A novel exercise for improving lower-extremity functional fitness in the elderly

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ABSTRACT. ***Background and aims:*** *Many falls in the elderly are caused by tripping. After tripping, a certain level of lower-extremity functional fitness is necessary, in order to make protective responses and to avoid falling. The purpose of this study was to test whether our new exercise program (a square-stepping exercise: SSE) would improve lower-extremity functional fitness in the elderly.* ***Methods:*** *Fifty-two individuals aged 60-80 years were divided into two groups (non-randomized control design); SSE (n=26) and controls (n=26). Lower-extremity functional fitness was defined as standing up from a lying position (agility), chair-stand in ten seconds (leg power), walking round two cones (locomotion speed), sit-and-reach (flexibility) and single-leg balance with eyes closed (balance). The SSE group participated in a six-month regimen of SSE once a week. SSE was performed on a thin mat of 250 cm by 100 cm, partitioned into 40 small squares (25 cm each side). SSE included not only forward steps but also backward, lateral and oblique steps, and step patterns were progressively made more complicated. Controls maintained their usual lifestyles.* ***Results:*** *In the SSE group, significant improvements were observed in agility, leg power, locomotion speed, flexibility and balance. No significant changes were detected in any tests in the control group.* ***Conclusions:*** *The SSE program improved lower-extremity functional fitness, lack of which constitutes a risk factor for falls in the elderly. This program should be tested further to determine if it can effectively reduce the incidence of falls in the elderly.*
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INTRODUCTION

In Japan, a national survey found the incidence (per 10,000 per year) of hip fracture in 1997 was 17.3 (men) and 40.8 (women) in persons 60-69 years old, and 57.4 (men) and 147.8 (women) in those 70-79 years old (1). Falls are the most common cause of hip fractures, leading to decreased mobility, restriction to bed, and/or death; in addition, not only hip fractures but also minor injuries such as joint dislocation, lacerations and bruises are also caused by falls (2). As well as fall-associated injuries, falls may lead to an increased fear of falling which can restrict social activities, thereby decreasing independence and overall quality of life.

An interview-based community survey (3) 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. Other causes, much less common, were dizziness (7.8%), black-out (6.4%) or accident (5.2%). For many elderly people, impact velocities at the ground after tripping were within one standard deviation of the estimate of the mean impact velocity needed to fracture a femur (4). Falling sideways, which is often observed after slipping, is also associated with the incidence of hip fractures (4, 5); the impact velocity after slipping also reaches the estimated femur fracture velocity (4). Therefore, the prevention of falls caused by elderly persons tripping or slipping is one of the most important areas for maintaining independence and quality of life in this age group.

Effective interventions for preventing falls should include quick stepping in any direction and the generation of enough force at push off to support the whole body following a trip or slip (6). Quickness (reaction speed/agility) and power in the lower extremity, which have been implicated as factors influencing falls, decrease with age (2, 7-10). In most elderly people, the ability to respond quickly and forcefully may be impaired, leading directly to falling. To the best of our knowledge, there are few studies concerning the development of an intervention program to improve speed and power in the lower extremities of the elderly. This study aimed at developing a novel exercise program for improving lower-extremity

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functional fitness in the elderly, and to assess its effects on fall-related risk factors.

METHODS

Study design

An age- and gender-matched, six-month intervention and non-randomized control trial was conducted in Gifu, the capital city of Gifu Prefecture, located in the centre of Japan.

Participants

Participants in the exercise group were recruited in two ways. One was by direct mailing to pensioners who had an account in the Juroku Bank (Gifu, Japan). Approximately 38,000 letters were sent to people who lived in the area around the building in which the exercise program was conducted. Another procedure was to use leaflets, which were placed in the main office and 60 branch offices of Juroku Bank in Gifu Prefecture. The mailer or leaflet, besides our program, also contained information on several free-of-charge culture classes for the elderly, such as Chinese conversation and "shogi" (Japanese chess) classes. Persons receiving the mailer or leaflet could attend and choose any class from the list, including our program.

