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Combining square-stepping exercise and strengthening exercise improve frailty status in pre-frail community-dwelling older adults

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ABSTRACT

Frailty is a complex syndrome affecting older people, characterized by unintentional weight loss, low muscle strength, feelings of exhaustion, reduced physical activity capacity, and slow walking speed. A decrease of muscle strength has been shown to be a major cause of frailty. The studies further agreed that frailty is a treatable condition. Intervention at the pre-frail state may offer the best opportunity to prevent, delay, or reverse existing symptoms of physical frailty. The evidence that multicomponent exercise (particularly resistance exercise) can have marked effects on frailty and sarcopenia is now forceful. Thus, we combine strengthening exercise and square-stepping exercise (SSE), a popular balance exercise, in community-dwelling pre-frail older adults. To evaluate the effectiveness of additional lower extremity strengthening exercise on frailty phenotype scores in pre-frail older adults who receive SSE. This study used an experimental, randomized control trial on pre-frail older adults aged between 60 and 70 yr. The participants were divided into 2 groups of 19 people each. The control group received SSE 3 x /wk, while the treatment group received SSE 3 x /wk plus lower extremity strengthening exercises 2 x /wk for 6 wk. The analysis of each group revealed an improvement in frailty phenotype scores in both the treatment and control groups. Ten participants (55.56%) in the control group experienced an improvement in the frailty phenotype status to robust (non-frail). Eleven participants (64.71%) in the treatment group experienced an improvement in frailty phenotype status to robust (non-frail). These findings suggest that SSE can improve frailty phenotype scores in pre-frail older adults, and that adding lower extremity strengthening exercises to SSE significantly improves frailty phenotype score compared to SSE alone.

ABSTRAK

Kerapuhan merupakan sindrom kompleks pada lansia, dengan ciri penurunan berat badan yang tidak diinginkan, kekuatan otot rendah, kelelahan, penurunan kapasitas aktivitas fisik, serta penurunan kecepatan berjalan. Penurunan kekuatan otot telah terbukti menjadi penyebab utama kerapuhan. Beberapa studi kemudian sepakat bahwa kerapuhan merupakan kondisi yang dapat diatasi. Intervensi pada status pre-frail mungkin menawarkan kesempatan terbaik untuk mencegah, menunda, atau mengembalikan gejala-gejala kerapuhan fisik. Bukti bahwa latihan multikomponen (terutama latihan resistensi) memiliki efek yang bermakna pada kerapuhan dan sarkopenia kini menjadi sangat kuat. Oleh karena itu, kami mengkombinasikan latihan penguatan dan *square stepping exercise* (SSE) yang merupakan latihan keseimbangan, pada lansia pre-frail yang tinggal di komunitas menentukan efektivitas penambahan latihan penguatan ekstremitas bawah terhadap skor frailty phenotype pada lansia pre-frail yang mendapatkan SSE. Studi ini merupakan studi eksperimental terkontrol acak pada lansia pre-frail berusia 60-70 tahun. Peserta dibagi menjadi dua grup masing-masing 19 orang. Kelompok kontrol mendapatkan SSE 3 kali per minggu sementara kelompok perlakuan mendapatkan SSE 3 kali per minggu ditambah latihan penguatan ekstremitas bawah 2 kali per minggu selama 6 minggu. Pada analisis masing-masing grup didapatkan perbaikan skor frailty phenotype baik pada kelompok perlakuan maupun kelompok kontrol. Sepuluh peserta (55,56%) pada kelompok kontrol mendapatkan perbaikan status menjadi robust (tidak rapuh). Sebelas peserta (64,71%) pada kelompok perlakuan mendapatkan perbaikan status menjadi robust (tidak rapuh). *Square stepping exercise* dapat memperbaiki skor *frailty phenotype* pada lansia pre-frail dan menambahkan latihan penguatan ekstremitas bawah terhadap SSE dapat secara signifikan memperbaiki skor frailty phenotype pada lansia pre-frail dibandingkan SSE saja.

Keywords:
pre-frail;
frailty phenotype;
square-stepping exercise;
older people

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INTRODUCTION

Frailty is a common and important geriatric syndrome characterized by an age-related decline in physiological reserve and function across multiple organ systems, leading to increased vulnerability to adverse health outcomes such as falls, institutionalization, and death.[1] The operational model of frailty developed by Fried *et al.* in the Cardiovascular Heart Study (CHS) concluded that frailty is a result of dysregulation in the stress response system, which is responsible for the organism's resilience. This dysregulation leads to a loss of homeostatic ability, increased susceptibility to stress, and the emergence of various syndromic phenotypes that are predictors of adverse clinical outcomes.[2,3]

Frailty develops gradually, with progressive declines often marked by acute events. It is manifested through the loss of skeletal muscle mass (sarcopenia), abnormal functioning of the inflammatory and neuroendocrine systems, and impaired energy regulation. Frail individuals have a 1.2- to 2.5-fold increase in risk of falls, institutionalization, and mortality, as well as a reduced ability of the body's physiological systems to maintain homeostasis during acute stress. In essence, frailty is the product of "excess demand imposed by reduced capacity". Once a person becomes frail, there is often a rapid, progressive, and self-perpetuating downward spiral toward failure to thrive and increased mortality.[4]

