Square-stepping exercise versus strength and balance training for fall risk factors

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*ABSTRACT. **Background and aims:** Feasible and low-cost exercise programmes targeting fall risk factors may decrease the risk of falling in older adults. The purpose of this study was to compare the effects of square-stepping exercise (SSE) training, which is a new and low-cost method designed to improve lower-extremity functional fitness, with strength and balance (SB) training. **Methods:** The study included 39 community-dwelling adults aged 65 to 74 years. The participants were randomized to either group SSE (n=20) or SB (n=19). They engaged in 70-min group exercise sessions twice a week for 12 weeks. The efficacy of the program was measured with both a 9-item test battery for assessment of physical performance and self-reported scales (fear of falling, pleasure in exercise, perceived health status). Fall incidence was followed up for 14 months. **Results:** The results of a 2-way ANOVA revealed that the time effect in 7 of the 9 performance tests was significant, although group-by-time interactions were not. No significant changes were observed in the self-reported scales. During the 14-month follow-up period, 7 falls in 6 participants in the SSE group and 12 falls in 11 participants in the SB group were reported. The incidence rate per person in the SSE group (30.0%) was not significantly different from that in the SB group (57.9%). The rate of falls per trip [falls/(falls + trips)] in the SSE group (17.1%) was significantly lower than in the SB group (50.0%). **Conclusions:** SSE is as equally effective as SB training in improving lower-extremity functional fitness. SSE may also be recommended for older adults, due to its low cost and effectiveness.*
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INTRODUCTION

A serious problem faced by older adults, their families, and health care practitioners is the increased prevalence of falls and fall-related hip fractures in adults aged 65 years or more (1). Decreased functional fitness such as poor muscle power, balance, and agility decreases the ability of older adults to prevent falls (1, 2). Balancing reactions to rapid stepping or reaching movements are critical in preventing falls (3). An interview-based community survey (4) reported that 35% of older residents had suffered one or more falls in the preceding year, and that 53% of the falls were caused by tripping. Therefore, strength and balance training or Tai Chi Chuan, which is advantageous in improving functional fitness, has received considerable attention recently (5-7). However, the optimal type of exercise training for fall prevention remains unclear (8).

Complementary and alternative low-tech and low-cost exercises such as strength and balance training (5) and Tai Chi Chuan (9) for improving functional fitness in order to decrease the risk of falls are gaining increasing research interest. However, another type of low-tech and inexpensive form of training is square-stepping exercise (SSE) (10). This novel type of exercise training can be performed on a thin felt mat (250 × 100 cm) divided into 40 small squares (25 × 25 cm). SSE includes forward, backward, lateral and oblique steps, and step patterns may be made progressively more complex. In a previous study (10) it was found that participants who underwent SSE training had significantly greater improvement in lower-extremity functional fitness, defined as improved leg strength, power, and locomotion speed, with respect to a no-activity reference group. Therefore, the objective of this study was to further compare the effects of SSE on lower-extremity functional fitness with those of traditional strength and balance (SB) exercise training. The research hypothesis was that the effects of SSE would be similar to those of SB. By verifying the hypothesis, we would add one more exercise program to the list of the existing fall-prevention programs, thus allowing older adults to select the one they prefer from the many programs available.

Key words: Accidental falls, exercise therapy, health promotion, physical fitness.
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METHODS

Study design

We conducted a parallel, group-randomized trial involving SSE and SB training groups. Each group participated in a 70-min exercise session twice a week for 12 consecutive weeks. Outcome measurements were functional fitness, self-reported scales, and fall incidence. The institutional review boards of the Kawage Health Center approved the research protocol; all study participants provided their written informed consent prior to enrolment.

Participants and their characteristics

The trial was restricted to healthy, independently living, older adults aged 65 to 74 years residing in Kawage Town, Mie Prefecture, Japan. A recruitment letter was sent to 300 adults (150 women, 150 men), randomly selected from those meeting the initial eligibility requirements (1061 women, 1043 men). Any neurological or mobility-limiting orthopedic condition was an exclusion criterion. We identified 41 older adults who agreed to participate. Of these, 2 were not suitable for the study because of back pain (1 woman) and time conflict (1 man). The remaining 39 were then assigned randomly to either the SSE (10 women, 10 men) or the SB training group (8 women, 11 men).

Participants completed a baseline questionnaire, which included questions on education, vision, medications, medical conditions, and exercise frequency (during the interviews and tests, all participants were able to understand the questions and interact normally, and nothing suggested that any of them was suffering from dementia). Body weight and height were measured by a health nurse. Body mass index was calculated from weight in kilograms divided by height in meters squared. Body fat was estimated by bioimpedance measurements (HBF-354; Omron Healthcare, Kyoto, Japan).