Twenty-six people aged 60-80 years agreed to participate in the study (6 men, 20 women). To lower the risks of accident by exercise, five consecutive low-intensity exercise sessions (60 minutes each) over a period of 10 weeks were given to participants before the study. These exercise sessions mainly consisted of stretching the lower extremities while sitting or lying on a mat, and calisthenics for the upper extremities while in a standing position. Participants then engaged in the pre-test and square stepping exercise (SSE) program (see below) for six months without interruption, but were not encouraged to engage in any other new forms of exercise. Once an exercise group was identified, age- (±3 years) and gender-matched controls were selected at random from among cohort members of another surveillance program, in which elderly individuals aged 60 or more living in the city attended as participants of another research program focused on aging and lifestyle. Controls were asked to maintain their lifestyles for six months and to refrain from engaging in the SSE program or any other new form of exercise. Individuals who were living in care facilities, who were regularly exercising twice or more weekly, had a history of illness or a condition that would affect balance (e.g., stroke or Parkinson's disease), or were unable to participate safely in the exercise program, were excluded.

The Juroku Bank and the University of Nagoya cooperated in the Revitalization of Physical and Social Activities of the Elderly Project and approved the study. All participants gave their informed consent before participating.

Outcome measures

Outcome measures were changes in functional fitness related to the risks associated with falling. Fallers are more likely to report difficulty rising from a bed or chair, and to have some form of gait abnormality (11). Lower limb weakness and poor tandem-walking ability have emerged as significant predictive factors among multiple clinical and functional falling risk factors (12). Gehlsen et al. (13) reported that functional fitness in those with a history of falls was lower than in those with no history of falls. In that study, functional fitness items included static balance (one-leg balance test), dynamic balance (backward-walking test), hip, knee and ankle joint strength, and hip and ankle flexibility tests.

From these studies, we assumed that agility, leg power, locomotion speed, flexibility and balance would be elements of functional fitness related to the risk of falls. Further, in the present study, five functional fitness tests were selected to match each element: standing up from a lying position (agility), chair-stand in 10 seconds (leg power), walking round two cones (locomotion speed), sit-and-reach (flexibility), and single-leg balance with eyes closed (balance). Details of the measurements of these fitness items have been reported elsewhere (14, 15). In standing up from a lying position on a signal, participants were asked to stand up as quickly as they could, to a stable erect position from a lying position. The process of moving to the standing position depended on each participant's customary method. Performance time was assessed in terms of time needed to reach a stable erect position. In the item of chair-stand in ten seconds, participants were asked to repeat the exercise of fully standing up and then fully sitting on a chair as many times as possible within ten seconds. During the measurement, participants crossed their arms at the wrists and held them to their chests. Walking round two cones was measured as follows: two cones were placed 1.8 m on both sides of and 1.5 m behind the chair. Participants rose from the chair, walked to the right going inside and round the back of the cone, returned to a fully seated position on the chair, stood up and 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). Performance time was recorded in units of 0.1 seconds. In the test of sit-and-reach, participants were asked to sit on the floor and push the plastic cursor forward slowly as far as possible with their middle fingers and without bending their knees. Performance was recorded as the maximum distance between toes and middle fingers; the farther forward the fingers, the greater the performance distance. The reference position, 0 cm, was at the level of the toes. Participants performed twice and the better (further) score indicated by the cursor was noted.

Descriptive variables, such as age, height, weight and attendance rate in the exercise program, were recorded.

Fig. 1 - *Square stepping exercise.*

Exercise intervention

Based on the mechanism and direction of falls, and on ladder training drills designed for athletes, we developed our SSE program and used it for the intervention described here. SSE was performed on a thin mat of 250 cm by 100 cm, partitioned into 40 small squares (25 cm each side). A smaller mat, 200 x 80 cm, also partitioned with smaller squares (20 cm each side), was prepared for shorter participants (i.e., those less than 150 cm in height). Participants were required to step in the length direction (250 or 200 cm), basically without treading on the lines making up the squares. The SSE program included forward, backward, lateral and oblique steps, and step patterns were progressively made more complicated (Fig. 1).

One hundred and nineteen step patterns were developed and categorized into Junior (8 patterns), Basic (19), Semi-Regular (17), Regular (26), Senior (35) and Master (14) patterns, according to difficulty. Examples of Junior, Basic, Regular and Master patterns are shown in Fig. 2. Junior patterns consisted of easy steps, i.e., forward steps only. For Basic patterns, lateral steps were added to the Junior patterns. Further, oblique and backward steps were added in the Semi-Regular patterns; somewhat complicated oblique and backward steps were added in the Regular patterns; complicated lateral, oblique and backward steps were added in the Senior patterns; and much more complicated steps were added in the Master patterns.

