid and reliable scale for evaluating newly developed digital health systems [42]. The SUS consists of 10 items on a 5-point Likert scale, with each item rated on a scale ranging from 1 (strongly disagree) to 5 (strongly agree). The SUS considers three usability criteria: effectiveness, satisfaction, and efficiency. To avoid response bias, odd-numbered items were positive statements and even-numbered items were negative statements. The total SUS score was obtained by summing the individual item scores and multiplying them by 2.5, ranging from 0 (worst) to 100 (best). A SUS score above 68 is considered above-average usability, and a score above 80 is considered high usability [43].

Acceptability

Semi-structured face-to-face interviews were conducted with all participants (16) who completed the study to assess the acceptability of the intervention from the recipient's perspective within one week of the endpoint intervention in the CHC. The interview topic guide was based on the seven dimensions of the Theoretical Framework for Acceptability (TFA) [44]: affective attitude, burden, perceived effectiveness, ethicality, intervention coherence, opportunity costs and self-efficacy. Each participant was given 20–30 min to describe their experiences and feedback on their involvement with the *PF-Life* program. All interviews were moderated, audio-recorded and transcribed verbatim by the first author, a PhD student with a Master's degree in Geriatrics and experience in qualitative research.

Data collection

The participants' physical function data were assessed at baseline and 8 weeks by geriatricians at the Fujian Geriatrics Center. Usability and acceptability were evaluated by researchers who did not participate in the direct intervention These evaluations were performed through data collection and structured interviews upon the completion of the study at the CHCs. Rigorous verification of all collected data was ensured by the research team. Afterward, staff members who were not associated with the intervention uploaded the information to the *PF-Life* Platform.

Table 1 Demographic and clinical characteristics of elderly with pre-frailty

Characteristics		Value (*n* = 16)
Age (years, mean ± SD)		68.8 ± 5.1
Gender (n, %)	male	7(43.8)
	female	9(56.2)
Education level (n, %)	primary school and below	2(1.3)
	middle school	4(25.0)
	high school	7(43.8)
	college	3(18.8)
Living status (n, %)	alone	1(6.3)
	With partner	7(43.8)
	with children	3(18.8)
	With partner and children	5(31.2)
Marital status (n, %)	married	13(81.3)
	widowed	2(12.5)
	divorced	1(6.3)
Smoking status (n, %)	never	14(87.5)
	current	1(6.3)
	former	1(6.3)
Drinking status (n, %)	never	13(81.3)
	current	2(1.2)
	former	1(6.3)
Comorbidity (median, 25–75%)		2 (1.0–3.0)
Polypharmacy (median, 25–75%)		3 (1.0–4.0)
BMI (kg/m^2)		24.3 ± 2.2
Physical activity (min/d)	SB	700.76 ± 67.76
	LPA	163.13 ± 64.62
	MVPA	14.13 ± 13.31

Note: Measures that follow a normal distribution with equal variance are expressed as mean±standard deviation (Mean ± SD), and measures that do not follow normal distribution are expressed as median (Q25, Q75) for their distributional characteristics. Count data were expressed as frequencies and percentages. Abbreviations: BMI = body mass index; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; SB = sedentary behavior

Statistical analysis

IBM SPSS 22.0 software was used to process and analyze quantitative data. Wilcoxon signed rank tests were used for baseline and follow-up data comparisons, and two-tailed tests were used for all statistical tests, with $P < 0.05$ considered statistically significant. In addition, due to the small sample size of this study, the effect size was expressed as a standardized mean difference (Cohen's d), calculated as mean follow-up data minus mean baseline data divided by baseline standard deviation. According to Cohen's d rating criteria, 0.8 is considered a large effect size, 0.5 a medium effect, and 0.2 a small effect. As this was a feasibility study, no rigorous sample size calculations were performed. A concise estimation of the sample size, based on parameters of previous studies, indicates that at least 12 participants are required [45, 46].

All interview data were managed using Nvivo11 software. Following the transcription of the material, the data were analyzed using qualitative content analysis methodology. Two independent researchers iteratively reviewed the interview transcripts to develop a comprehensive understanding of the content, during which they documented reflective observations and made annotations. Subsequently, the TFA framework was used as an established theoretical model for direct content analysis, conducting a detailed line-by-line analysis of the data. This analysis involved organizing and summarizing the data systematically to discern themes.