Frailty syndrome consists of a combination of decreased walking speed, weakness, weight loss, decreased activity level, and fatigue. Meanwhile, pre-frailty is a condition that precedes frailty. Individuals experience some deficits in the frailty phenotype but have not yet reached full frailty status. People who are in pre-frailty are more likely to progress to frailty and have an increased risk of falls, institutionalization, and mortality, but not as high as frail people.[4] A multicenter study in Indonesia found that among individuals aged 65 years or older, the prevalence of pre-frailty and frailty was 60.6% and 25.2%, respectively.[2]

Frailty is a dynamic condition that allows for changes in status, either towards improvement or deterioration. A study by Kojima *et al.*,[5] observed that approximately 25% of that approximately 25% of the study population improved from pre-frail to fit/strong status, which is much greater than the number of older adults who transitioned from the frail to fit/strong stage (3%). The role of physical exercise is critical in improving this condition, and research has proven that pre-frailty status can be improved with multicomponent physical exercise consisting of muscle strengthening, aerobic, balance, and flexibility exercises.[6]

These exercises not only increase muscle strength but also reduce the risk of falls and improve overall quality of life. However, participation in physical exercise programs is often hampered by various factors, such as limited transportation, bad weather, lack of facilities or costs, and physical and mental limitations in elderly individuals. These barriers often lead to decreased participation rates in structured exercise programs. Therefore, while directly supervised exercise programs may provide better results, home-based interventions, such as home-based strengthening exercises or video game-based programs, are an attractive alternative. Home-based exercise programs are more accessible, less expensive, and can be performed at the individual's convenience without depending on location or weather.

Literature to date suggests that pre-frail older adults, those with 1-2 deficits on the Cardiovascular Health Study frailty phenotype (CHS frailty phenotype), should exercise 2-3 times a week for 45-60 min incorporating aerobic, resistance, flexibility, and balance training components, with emphasis on resistance and balance activities.[6] Several studies support the implementation of physical exercises focused on resistance or muscle strengthening to overcome sarcopenia. Moderate to severe resistance training interventions can improve sarcopenia, functional status, bone density, cardiometabolic health, mental health, and cognitive function.[7] Bray *et al.*,[6] propose that program onset should occur at 55% of 1RM (endurance) and progress to higher intensities of 80% of 1RM (strength) to maximize functional gains.

Although several exercise programs have been developed to reverse frailty,[8-11] there is still a lack of multicomponent interventions specifically targeting pre-frail older adults. Furthermore, participation in such programs may be reduced by lack of transportation, fixed income, or inclement weather. Thus, although supervised exercise programs tend to yield better outcomes in terms of strength and balance, home exercise or video game-based interventions could be a good option for some patients. As the impact of social isolation on frailty is well established, group exercise enjoys the benefit of socialization. Moreover, we offer a combination of group-based exercise program, which has previously been shown to motivate participants to perform exercise more effectively,[12] and an individualized home-based strengthening exercise program to overcome these barriers.

Square stepping exercise (SSE) was first introduced by Shigematsu and Okura as an exercise that improved lower extremities' functional fitness. It was subsequently widely used as an exercise program for the prevention of falls in older adults. In SSE, step patterns are performed on a mat with 40 squares of adaptive difficulty and can be supplemented with additional elements. Square stepping exercise follows the principle of proactive and reactive response improvement. It further enhances the ability to regain balance by taking corrective steps after stumbling. It is further hypothesized to induce agonist and antagonist muscle activation in the lower extremities, thus improving lower extremity fitness. By combining a physical and a cognitive aspect, SSE seems to be particularly suitable as an exercise intervention in the geriatric clientele. It is also easy to implement, inexpensive, and offers a playful component for conventional physiotherapy. The benefit of SSE also extends beyond preventing fall such as improving functional ability, fitness of lower extremities and health status among older adults.[13,14]

Two studies investigated the effects of SSE in specific populations of older adults. Ravichandran *et al.*,[15] confirmed that a 4 wk SSE program can effectively improve gait and balance in older adults with Parkinson's disease, showing superiority over conventional physiotherapy in these two parameters. A recent study conducted by Franzel *et al.*,[14] on the older adults during the hospitalization period found that SSE in combination with a reduced number of sessions of conventional physiotherapy was as effective as conventional physiotherapy for inpatients in early geriatric rehabilitation to increase physical function and gait characteristics.

MATERIAL AND METHODS

Trial design

This study employed a randomized controlled trial design and was conducted in Semarang, Indonesia, from May to

July 2023. The protocol was approved by the Medical Research Ethics Commission of the Faculty of Medicine, Universitas Diponegoro, Semarang with the number 82/EC/KEPK/FK-UNDIP/III/2023, and the intervention was executed in accordance with the Declaration of Helsinki, Good Clinical Practice, and the Consolidated Standards of Reporting Trials (CONSORT) Statement guidelines.[16]

Participants

Potential participants who were willing to undergo screening were recruited through an announcement by the head of the local community association. The inclusion criteria comprised individuals aged between 60 and 70 yr, able to walk without assistive devices, not malnourished as indicated by a mini nutritional assessment (MNA) score[17] of >7, with normal cognitive function based on a Montreal cognitive assessment Indonesian version (MoCa-Ina) score[18] of ≥26, categorized as pre-frail based on the Fried frailty phenotype,[19] and have not participated in other routine physical exercises in the last 3 mo. Participants were excluded from the study if they met any of the following criteria: visual or hearing impairments, proprioceptive disorders, comorbid diseases (heart failure, stroke, Parkinson's disease, knee pain with varus or valgus deformity, coxitis, ischialgia, or diabetes mellitus with neuropathy), moderate to severe pain in the pelvis, knees, or ankles (visual analogue scale ≥4), severe neuromuscular and musculoskeletal disorders, blood pressure <100/80 mmHg or >180/100 mmHg, uncontrolled diabetes mellitus, taking drugs that have sedation side effects, leg length discrepancy of >2 inches, fear of falling with a falls efficacy scale (FES) score[20] of >70, and major depression (geriatric depression scale/ GDS) score[21] of ≥10). Fifty older adults were proposed to participate in the study. However, 12 participants met the exclusion criteria (1 with hearing impairment, 1 with visual impairment, 1 with stroke, 1 with heart disease, and 8 refused to participate). After sorting the initial 50 respondents, a total of 38 remained eligible (FIGURE 1).