There were some options, so that step patterns in each category were more complicated. Many patterns required a wide stance over one or two squares. Some patterns had bilateral symmetry, which led participants to grasp the pattern image easily. Each pattern consisted of two to 16 steps; participants were asked to repeat the step pattern until they got to the end of the mat. Once a pattern was performed, a mirror-imaged pattern was then also performed.

The exercise group participated in a six-month regimen of SSE once a week. Each SSE class consisted of 10-min warm-up activities, such as walking and mild stretching, 30-min SSE, 10-min whole-body light resistance training, and 10-min cool-down. To familiarize participants with SSE, only Junior patterns were used for the first month. From the second month, Junior patterns were performed as the warm-up. Participants were encouraged to try some new patterns in the Basic or more complicated categories. Essentially, a one-step pattern was repeated 3-5 times and then the mirror-image pattern was repeated the same number of times. If participants could not step a pattern smoothly, they repeated it until it was accomplished, and then they progressed to a new step pattern. The Basic and more complicated category patterns which included lateral, oblique and backward steps were carefully introduced, because many participants needed a long time to learn each new pattern. During the SSE program, step patterns drawn on leaflets or boards were not provided. Participants were asked to learn the pattern by watching an instructor's movements.

Participants were also asked to go forward on the mat one-way, to pass back by the mat walking normally, and then to stand in a line for the next stepping exercise: this meant that the number of steps did not differ among participants. Raising the heels was a recommended option: this made it more difficult for participants to step the patterns and ensured improvements in agility, locomotion speed and balance. Although step cadence was not determined, participants stepped slowly at first and then were able to step faster after some practice. For example, in the Basic pattern shown in Fig. 2, participants stepped at approximately 1 step/sec. They needed some time to remember where they should place their feet during the steps, and so took 20 to 30 seconds in one direction. After some practice, they could step out the patterns at approximately 2 steps/s: and took 20 or fewer seconds to complete.