Results

Baseline characteristics

The demographic and clinical characteristics of the study participants are displayed in Table 1. Sixteen pre-frail older adults were included, of whom 56.3% (9/16) were females. The mean age was 69 years (range 65–83 years). Approximately 62.5% (10/16) of the participants had an education level of high school and above, and the median total number of diseases was 2.

Feasibility

All participants completed the study with a retention rate of 100%. Participants exercised an average of 4.68 (±0.60) days per week, with an average of 15.63 (±0.62) exercise sets per day. At the 2-month mark, 88% of participants adhered completely to the study protocol, and 95% had

Table 2 Baseline and follow up results for the physical activity levels

	Baseline ($n=16$)	Follow up ($n=16$)	Mean change Mean (SD)	*P* value	Cohen's d
Physical activity (min/d)					
SB	700.76±67.76	668.23±50.71	-32.53±29.06	0.022	0.53[b]
LPA	163.13±64.62	193.93±53.30	30.80±28.29	0.013	0.50[b]
MVPA	14.13±13.31	17.84±9.54	3.71±12.91	0.445	NA
Percentage of physical activity (%)					
SB	79.63±7.69	75.93±5.76	-3.69±3.30	0.022	0.53[b]
LPA	18.54±7.34	22.03±6.05	3.50±3.21	0.013	0.50[b]
MVPA	1.60±1.51	2.03±1.08	0.42±1.46	0.445	NA

Note: Baseline and follow-up values are means (standard deviations); a indicates a small effect size, b indicates a medium effect size, and c indicates a large effect size

Abbreviations: LPA=light physical activity; MVPA=moderate-to-vigorous physical activity; SB=sedentary behavior

Table 3 Baseline and follow up results for the physical function

	Baseline ($n=16$)	Follow up ($n=16$)	Mean change Mean (SD)	*P* value	Cohen's d
TUG (s)	8.23±1.33	7.48±2.01	-0.70±1.23	0.017	1.647[a]
30-second chair rise (reps)	17.13±4.30	20.04±4.54	2.91±3.10	0.004	0.940[a]
Handgrip strength (kg)	21.41±6.38	24.12±6.62	3.05±3.60	0.010	0.714[b]

Note: Baseline and follow-up values are means (standard deviations); a indicates a small effect size, b indicates a medium effect size, and c indicates a large effect size

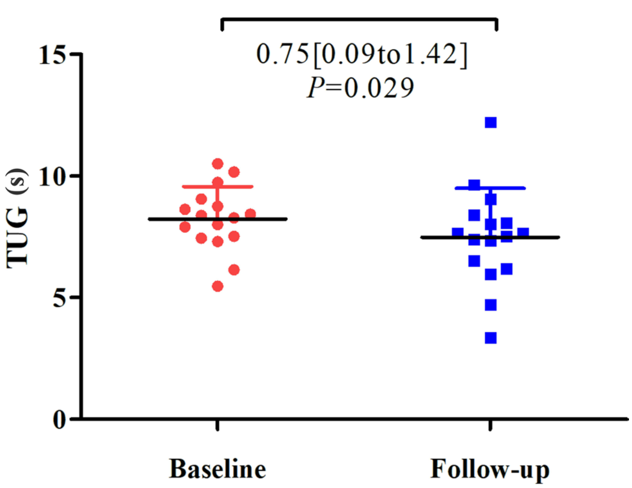

Fig. 3 Mean changes in the timed up and go time

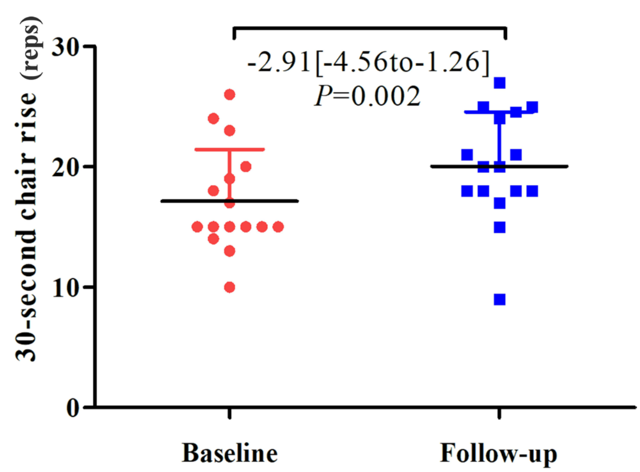

Fig. 4 Mean changes in the 30-second chair rise score

completed at least 75% of the prescribed experimental duration. All participants engaged with geriatricians for voice or video communication interactions averaging 6 times/person. One non-intervention-related foot sprain occurred during the 8-week intervention period.