Interventions

The treatment and control groups underwent SSE (FIGURE 2) three times a week using 8 predetermined patterns (FIGURE 3). Before starting the exercise, all participants participated in the familiarization exercise. The SSE was conducted in groups of a maximum of 4 people with the same mat and was led by 1 instructor. The participants were asked to step on the mat according to the pattern used. In the initial 7 patterns, the participants always started by stepping their right foot first. The participants stepped with their left foot first, only in the last pattern (Advanced 2).

In the first and second weeks, the exercises started with the Elementary 1 to 4 patterns. In the third and fourth weeks, the exercises were performed with Elementary 1 to 4 patterns and Intermediate 1 and 2 patterns. Finally, in the fifth and sixth weeks, the participants used all eight patterns. The SSE was performed for 20 minutes per session. The participants repeated the same pattern twice or three times before proceeding to the next pattern.

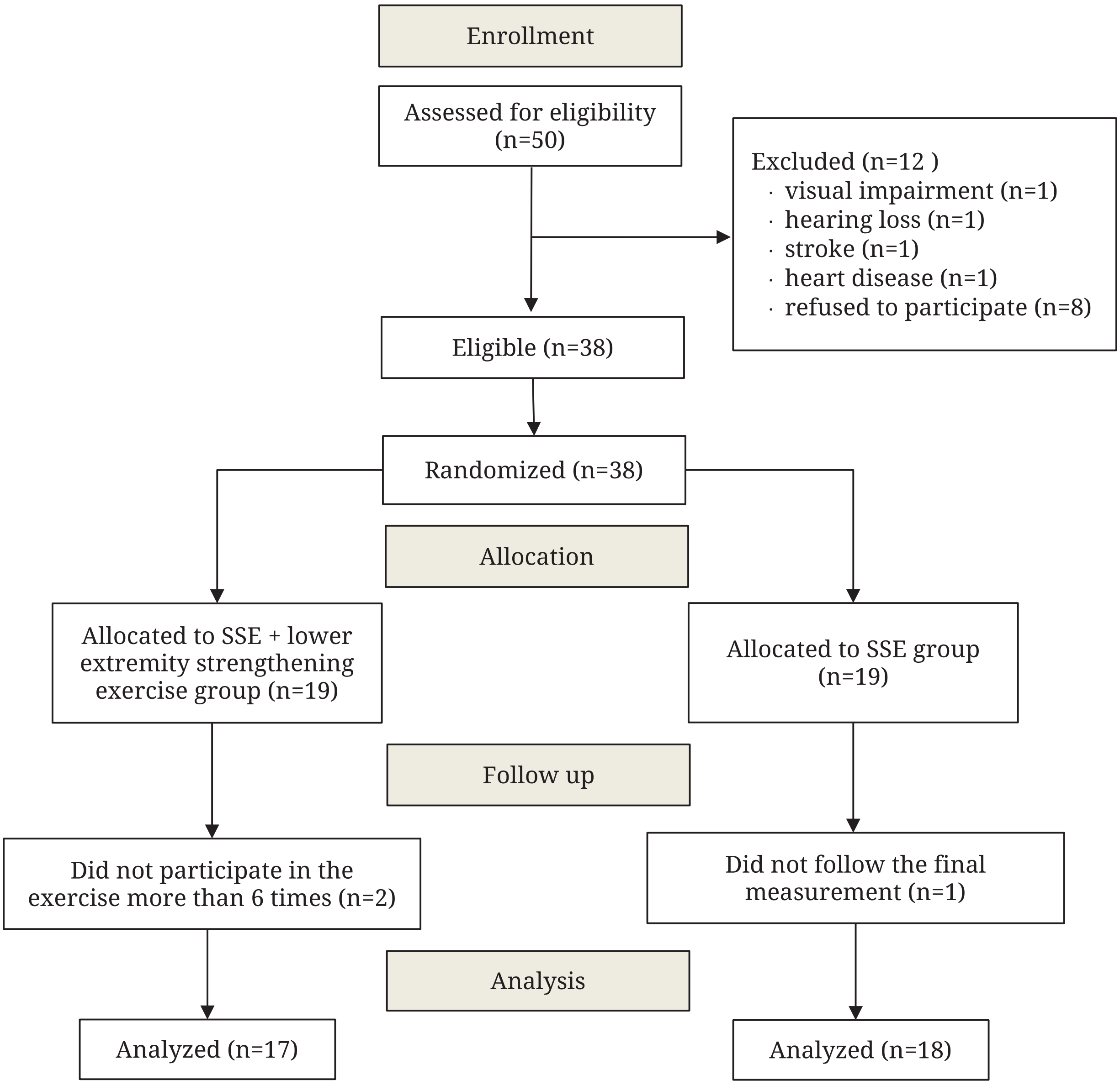


FIGURE 1. Flow diagram of the study's participants

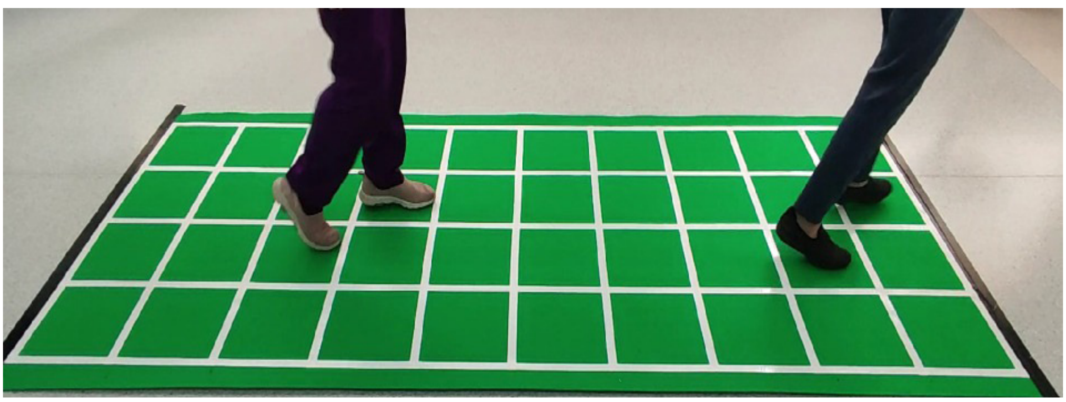


FIGURE 2. Square stepping exercise (SSE)

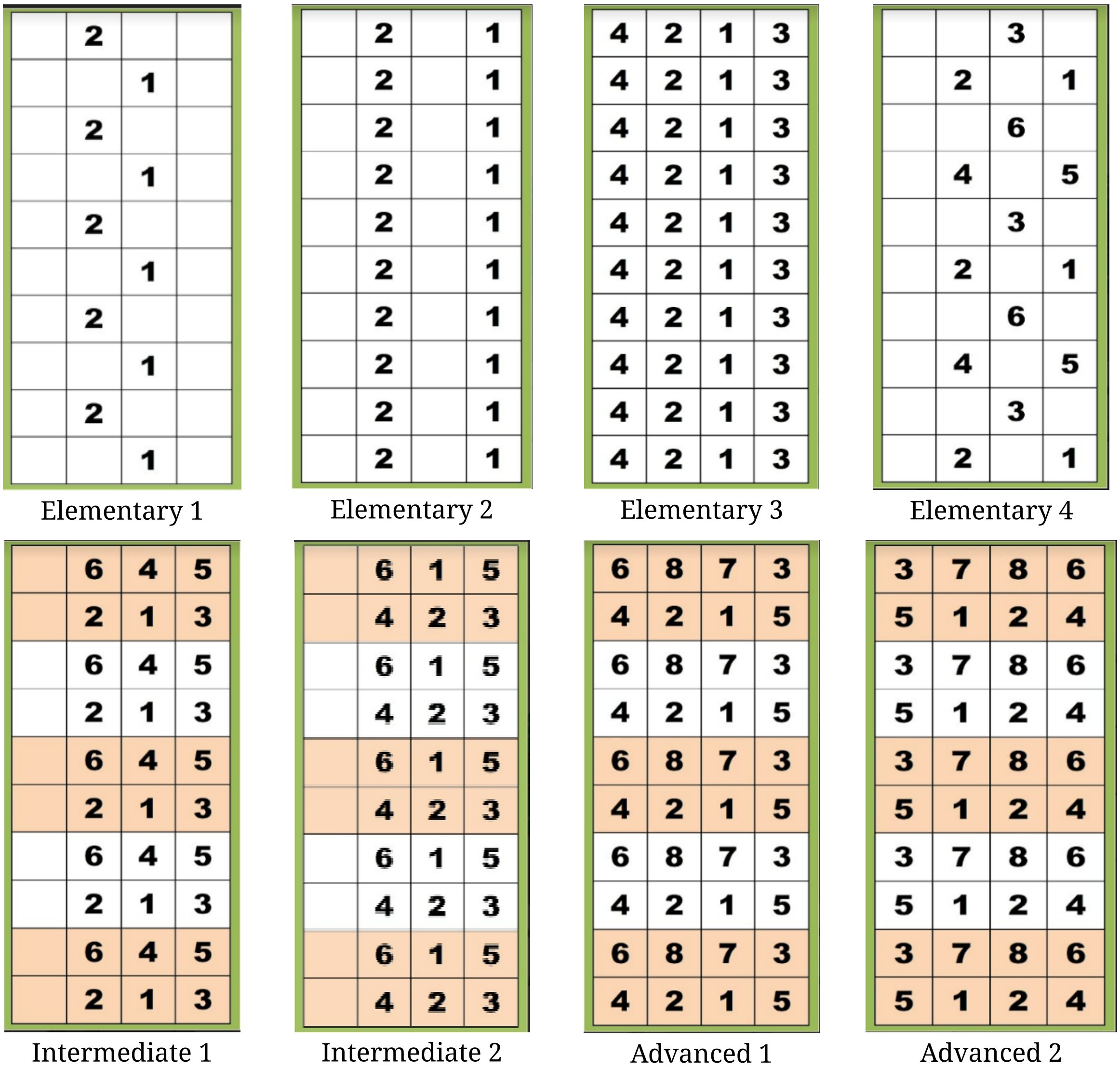
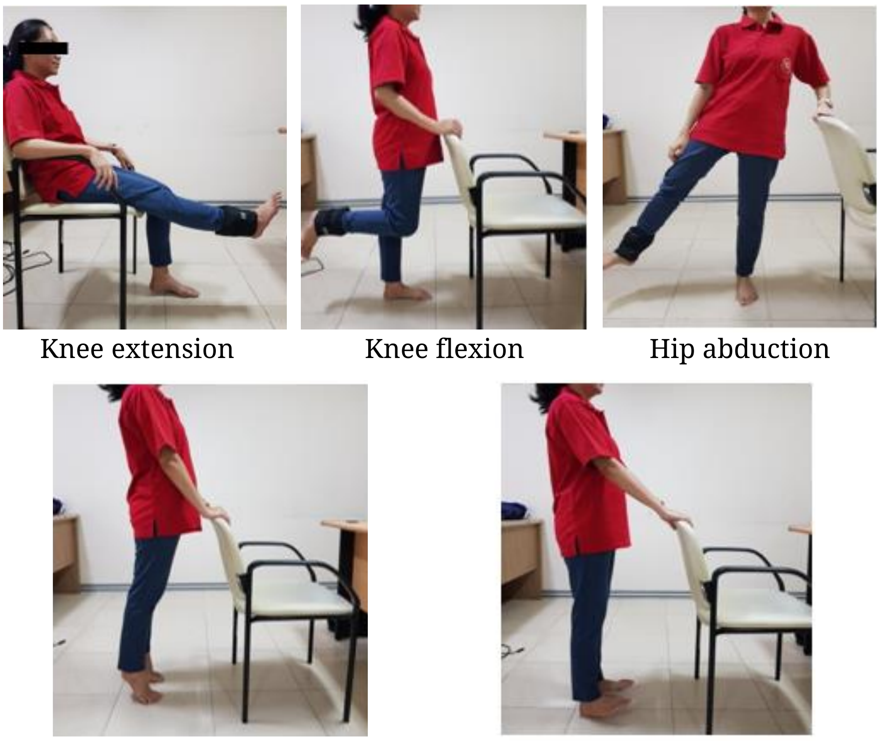