Training regimen

A detailed description of the SSE method is given in another report (10). In brief, SSE was performed on a thin felt mat (250 × 100 cm) divided into 40 squares (25 × 25 cm). Participants were asked to walk (step) fast from one end of the mat to the other according to the step pattern provided; they were also asked to walk on their toes with their heels lifted without treading on the frames of the squares (Fig. 1). The SSE patterns included forward, backward, lateral and oblique steps, and step patterns were made progressively more complex. A total of 196 step patterns was developed, distributed into 8 progressively more difficult categories (detailed description available from the authors on request). After 2 weeks of familiarization with SSE, the complexity of the step patterns was increased progressively. In each exercise session, they were demonstrated by an instructor with a verbal explanation. Written instructions were not given to participants. Step cadence was not specified and, although all participants stepped at a self-selected pace, they were asked to step slowly at first and then faster, after some practice. The SSE session consisted of a 15-min warm-up activity, 40-min SSE, and 15-min cool-down activity.

Fig. 1 - *Square-stepping exercise.*

The sessions in the SB group were similar to those in the SSE group, except that the former performed 40 min of strength and balance exercise instead of SSE. The duration of strength training, using body weight and rubber resistance bands, was approximately 20 min per session. The program consisted of 3 sets with 10 repetitions of the following exercises: squat, front lunge, leg extension, hip abduction and adduction, calf raise, abdominal curl, and back extension. Participants were encouraged to adjust their body joint angle or rubber resistance, in order to feel somewhat exhausted in the last three repetitions of each set. Balance training consisted of one-leg and two-leg balance with the toes or heels raised, tandem standing/walking with eyes open/closed (standing position), and balancing the body on the buttocks with the feet off the ground (seated position). Balance training was usually performed for 10 s or for a distance of 5 m of walking in each exercise. During balance exercises, participants were encouraged to maintain their balance for as long as possible.

These exercises were always performed under the supervision of the same instructor who led the SSE and, if necessary, with an exercise partner (study participant). The exercise instructor was certified in first aid and was encouraged to report any negative sign or symptom resulting from the exercises during the classes. During the exercise period, participants in both groups were instructed to continue their routine daily activities and not to perform any new exercise except for SSE or SB.

Outcome measures

The items used for testing functional fitness (fall risk factors) were adopted from previous studies (10-13). The test items used were chair stands, leg extension power, one-leg balance with eyes closed, functional reach, standing up from a lying position, stepping with both feet, walking around 2 cones, 10-m walk, and sit and reach (details in *Appendix*).

The self-reported scales (psychological factors) consisted of fear of falling, pleasure in exercise, and perceived health status. The occurrence of falls and trips was recorded. A fall was defined as a sudden, unintentional change in position causing an individual to land at a lower level on an object, the floor or the ground, for reasons other than a sudden onset of paralysis, epileptic seizure, or overwhelming external force (14). Falls caused by losing balance from an external force were not included in this study. Further, only the occurrence of falls by tripping was measured because tripping is the most frequent cause of falls, but they may be prevented by a status of good functional fitness (4). A trip was defined as stumbling over something but not landing on any part of the body. As trips may cause false positives because some individuals may report a trip as a fall (15), participants were told the difference between a fall and a trip and instructed to record the occurrence of either (or both), separately, every day from the end of the 12-week training regimen to the end of the 14-month post-regimen, using a self-reported fall schedule. All participants received a fall schedule on a prepaid postcard at the beginning of each month; they recorded any falls or trips daily, and mailed the card at the beginning of the following month. A telephone or face-to-face interview was conducted in order to ascertain the reports of falls and trips.

Statistical analysis

Baseline demographic characteristics, incidence of falls, and mean percentage of classes attended during the study period were compared between the groups by independent *t*-tests or chi-square tests. A paired *t*-test was used to examine within-group effects. All analyses of post-regimen measurements were conducted on an intention-to-treat basis, so that all participants were included according to the original treatment assignment and analysed, regardless of their adherence to the treatment or drop-out status. A repeated-measures analysis of variance (ANOVA) was used to compare baseline and post-regimen changes in outcome measures. All outcome variables were normally distributed, thus satisfying the basic assumption for ANOVA. SPSS 12.0.1 software (SPSS, Chicago, IL) was used for all statistical analyses. A *p*-value of less than 0.05 was accepted as significant. All values are expressed as means ± standard deviation (SD).