PA and SB

PA parameters were measured using ActiGraph GT3X-BT. SB decreased by a mean of 33 min/day ($P<0.01$) and LPA increased by 31 min/day ($P<0.01$) during the intervention. Accordingly, the percentage of SB decreased by 3.7% ($P<0.01$) and LPA increased by 3.5% ($P<0.01$), with a medium effect size for the difference (d=0.50–0.53), no significant change was found in the MVPA (Table 2).

Physical function

Changes were observed from baseline to follow-up for total HGS (21.41±6.38 vs. 24.12±6.62 kg, $P<0.05$, d=0.714), TUG (8.23±1.33 vs. 7.48±2.01 s, $P<0.05$, d=1.647) and 30-second chair rise test (17.13±4.3 vs. 20.04±4.54 repetitions, $P<0.01$, d=0.94) (Table 3; Figs. 3, 4 and 5).

SUS

The *PF-Life* platform (APP) had high usability with an average score of 85, which is above average and excellent. According to the 5-point Likert-type scale, the highest scores were observed for 'I think the system is easy to use' and 'I think most people will learn to use this system quickly' (mean 4.69, SD 0.60), followed by 'I feel confident about using this system' (mean 4.31, SD 0.79).

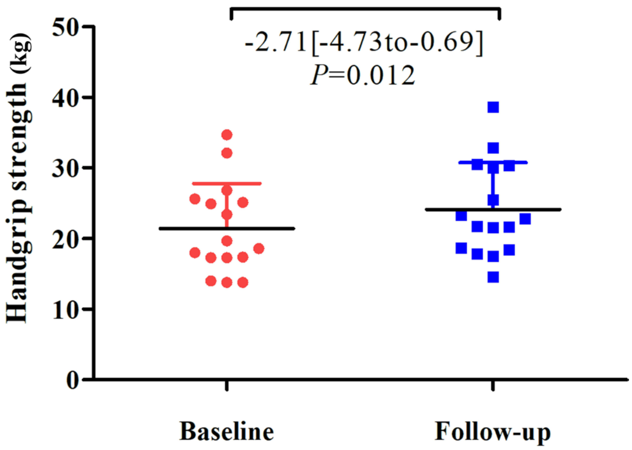

Fig. 5 Mean changes in the handgrip strength from baseline to follow-up

Acceptability

The TFA framework was used to conduct a qualitative analysis, the findings of which are presented in Table 4. The majority of participants found the program to be straightforward, adaptable, and easily integrated into their daily routines. They reported that the program positively impacted their physical, mental, and emotional well-being. The provision of reminders, incentives, and feedback through the app was deemed age-appropriate. However, a minority of participants reported that navigating technological systems necessitated support and assistance from family members.

Discussion

The current study comprehensively evaluated the feasibility, usability, and acceptability of the *PF-Life* program. Both qualitative and quantitative findings from a multimodal evaluation indicated that the program was feasible for pre-frail older adults, as evidenced by optimal compliance, retention rates, and safety measures, and it was well-received by the target population. In terms of usability, all participants achieved the predetermined SUS objectives. Qualitative interviews revealed that most participants perceived the program to be easily integrated into their daily routines. Additionally, preliminary results of the *PF-Life* program's effectiveness were also promising.

Feasibility

Established quantitative indicators were used to assess the core elements of the feasibility of the *PF-Life* program. Notably, 88% of the participants demonstrated full compliance with the study protocol. Geraedts et al. reported that the overall adherence rate of pre-frail older people to a home-based exercise program driven by a tablet APP was 60.9% [47]. A recent systematic review highlighted significant variation in the dropout rate (0–36%) and adherence rates (67.78–100%) for technology-assisted exercise programs for the elderly [48]. This heterogeneity appears to be related to the characteristics of the exercise program. Integrating exercise into daily life may remove the constraints of time, resources, equipment, and transportation required for older adults to exercise, allowing flexibility and freedom in choosing when and where to exercise, potentially resulting in a greater sense of autonomy and control [49].