FIGURE 3 Square stepping exercise patterns

The participants in the treatment group received additional lower extremity strengthening exercises that were performed at home. These exercises required the participants to use ankle weights. The one repetition maximum (1-RM; the heaviest weight that can be lifted only once) of each participant for the submaximal strength exercises was estimated by using the Oddvar Holten diagram. This prediction was conducted by the researchers estimating the weight that can be lifted 10–20 times, recording the number of repetitions that can be maximally performed with the estimated ankle weight, and determining the participants' percentage of intensity through the Oddvar Holten diagram at the number of repetitions.[22] For example, if a participant can do 16 repetitions with 2 kg weights [i.e., 75% of 1 RM in the diagram], then 2 is divided by 0.75 to obtain a 1RM of 2.6 kilos.

The lower extremity strengthening exercises were conducted twice a week with 2 sets of 8 repetitions with ankle cuff weights. The intensity was 60% 1RM in the first week to the third week and 70% 1-RM in the fourth week to the sixth week to target the knee flexor, knee extensor, hip abductor, dorsiflexor, and ankle plantar flexor muscle groups (FIGURE 4).



Knee extension Knee flexion Hip abduction

Ankle plantar flexion Ankle dorsiflexion

FIGURE 4 Lower extremity strengthening exercises

Outcome measurements

The frailty phenotype used in this study according to Fried *et al.*,[19]: (1) unintentional weight loss, meaning weight loss (not due to dieting or exercise) of more than 4.5 kg in the last 12 mo; (2) self-reported exhaustion measured using two questions from the Center for Epidemiologic Studies Depression (CES-D) scale, namely “How often did you feel that everything you did was an effort?” and “How often did you feel that you could not get going?” This criterion was met when participants felt either of these two feelings for over 3 d in the last 7 d; (3) low physical activity, based on a physical activity scale for older adults (PASE) score of <64 for men and <52 for women. Participants were asked how often they engaged in 12 hobbies and domestic or professional activities during the previous week. Each activity has a specific weight on a scale according to its intensity level (rarely, sometimes, or often); (4) slow walking speed, meaning needing more than 7 seconds to walk 15 feet for men ≤173 cm or women ≤159 cm or needing more than 6 seconds for men >173 cm or women >159 cm; and (5) weak grip strength, measured with the participant’s dominant hand three times and determining the mean value. Weak grip strength is stratified by gender, with <28 kg in men or <18 kg in women indicating weak grip.

The frailty syndrome measurement results were categorized as: frail if 3 or more of the frailty phenotypes were observed, pre-frail if 1 or 2 of the frailty phenotypes were observed, and robust/ not frail if none of the frailty phenotypes were observed. All measurements were performed before and after the intervention.

Randomization/blinding

Concealment was conducted using closed envelopes, numbered 1 for the treatment group and 2 for the control group. The participants were allocated into groups according to randomly drawn envelopes. They were also informed and reminded not to discuss their randomization assignment with other participants.

Statistical method

Data were analyzed using Stata® version 13.1. Nominal/categorical data, including gender, phenotype frailty score, education level, and occupation type, were tested using the Chi-Square test. The data distribution normality test was performed using the Shapiro-Wilk test. Normal distribution data were obtained on age, weight, body mass index, Moca-Ina score, GDS score, MNA score, and FES score. Therefore, the difference between groups was tested using an unpaired t-test. The abnormally distributed variable is height, so the differences between groups were tested using the Mann-Whitney test. Differences in frailty phenotype scores before and after the intervention in the treatment and the control groups were tested using the Wilcoxon test. Moreover, differences in frailty phenotype scores before and after the intervention between the control and treatment groups were tested with the Chi-square test.