RESULTS

Participant characteristics, compliance, and adverse events

The SSE and SB groups were comparable and well matched with regard to the baseline descriptions (Table 1). The mean percentage of classes attended was 87% (range, 77-89%) for the SSE group and 83% (range, 56-92%) for the SB group, indicating no significant difference in the mean class attendance rate (p=0.47). None of the participants dropped out from the program during the regimen. No adverse events such as falls and episodes of fear felt by participants were observed during sessions.

Effects of regimen on outcomes

The group statistics at baseline and post-regimen and group-by-time interactions are listed in Table 2. At baseline, none of the functional fitness items in the SSE group was significantly different from that in the SB group.

A significant within-group improvement in one-leg

Table 1 - *Baseline characteristics of study participants by randomized groups.*

Characteristics	SSE (n=20)	SB (n=19)	*p*
Women, n (%)	10 (50)	8 (42)	0.43
Age, y	68.8 ± 2.4	69.3 ± 3.2	0.57
Body weight, kg	58.4 ± 11.4	61.9 ± 11.5	0.35
Height, cm	156.8 ± 9.6	158.5 ± 9.4	0.56
Body mass index, $kg \cdot m^{-2}$	23.6 ± 3.0	24.5 ± 3.5	0.37
Body fat, %	30.0 ± 5.9	29.2 ± 6.1	0.70
Education, y	11.6 ± 2.0	11.2 ± 3.0	0.64
Vision[a]	2.80 ± 0.83	2.94 ± 0.56	0.56
Medications, n (%)	10 (50)	12 (63)	0.65
Common medical conditions, n[b]	0.67 ± 0.90	0.84 ± 1.01	0.60
Exercise frequency[c]	3.05 ± 1.39	2.82 ± 1.42	0.90

SSE= square-stepping exercise; SB= strength and balance training. "Women" and "Medications" refer to percentage of participants who were women or had one or more medications. Body fat was estimated by bioimpedance measurements. [a]Measured on a 5-point Likert scale: 1= poor, 5= excellent; higher scores indicate better vision. [b]Recorded out of 21 possible common medical conditions (e.g., cerebrovascular disease, hypertension, heart disease). [c]Recorded on a 4-point Likert scale: 1= not at all, 2= one or two days a month, 3= one day a week, and 4= two days or more a week; higher scores indicate frequent exercise.

Table 2 - *Functional fitness items by group at baseline and post-regimen.*

Endpoint	Baseline	Post-regimen	Between-Group *p*-value at baseline	Change (%)	Time effect *p*-value	Group-by-time *p*-value
Leg strength and power						
Chair stands, n·30 s^{-1}						
SSE	15.6 ± 0.7	17.9 ± 0.7	0.62	14.0 ± 15.3	<0.001	0.60
SB	16.1 ± 0.7	18.5 ± 0.7		18.0 ± 13.8		
Leg extension power, W						
SSE	271.9 ± 30.0	339.8 ± 24.9	0.32	31.4 ± 37.1	<0.001	0.60
SB	312.3 ± 28.8	348.8 ± 25.6		19.8 ± 28.4		
Balance						
Single-leg balance with eyes closed, s						
SSE	6.4 ± 2.4	11.0 ± 2.7	0.22	86.3 ± 105.7	0.04	0.16
SB	10.5 ± 2.1	11.4 ± 2.4		24.7 ± 75.0		
Functional reach, cm						
SSE	32.3 ± 1.3	31.8 ± 1.1	0.20	-0.7 ± 9.5	0.30	0.18
SB	30.1 ± 1.1	32.1 ± 0.9		8.3 ± 16.1		
Agility						
Standing up from a lying position, s						
SSE	3.25 ± 0.26	3.05 ± 0.19	0.84	4.0 ± 16.3	0.05	0.95
SB	3.23 ± 0.22	3.04 ± 0.17		4.7 ± 13.7		
Stepping with both feet, n·10 s^{-1}						
SSE	59.0 ± 3.3	67.8 ± 2.8	0.60	17.1 ± 13.0	<0.001	0.75
SB	56.5 ± 3.2	62.2 ± 2.7		11.4 ± 14.0		
Walking speed						
Walking around two cones, s						
SSE	22.9 ± 0.9	21.5 ± 0.8	0.72	7.7 ± 6.4	<0.001	0.92
SB	22.5 ± 0.8	20.9 ± 0.7		6.5 ± 8.5		
10-m walk, s						
SSE	5.87 ± 0.30	4.75 ± 0.24	0.19	18.2 ± 12.0	<0.001	0.32
SB	5.33 ± 0.26	4.68 ± 0.22		11.8 ± 11.4		
Flexibility						
Sit and reach, cm						
SSE	6.0 ± 2.3	8.1 ± 2.2	0.49	35.9 ± 62.8	0.003	0.95
SB	8.2 ± 2.0	9.8 ± 1.9		10.6 ± 41.0		