The compliance rate to the *PF-Life* program in this study surpasses that of several preceding LiFE study [50]. This superiority may be closely related to several important features of the *PF-Life* platform built on the behavior change theory, including goal setting, visualization videos, prompts/cues, and interactive communication. Goal setting enhances older adults' sense of exercise engagement; visualization videos provide accurate exercise instruction; prompts/cues reduce memory burden; and interactive communication via voice or video provides positive motivation. This is consistent with the findings of Tsiouris et al., in which mHealth platforms were found to be effective in improving patients' exercise adherence through monitoring and real-time feedback in exercise-based cardiac rehabilitation and Parkinson's disease management [51]. Daly et al. [30] concluded that an exercise program is feasible if the retention rate is higher than 90% and the average overall adherence rate is higher than 75%.

Safety assurance is an integral component of feasibility assessments. Although one participant experienced a foot sprain while descending stairs during the intervention, this incident was unrelated to the intervention. Historically, AEs have been infrequently reported in the LiFE program [52, 53]. This rarity might be associated with the inherent low intensity of the LiFE activities. Additionally, tailoring exercise tasks to the functional capacity of pre-frail older adults, coupled with comprehensive instructions and safety guidelines for each exercise provided in the exercise video, are crucial factors that help ensure the safe execution of exercises by participants.

Usability

The SUS is a reliable and valid standardized scale for evaluating the perceived usability of technology [42, 54]. Participants in this study scored an average of 85 points on the APP, which surpasses the report by Daly et al. [30]. This indicated that the APP designed in the present research exhibited high usability and was suitable for the elderly population in Chinese communities. Notably, the top three most common barriers to APP use among older adults included (i) small font size, screen size, and font type; (ii) lack of technology experience and knowledge and (iii) many menu options and navigation [55]. Consequently, this study aimed to design the APP with succinct content, clear communication and navigation, and

Table 4 Qualitative analysis using the theoretical framework of acceptance domains