RESULTS

The research involved 35 participants divided into control (n = 18) and intervention (n = 17) groups. The majority of participants were female (77.78% in the control group and 64.71% in the intervention group). The mean age of participants was similar between the two groups (65.17 ± 4.41 vs. 66.12 ± 3.08 yr; p = 0.467). There were no significant differences between groups in terms of in weight, height, body mass index (BMI), cognitive scores (MoCA Ina), depression (GDS), nutritional status (MNA), and confidence in balance (FES). Most participants were categorized as pre-frail with a frailty phenotype score of 1 (83.33% in the control group, 76.47% in the intervention group, p = 0.612). Education and occupation levels were also not significantly different between groups. Overall, the baseline characteristics of participants were well balanced, ensuring more valid intervention results without bias from individual factors.

At baseline (pretest), the majority of participants were classified as having a frailty phenotype score of 1 category (83.33% in the control group and 76.47% in the intervention group), with no significant difference between groups (p = 0.612). After the intervention, both groups showed improvement in frailty status: 55.56% of control participants and 64.71% of intervention participants achieved a score of 0 (non-frail). However, the difference between groups after the intervention was not significant (p = 1.000). Intragroup analysis showed a significant change (p = 0.000), indicating that participation in either intervention led to measurable benefits. With an effect size of 0.203, the intervention had a small to moderate effect, indicating that both SSE alone and in combination with strengthening exercises were effective in improving frailty status in pre-frail elderly.

During the pretest stage, the majority of participants in both groups had no weight loss with 88.89% in the control group and 94.12% in the intervention group with no significant difference between the two (p = 0.581). Following the intervention, the proportion of participants without weight loss remained unchanged in both groups, with percentages identical to those at pretest (p = 0.581). Intragroup analysis using the Wilcoxon test showed no significant change in weight loss patterns in either the control (p = 1.000) or intervention (p = 1.000) groups. These results suggest that the interventions, both SSE alone and in combination with strengthening exercises, did not affect weight change in pre-frail elderly.

TABLE 1. Characteristics of participants

Variable	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Gender [n (%)]			0.392¥
• Man	4 (22.22)	6 (35.29)	
• Woman	14 (77.78)	11 (64.71)	
Age (yr)	65.17 ± 4.41	66.12 ± 3.08	0.467§
Weight (kg)	55.11 ± 3.77	55.41 ± 4.36	0.828§
Height (cm)	155.28 ± 3.43	155.41 ± 3.20	0.777‡
BMI (kg/m²)	22.86 ± 1.48	22.86 ± 1.34	0.989§
MOCA-Ina score	27 ± 0.69	27.24 ± 0.75	0.340§
GDS score	1.5 ± 0.51	1.47 ± 0.51	0.867§
MNA score	12.67 ± 1.19	13.29 ± 1.16	0.124§
FES score	15.83 ± 6.47	14.71 ± 4.13	0.546§
Frailty phenotype score [n (%)]			
• 1	15 (83.33)	13 (76.47)	0.612¥
• 2	3 (16.67)	4 (23.53)	
Education [n (%)]			
• Elementary	2 (11.11)	1 (5.88)	
• Junior high school	7 (38.89)	3 (17.65)	0.457±
• Senior high school	7 (38.89)	11 (64.71)	
• Diploma	2 (11.11)	2 (11.76)	
Occupation [n (%)]			
• Unemployed	0 (0)	2 (11.76)	
• Housewife	13 (72.22)	9 (52.94)	0.383±
• Self employed	3 (16.67)	2 (11.76)	
• Retirees	2 (11.11)	4 (23.53)	

Note: BMI: body mass index; *Significant ($p < 0.05$); §Independent t; ¥Chi-Square; ±Fisher's exact; ‡Mann-Whitney

TABLE 2. Comparison of frailty phenotype scores between control and treatment groups

Frailty phenotype score	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Pretest [n (%)]			
• 1	15 (83.33)	13 (76.47)	0.612¥
• 2	3 (16.67)	4 (23.53)	
Post test [n (%)]			
• 0	10 (55.56)	11 (64.71)	
• 1	6 (33.33)	5 (29.41)	1.000±
• 2	2 (11.11)	1 (5.88)	
p	0.000†*	0.000†*	
		Effect size	0.203

Note: *Significant ($p < 0.05$); ¥Chi-square; †Wilcoxon; ±Fisher's exact

At the pretest stage, hand grip strength showed no significant difference between the control (19.58 ± 6.49 kg) and intervention (21.14 ± 6.66 kg; p = 0.490) groups. After the intervention, both groups showed an increase in mean grip strength: 21.02 ± 7.20 kg in the control and 22.74 ± 8.04 kg in the intervention, but the difference remained insignificant (p = 0.508). Intragroup analysis showed a significant improvement in grip strength within the intervention group (p = 0.020), while the improvement in the control group did not reach statistical significance (p = 0.123). Nonetheless, the difference in improvement between groups was not significant (p = 0.563) with an effect size of 0.990 indicating an almost neutral effect. These results indicate that the combination of SSE and strengthening exercises can significantly improve hand grip strength in the intervention group, although the difference compared to SSE alone was not statistically significant.