Values are as means ± standard deviation. SSE= square-stepping exercise; SB= strength and balance training. Percentages of change were calculated as (post – baseline)·$baseline^{-1}$; however, standing-up from a lying position, walking around two cones and 10-m walk were calculated as (baseline – post)·$baseline^{-1}$.

balance was observed only in the SSE group. Functional reach improved significantly only in the SB group. However, performance on 6 other tests (chair stands, leg extension power, stepping, walking around 2 cones, 10-m walk, and sit and reach) improved significantly in both groups. Standing up from a lying position did not improve. There were significant time effects in 7 tests. The group-by-time interaction in each test was not statistically significant, indicating that SSE participants exhibited improvements similar to those in SB participants. In 6 of the 9 tests, however, the percentage change from baseline to post-regimen status in the SSE group was higher than that in the SB group (Table 2).

There was no significant pre- to post-regimen improvement in any of the self-reported scales (Table 3), although SSE participants reported a significant within-group improvement with regard to pleasure in exercise. There was no effect of either regimen on the fear of falling or perceived health.

During the 14-month post-regimen follow-up, 7 trip-induced falls in 6 participants in the SSE group (incidence rate per person, 30.0%) and 12 trip-induced falls in 11 participants in the SB group (57.9%; p=0.08) were reported. However, 34 trips in the SSE group and 12 in the SB group were observed during the same period, indicating that the rate of falls per trip reported [fall/(fall+trip)] in the SSE group (17.1%) was significantly lower than that in the SB group (50.0%; p=0.04).

DISCUSSION

The primary finding of this study was that SSE was as effective as SB in improving lower-extremity performance and in preventing falls in older community-dwelling people. The SSE program was tolerated well by participants. SSE is a low-tech and low-cost form of exercise and therefore potentially suitable to be carried out in the context of care for older people.

An interview-based community survey reported that

35% of older residents had suffered one or more falls in the preceding year, and that 53% of the falls had been caused by tripping (4). After tripping, a quick, firm step movement to prevent a fall that involves high flexion velocities in the hip, knee and ankle plantar is important (16, 17). Because SSE training offered steps that consisted precisely of quick hip, knee and ankle plantar flexions, the SSE participants acquired adequate step ability after a 12-week regimen.

Our findings also suggest that SSE training is appropriate to achieve the desired results in static balance, agility and walking speed. It was hypothesized that this particular exercise would significantly affect these fitness categories, because SSE consists of quick, multi-directed movements, heel lifts and smooth transfers of weight, which all contribute to improving balance, agility and walking speed. Significant improvement in these parameters may also prevent falls after tripping (8). In this study, we did find that total falls and the rate of falls per trip reported in SSE training were lower than in SB training, therefore results suggest that SSE participants successfully recovered from tripping due to better functional fitness in the lower extremities, and that SSE training may be superior to SB training in preventing falls. In order to confirm these merits precisely, further kinematic studies are needed to assess the effect of SSE on the recovery movement after a trip in a fall-simulated situation.

SB training also improved fall risk factors; this fits previous findings (5, 6, 8). However, in the current study, the effects of SB were smaller than those of SSE. The difference in effect size between the 2 training regimens may be due to the specificity of training, particularly the quick movements in SSE. In order to prevent falls, Thelen et al. (17) emphasized that it is necessary to produce a sufficient amount of muscle power quickly. Although leg reaction time indicates the ability to react to a stimulus very quickly, this may not be enough if the power output of the response movement is not sufficient to counteract the forces produced by the displacement of the body's centre of gravity. Each type of training focuses mainly on the leg muscles, but SSE training produced quicker leg movements than SB, and hence SSE participants received greater benefit with respect to fall risk factors.

In order to confirm the significance of the SSE regimen, advantages and disadvantages should be discussed. In the first 2 weeks, some participants appeared to be disinterested in SSE; however, after several sessions, all participants started enjoying them, and attempted to follow the complex step patterns. Portable, low-cost (approximately 10 EUR), low-tech mats, such as those used in this study, have the additional advantage of being unaffected by weather, space, or availability of time; SSE can be performed at home, in community centers, or in parks. Because no adverse events were observed, we can only speculate on the disadvantages. One example may be that SSE itself, particularly when lifting the heels, is associated with falls, due to the accompanying shift in gravity. Therefore, the speed and complexity of SSE should be increased gradually, depending on each participant's ability. This approach can also help participants to familiarize themselves with this type of training.