TFA Domain	Theme	Illustrative Quotes
Affective Attitude	Flexible	This exercise format is simple and flexible, and you don't require setting up any special equipment. ***Male*, *aged 72 years*** It can be done at home or outdoors. You can do it in the morning or at night, as long as you complete the required exercise. That suits me fine. ***Female*, *aged 73 years***
	Beneficial	This APP is great. You can check your exercise time daily or weekly. You can also get reminders from the App. I need that feedback to make adjustments. ***Female*, *aged 80 years*** The watch is very rewarding (ActiGraph wGT3X-BT) and for the first time I know how much time I'm sitting cumulatively each day and it is a good reminder. ***Female*, *aged 73 years***
	Useless	I understand that this program is designed to be very comprehensive. However, I find exercise like wringing out a towel too easy for me and I doubt that it does anything for the body. ***Male*, *aged 67 years***
	Easy to integrate	You almost always just need to spend a little extra time exercising. For example, I would practice arm curl with water bottles while watching TV; I would practice flamingo exercise, while I waited for doing something. ***Female*, *aged 67 years*** I frequently practice walking in a straight line while waiting for the bus. In addition, after playing a game of chess, I practice bending over and touching my legs. These movements never feel burdensome; instead, they are quite relaxing. ***Female*, *aged 73 years***
Burden	Need technical support	Sometimes my phone doesn't have an internet connection anymore and I need my kids to come home from work to help me fix the internet. ***Female*, *aged 73 years*** My phone broke and I got a new one and when I reinstalled the app it was a pain to have to register again. ***Female*, *aged 72 years***
Ethicality	Meeting the health needs	I like the chair-sit-stand exercise, which is good for lower body strength. Older people need to do this type of exercise more often. ***Female*, *aged 73 years*** I particularly enjoy the balancing exercises as I find them highly effective. Maintaining balance is crucial for preventing falls, and I believe it's important for more people to engage in these exercises. ***Male*, *aged 68 years***
Intervention coherence	Physical limitations affect	My back hurts. I can't do the bending over and touching legs exercise. I basically don't do the flamingo exercise because I have bad feet and I'm afraid of falling.
	Participation	The APP is very suitable for seniors. The exercise videos in the APP are very detailed describe about why you should do it, how many times you should do it, how to do it, how to avoid falling, and so on. ***Male*, *aged 73 years*** The app also sends me notifications and reminders, and as an old person with a poor memory, I find it's very, very useful. ***Female*, *aged 76 years***
Perceived effectiveness	Physical health	The exercise regimen has made a significant improvement in my overall well-being. Previously, I struggled to lift my left arm and couldn't reach my back with my hand, but now I can perform these movements with ease, and I've noticed a marked improvement in my flexibility. ***Female*, *aged 72 years*** I can now get up from a chair and sit down 30 times in a row, whereas before I could only do it 5 times. ***Female*, *aged 69 years*** I have achieved a better sense of balance, I walk more confidently and I'm not always afraid of falling down. ***Female*, *aged 76 years***
	Mental and emotional health	I have lost about 10 pounds in the last year and I've been in a bad mood. I feel so much better emotionally when I come to this event. ***Female*, *aged 72 years*** I feel much better mentally, my body has improved, I have more energy than before, and my mind has become more flexible. ***Female*, *aged 65 years***
Opportunity cost		There has been no mention of opportunity costs in the interviews.
Self-Efficacy	Confidence growth over time	Initially, I was unfamiliar with the concept of lifestyle integration exercise, but now I comprehend and appreciate its importance in incorporating physical activity into everyday routines. ***Female*, *aged 72 years*** In the beginning, I was worried about whether my physical was fit to exercise, Now I try to get as much exercise as I can and looks for opportunities to exercise in everyday life. ***Female*, *aged 80 years***
	Professional support helpful	Yes, you can always contact a healthcare professional if you have any questions. They also send me messages of encouragement and praise. They're really nice. ***Female*, *aged 68 years*** As I age, I've experienced a decline in my memory. However, my personal trainer sends me reminders if I miss a workout. With the exercise videos provided, I do not have to worry about remembering the routines; I simply follow along. This system has been a game-changer for me, and I'm committed to sticking with it. ***Female*, *aged 80 years***
	Some suggestions for further use	In fact, I've recommended it to my sister and now we encourage each other to complete our daily exercise challenges. I am looking forward to the addition of some exercise rankings to the software, which would give us seniors more of a sense of belonging. ***Female*, *aged 72 years*** I will continue to use the software. However, I find that the speech in the videos is slow and doesn't match my pace. I also find that the software sometimes displays my exercise time incorrectly. ***Female*, *aged 65 years***

harmonious colors and text to ensure user-friendliness [56, 57]. During qualitative interviews, a majority of participants expressed that they found significant value in utilizing the app to guide the lifestyle- integrated multicomponent exercise. They encountered minimal technical issues while using the APP and expressed intentions to continue its use as well as recommend it to relatives and friends.

Effects of the training

The data from this study indicated that the *PF-Life* program effectively reduced participants' sedentary time while increasing their LPA, without augmenting MVPA duration. These findings align with the outcomes of other LiFE studies [45]. The fundamental premise of the LiFE program is not to mandate elderly individuals to undertake specific exercises of moderate-to-high intensity at particular times and locations. Instead, it encourages older adults to integrate physical activities into their daily routines as much as possible, identifying suitable exercise contexts and cues within their everyday life. This approach facilitates the transformation of prolonged sedentary periods into shorter, more frequent bouts of LPA, thereby enhancing the cumulative volume of PA [58]. This philosophy is also congruent with the current International Physical Activity Guidelines (IPAG) recommendations [59].

Although our study was not designed to infer causality, the findings suggest an association between *PF-Life* program and improvements in lower body strength (30-second chair rise), upper body strength (HGS), and dynamic balance and mobility (TUG). There was a large effect size for improvement in TUG and a moderate effect size for improvement in HGS and 30-second chair rise. A systematic review reported that LiFE was effective in improving motor performance and performed better on specific outcomes related to balance, strength (e.g. ankle), and functional performance [49, 60]. This may be because LiFE is performed to improve basic activities of daily living, such as getting up from a chair, and focus on the specificity of the training [26]. Besides, these exercises are associated with specific outcomes related to daily living, such as wring a towel.