Moreover, of the 5 aspects of the frailty phenotype score assessment, the control and intervention groups experienced statistically significant improvements in the walking speed, fatigue score, and PASE score components, evidenced by the p-values of <0.05 obtained (TABLE 5 - 7).

TABLE 3. Comparison of weight loss between control and treatment groups

Weight loss	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Pretest [n (%)]			
• No.	16 (88.89)	16 (94.12)	0.581¥
• Yes	2 (11.11)	1 (5.88)	
Post-test [n (%)]			
• No.	16 (88.89)	16 (94.12)	0.581¥
• Yes	2 (11.11)	1 (5.88)	
p	1.000†	1.000†	

Note: *Significant ($p < 0.05$); ¥Chi-Square; †Wilcoxon

TABLE 4. Comparison of grip strength between control and treatment groups

Grip strength	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Pretest	19.58 ± 6.49	21.14 ± 6.66	0.490§
Post-test	21.02 ± 7.20	22.74 ± 8.04	0.508§
p	0.123¶	0.020†*	
Difference	1.43 ± 3.77	1.60 ± 3.00	0.563‡
		Effect Size	0.990

Note: *Significant ($p < 0.05$); §Independent t; ¶Paired t; ‡Mann-Whitney; †Wilcoxon

TABLE 5. Comparison of walking speed between control and treatment groups

Walking speed (s)	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Pretest	6.38 ± 2.38	6.01 ± 1.71	0.601§
Post-test	5.73 ± 1.61	4.34 ± 1.12	0.003‡*
p	0.032¶*	0.000¶*	
Difference	0.66 ± 1.19	1.67 ± 1.35	0.024§*
Effect Size			0.510

Note: *Significant ($p < 0.05$); §Independent t; ¶Paired t; ‡Mann-Whitney; †Wilcoxon

TABLE 6. Comparison of fatigue score between control and treatment groups

Fatigue score	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Pretest [n (%)]			
• 1	5 (27.78)	8 (47.06)	
• 2	13 (72.22)	5 (29.41)	0.014±*
• 3	0 (0)	4 (23.53)	
Post-test [n (%)]			
• 1	11 (61.11)	13 (76.47)	0.581¥
• 2	7 (38.89)	4 (23.53)	
p	0.034†*	0.044†*	
		Effect size	0.0001

Note: *Significant ($p < 0.05$); ¥Chi-Square; †Wilcoxon; ±Fisher's exact

TABLE 7. Comparison of PASE score between control and treatment groups

PASE score	Groups		p
	Control (n = 18)	Intervention (n = 17)	
Pretest	89.81 ± 34.06	90.12 ± 40.63	0.981§
Post-test	99.76 ± 25.04	100.07 ± 33.53	0.976§
p	0.000†*	0.000†*	
Difference	9.95 ± 13.36	9.95 ± 15.04	0.641‡
		Effect size	0.999

Note: *Significant ($p < 0.05$); §Independent t; ‡Mann-Whitney; †Wilcoxon

The walking speed was not significantly different between groups at the pretest stage (p = 0.601), but after the intervention, the intervention group had a greater improvement (p = 0.003; effect size 0.510), suggesting that the combination of SSE and strengthening exercises was more effective. Fatigue scores were initially significantly different (p = 0.014), but after the intervention, the difference was no longer statistically significant (p = 0.581), with significant improvements in both groups ($p < 0.05$) but a small effect size (0.0001), indicating minimal impact. The PASE scores improved significantly in both groups (p = 0.000), with no difference between groups (p = 0.641; effect size 0.999), indicating that both SSE and its combination with strengthening exercises are equally effective in increasing physical activity of pre-frail elderly.

DISCUSSION

The results showed that a 6-wk intervention with SSE, as well as a combination of SSE and lower limb strengthening exercises, was effective in improving frailty scores in pre-frail elderly. The baseline characteristics of the participants were relatively balanced between the control and intervention groups, ensuring the validity of the study results. After the intervention, the group receiving SSE three times a week had significant improvements in walking speed (p = 0.003) and PASE score ($p < 0.001$), although no significant between-group difference was observed in physical activity improvement. In contrast, the group receiving SSE with additional lower limb strengthening exercises showed significant gains in walking speed, hand grip strength, and PASE score. Frailty status improved significantly in both groups ($p < 0.001$), although with no significant difference between groups (p = 1.000), with an effect size of 0.203 indicating a small to moderate effect. In addition, the intervention did not affect participants' weight change (p = 1.000). Overall, both SSE and its combination with strengthening exercises were effective in improving some aspects of frailty, especially walking speed, but did not show significant differences in overall frailty status improvement. Each component of the frailty phenotype showed observable improvement in both groups.