This study has a few noteworthy limitations. First, 259 potential subjects (86%) who received the recruitment letter did not participate. The most plausible reason for non-participation is that the days of the week and the time at which the sessions were to be conducted were inconvenient. Because the type of training was not disclosed, their decision not to participate in the study may have been based on their general lack of interest in exercising and not on the training program. Second, SSE can be applied only to mobile adults such as those in the current study population. This is a general limitation. However,

Table 3 - *Self-reported scales by group at baseline and post-regimen.*

Endpoint	Baseline	Post-regimen	Between-Group *p*-value at baseline	Change (%) (Improvement)	Time effect *p*-value	Group-by-time *p*-value
Fear of falling[a]						
SSE	2.12 ± 0.16	2.24 ± 0.16	0.29	18.9 ± 5.0	0.30	0.33
SB	2.36 ± 0.15	2.20 ± 0.15		-6.9 ± 15.7		
Pleasure in exercise[b]						
SSE	75.5 ± 6.6	93.5 ± 5.6	0.83	39.7 ± 48.0	0.85	0.50
SB	77.4 ± 6.0	87.6 ± 5.1		23.0 ± 53.7		
Perceived health status[c]						
SSE	2.04 ± 0.15	2.28 ± 0.16	0.67	6.7 ± 24.8	0.20	0.36
SB	2.13 ± 0.14	2.16 ± 0.15		-1.4 ± 17.7		

Values are as means ± standard deviation. SSE= square-stepping exercise; SB= strength and balance training. Percentages of change were calculated as (post – baseline)·baseline^{-1}. [a]Recorded on a 3-point Likert scale: 1= very afraid, 2= afraid, 3= not afraid. [b]Recorded on a line scale: left edge= not pleasant (0), right edge= very pleasant (100); higher scores indicate more pleasure. [c]Recorded on a 5-point Likert scale: 1= very bad, 5= very good; higher scores indicate good perceived health status.

older adults with good muscle power and confidence in avoiding falls tend to fall because they walk briskly like young people (2). If this is the case, SSE may be particularly useful in helping these people to avoid falls. Third, the follow-up duration and number of participants were not sufficient to justify a strong recommendation for SSE. The short duration of the regimen period is one possible reason for the failure to show significant improvements in the self-reported scales; demonstrating such improvements may require a longer regimen. Further, follow-up for the occurrence of falls in a large SSE cohort is also required. Another limitation is that no information on physical activity or exercise during the 14-month follow-up period was collected.

CONCLUSIONS

The results of this study suggest that SSE is safe and acceptable and, is as equally effective as SB training in improving lower-extremity functional fitness, which is a fall risk factor. This new type of training provides an effective alternative for health-enhancing community exercise.

APPENDIX

Measurements of functional fitness

Chair stands: Participants were asked to stand up erect and then sit down firmly on a chair, as many times as possible within 30 s.

Leg extension power: Participants sat on a leg extension apparatus. The equipment, which included a variable inertial load, was calibrated before each measurement. Power was assessed with the leg extension power rig (T.K.K.1865, Takei Scientific Instruments, Niigata, Japan). Subjects pressed a foot lever, attached to a flywheel, in the horizontal plane.

Single-leg balance with eyes closed: Participants were asked to place their hands on their hips, gradually raise their preferred foot forward, with the knee slightly extended, to approximately 20 cm above the floor; close their eyes; and maintain this position as long as possible (60 s maximum).

Functional reach: Participants were asked to stand and then raise both arms in front of them to shoulder level. Performance was assessed as the maximal distance that participants could reach beyond arm's length while the heels touched the ground. Participants were allowed to bend at the waist during measurements.

Standing up from a lying position: At a signal, participants were asked to stand up as quickly as possible to a stable erect position from a supine position.

Stepping with both feet: Participants were asked to step as quickly as possible within 10 s using the 60 × 55 cm stepping-sheet rig (T.K.K.5301, Takei Scientific Instruments, Niigata, Japan).

Walking around two cones: Two cones were placed 1.8 m on both sides of a chair, at 1.5 m behind it. Participants rose from the chair, walked to the right, going inside and round the back of the right cone, returned to a fully seated position on the chair, stood up again, walked round the left cone, and returned to a fully seated position. One trial consisted of two complete circuits (total distance about 16.8 m).

10-m walk: Participants walked at a maximal pace on a 10-m straight course.

Sit and reach: Participants sat on the floor and pressed their soles against a box. They slowly pushed forward a plastic cursor, which was attached to the box, as far as possible with their middle fingers, without bending their knees. The reference position, 0 cm, was at the level of the toes.

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