Acceptability

Our data showed that the *PF-Life* program has a high level of acceptability, including high perceived effectiveness and increased self-efficacy. The results are consistent with the construction of a TFA framework of healthcare interventions [44, 61, 62]. Elderly individuals found this exercise regimen to be time-efficient, simple, and requiring minimal equipment, which made it easier to incorporate into their daily routines. Importantly, the program effectively addressed key health concerns such as enhancing muscle strength and balance function, as well as improving mood. However, there were individual differences in the level of intervention burden and ethical decisions made by participants. The incorporation of mHealth platforms introduces new technical hurdles for seniors. Those with higher education levels may exhibit greater interest in emerging technologies, demonstrating a quicker adaptation capability. Furthermore, the social milieu and network of older adults significantly influence their ethical decision-making processes. Family and community support is pivotal in encouraging elderly participation in exercise interventions. Individual participants expressed the need for their children's assistance to navigate the program due to unreliable community networks.

Limitations

The study has several limitations. Firstly, the constrained sample size impacts the generalizability and reliability of our results, suggesting that statistical outcomes should be deemed exploratory rather than definitive. Despite this limitation, the high retention rate observed in this study, coupled with positive feedback from a majority of the older adult participants, underscores the potential feasibility and acceptance of the research design for the pre-frail elderly population. Future research plans include expanding the sample size to address current constraints. Secondly, the absence of a control group precludes definitive attribution of the observed enhancements in physical activity levels and physical function to the intervention. Self-reported measures may introduce bias, thus the study's findings should be interpreted with caution. Thirdly, the short-term nature of the intervention and lack of extended follow-up measures restrict our capability to ascertain whether tangible modifications in physical function, sedentary behavior, and physical activity or if participants maintain elevated compliance and acceptance over time. Future RCTs aim to investigate long-term benefits and sustained alterations in physical function post-intervention. Finally, while our population was drawn from representative communities in China, these findings may not be extrapolated to a wider range of older adults in China and elsewhere, especially those with limited education, lacking smartphones, or residing in regions devoid of 4G or 5G network coverage. Additionally, in areas where Chinese is not the primary language, applicability may also encounter challenges.

Conclusion

In conclusion, this study provided preliminary evidence that the *PF-Life* program had commendable compliance, safety, and usability. Encouraging results were also found in improving physical function and increasing levels of physical activity. However, the study design did not conclusively determine the effectiveness of the intervention and required further investigation through RCT. Nonetheless, these initial findings suggested that the *PF-Life* program, which incorporated exercise into daily routines, was a promising exploration.

Abbreviations

RCTs	Randomized controlled trials
LiFE	Lifestyle-integrated Functional Exercise
mHealth	Mobile health
PA	Physical activity
APPs	Mobile applications
BCTs	Behavioral change techniques
CHC	Community health centers
MVPA	Moderate-to-vigorous PA
RPE	Rate of perceived exertion
AEs	Adverse events
CPM	Counts per minute
LPA	Low-intensity physical activity
TUG	Timed up and go
HGS	Handgrip strength
SUS	The System Usability Scale
TFA	Theoretical Framework for Acceptability
IPAG	International Physical Activity Guidelines

Supplementary Information

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Supplementary Material 1

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Author contributions

N. L.: Data collection, Data analysis, Writing-original draft.C. L.: Data collection, Writing-original draft. F. H.: Writing - review & editing, Coordinated the study. N. W., S. L., and Y.Y.: Data collection. P. Z.: Methodology, Funding, Writing - review & editing. All authors contributed to reviewing and revising the manuscript, read and approved the final manuscript.

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Data availability

The datasets generated during and/or analyzed during the present study will be available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study has been approved by the Ethics Committee of Fujian Provincial Hospital. We conducted the study by the Helsinki Declaration and the underlying data protection regulation. All participants were informed on the aim of the research, the methods used, how the results will be presented, and the right to decline to participate in the study or to withdraw consent to participate at any time without further explanation. Informed consent was obtained from all the participants before data collection.

Consent for publication

Written informed consent was obtained from the participant(s) for their anonymized information to be published in this article.

Conflict of interest

The authors declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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