The average intra-group walking speed in both groups before and after treatment, analyzed using the paired t-test, showed significant differences. This improvement is attributed to the effect of exercise, both SSE and lower extremity strengthening exercises, on walking speed. Gait is a sequence of repeated movements of the lower extremities intended to move the body forward while simultaneously maintaining postural stability. For the harmonious performance of these movements, there must be a precise balance between external forces acting on the body and the response of internal forces from muscles, tendons, bones, ligaments, and joint capsules. Gait speed can be influenced by individuals' health status, neuromuscular control, cardiorespiratory condition, physical activity level, sensorial and perceptual functions, as well as by characteristics of the environment where they walk. Over time, these combined factors may contribute to a decline in available energy, including that needed to maintain the body's homeostatic balance. Thus, older adults may develop adaptive behaviors, such as reduced gait speed.[23] The SSE increases walking speed through the repetitive process of stepping that requires postural adjustments to ensure the body is stable enough to move forward. Similarly, as the cycle progresses, one needs to constantly maintain equilibrium as the center of mass moves away from the base of support.[24] The strength of the lower extremity muscles, especially the pelvic abductors, knee flexors and extensors, dorsiflexors and plantar flexors of the ankles, has been widely studied and is closely related to walking speed. The force of the pelvic abductor plays a role in maintaining lateral stability during the single stance phase when walking, while the ankle muscles are responsible for the correction of small errors so as to strengthen the postural response of the ankle hip strategy. The dorsiflexor and plantar flexor muscles of the ankle play an important role in maintaining balance and generating the propulsion force when walking. Meanwhile, the quadriceps femoris muscle group facilitates knee extensions, which is essential for both lifting and lowering movements. The strength of the knee extensor also generates the necessary extension momentum during walking.[25]

Furthermore, low physical activity in older adults can be caused by multiple factors such as pain or injury, lack of social support, lack of knowledge, and illness or poor health. It is possible that reduced activity may lead to loss of physical capacity, and consequently, to increased inactivity-related fatigue through a reversed causal pathway. Fatigue may decrease motivation to be physically active, and motivational factors have been shown to play an important role in determining physical activity levels in older people.[26] Previous studies have shown increased physical activity levels in patients with multiple sclerosis who performed SSE for 12 wk. Research on 10 inactive older adults aged ≥ 65 who participated in SSE for 3 wk also showed an increase in physical activity, with participants reaching up to 7000 steps per d.[27] One study on inactive older adults indicated that SSE can be classified as a moderate-intensity exercise if more than 50% of the heart rate reserve is achieved in 80% of participants.[27] The increase in physical activity levels observed through improvements in PASE scores in this study was in line with the observed improvement in fatigue levels.

In lower extremity strengthening exercises, the strengthening effect occurs through neural and skeletal muscle adaptations. Initially, the number of motor units recruited increased, and muscle excitability speed and synchronization improved (neural adaptations). If moderate to high-intensity strengthening exercises are continued, then in a few weeks there will be an increase in the size of muscle fibers (muscle hypertrophy), a change in the composition of muscle fiber type from type IIb to type IIa, and the possibility of muscle fiber hyperplasia. Ultimately the physiological response will lead to an increase in muscle strength.[28] Interestingly, the study found that decreases in isokinetic leg muscle torque were two to five times greater than losses in CSA with aging. This implies that the loss in muscle strength with age (dynapenia) is more related to impairments in neural activation and/or reductions in the intrinsic force-generating capacity of skeletal muscle. Based on these findings, it is plausible to argue that primarily neural adaptations account for training-induced improvements in muscle strength, whereas improvements in measures of muscle morphology playing a minor role, particularly during the early phase of resistance training.[29] This may explain the observed improvement in muscle strength or hand grip, while the increase in muscle mass represented by weight gain was not reported in this study.

The increase in hand grip strength observed in the intervention group was likely the effect of moderate-intensity strengthening exercises 2 x/wk for 6 wk. Although these exercises were not performed on the upper extremities, the use of grip strength as a biomarker of current health status is most directly supported by research showing a cross-sectional association between grip strength and the strength of other muscle groups in both healthy individuals and adults with various pathologies.[30] However, we acknowledge that grip strength does not eliminate the need for specific assessments of different muscle groups, when indicated. The results of this study have practical implications for frailty prevention and mobility improvement in older adults, SSE can be applied as a simple and safe intervention, either at home or in group settings, to improve walking speed and reduce fatigue. The combination of SSE with lower extremity strengthening exercises may serve as a rehabilitation strategy for older adults at higher risk of frailty, and could be recommended in clinical practice as part of a comprehensive frailty prevention program. This intervention can be implemented in healthcare facilities or elderly communities to improve their quality of life and independence and can be combined with other rehabilitation approaches to accelerate recovery from mobility impairment. Further research is needed to evaluate the long-term effects of this intervention through re-measurement after several months, assessing physiological changes in more detail, and involving a larger control group to strengthen the validity of the findings.

In this study, the mat with the SSE patterns was tightly glued to the floor to ensure the participants' safety during the exercises. The training process and the distance between participants were also supervised by researchers and research assistants so that the participants did not bump into each other. During the study, there were no incidents of falls during exercise. The researchers also regularly monitored the participant's compliance with the lower extremity strengthening exercises by providing exercise guides, logbooks, and communication through WhatsApp. The low drop-out rate in this study also indicates satisfactory participant compliance. Additionally, exercising together made participants feel more enthusiastic about joining the sessions, as they could interact face-to-face and motivate one another.

Nevertheless, this study has some limitations. First, the evaluation was conducted only once after the intervention, so the long-term effects could not be determined. Second, this study did not directly measure changes in muscle strength following the strengthening exercises, which could have provided additional insight into the physiological mechanisms involved. In addition, factors such as participant motivation and other underlying health conditions that may have influenced the outcome were not fully controlled.

CONCLUSION

The results of this study showed that SSE was effective in improving frailty phenotype scores in pre-frail elderly, but the impact was more significant with the addition of lower limb strengthening exercises. These improvements were seen in grip strength, walking speed, fatigue score and PASE score. These findings indicate that interventions that are more specific to muscle weakness may accelerate improvements in the physical condition of pre-frail elderly. Thus, exercise programs for this population should include a combination of aerobic and muscle strengthening exercises for optimal results.

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