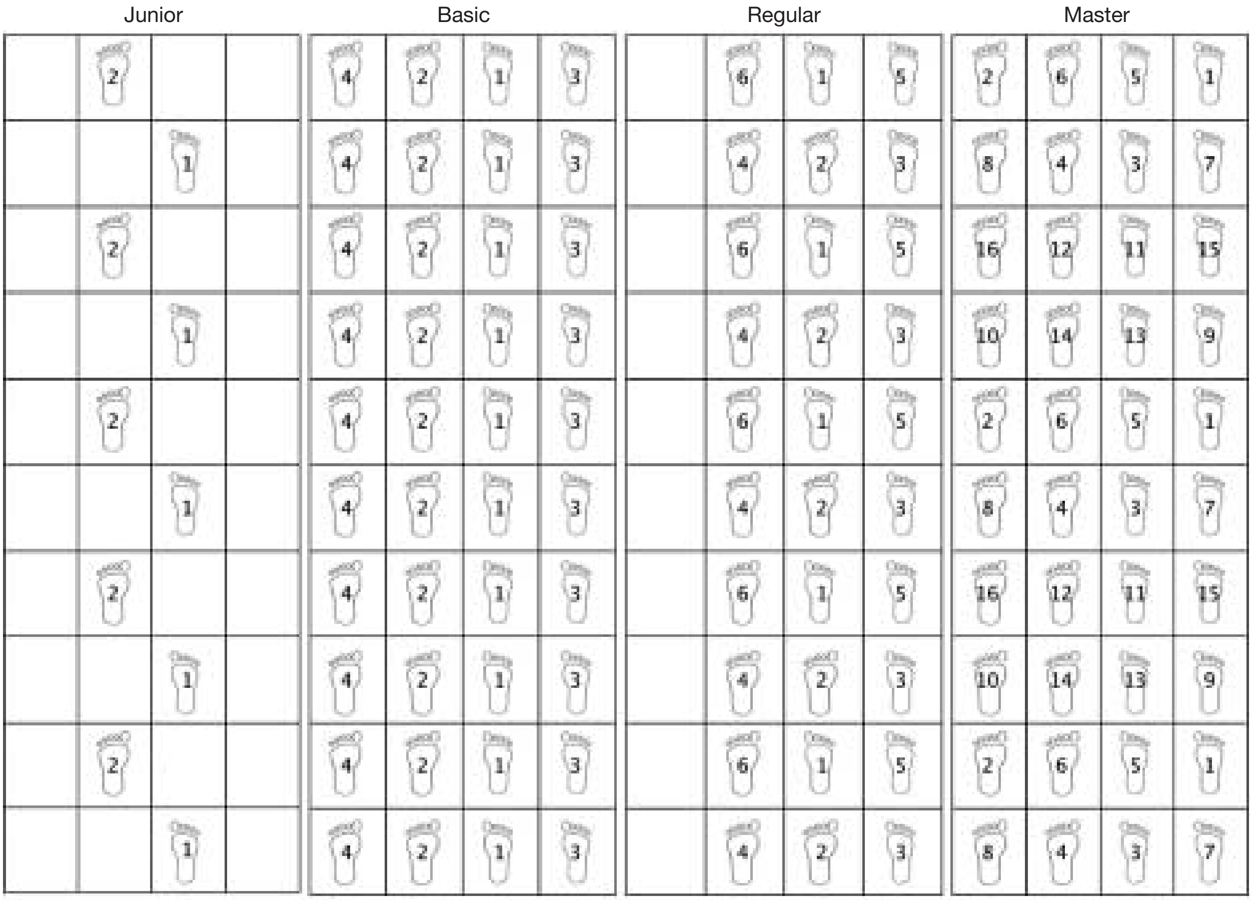

Fig. 2 - *Examples of Junior, Basic, Regular and Master patterns of square stepping exercise. Steps were performed according to numbers, from lower end of each figure to upper end. Odd and even numbers indicate location of right and left feet, respectively.*

In each SSE class, participants gathered in a room in a Juroku Bank branch building; no transportation was provided. The floor of the venue in which classes was held was fitted with a thin carpet. Two instructors concurrently taught all SSE participants.

Statistical analysis

Data are presented as means ±SD. The overall design employed a 2 (group) by 2 (time) repeated-measures format. Repeated-measures techniques were conducted to determine time-by-group interactions. Before this, the Kolmogorov-Smirnov test was applied to determine if data on each test significantly differed from normal distribution. The Levene test was then used to verify the assumption that variances were equal across groups. When significances in these tests were found, the Wilcoxon signed-rank test for paired data was used. Two kinds of correlation coefficients in the SSE group were also calculated: the first between baseline data and the pre-post change for each test; the second between the change in one test and the change in another test. These coefficients were calculated by: (i) Pearson's correlation analysis, when data were similar to normal distribution, and (ii) Spearman's correlation analysis when data were significantly different from normal distribution. All statistics were computed using SPSS version 11.5.1 J. The level of significance was set at α= 0.05.

RESULTS

The baseline characteristics of the two groups were very similar (Table 1). Data of the SSE group in agility, leg power, locomotion speed, flexibility and balance measures were comparable with those of the control group at the beginning of the study (Table 2). Average attendance in the SSE program was 92% (±7.9, range= 75-100%). In the exercise group, no participants discontinued involvement or claimed knee or back pains that had not already existed at the start of the study. No falls or injuries

Table 1 - *Baseline characteristics of participants.*

Measure	Control (n=26)	Exercise (n=26)
Age (yrs)	68.3±6.3	67.5±4.9
Height (cm)	151.4±6.3	148.5±4.3
Weight (kg)	52.5±9.3	53.2±7.0

resulted directly from the exercises. Of all the participants in the exercise group (n=26), one achieved only the Basic pattern, ranked as the second easiest category, by the time the six-month intervention was over. He could step Basic patterns easily and safely, but had difficulty in stepping the more complicated ones. Two other participants achieved Semi-regular patterns. Of the remaining participants, 14, 4 and 5 could step Regular, Senior and Master patterns, respectively, at the end of the six-month regimen. Compliance among controls was 100%, i.e., no controls engaged in any new form of exercise, they all maintained their lifestyles, and attended pre- and post-measurement sessions.

A repeated-measure ANOVA revealed a significant group-by-time interaction for standing up from a lying position ($p<0.01$). Univariate follow-up analysis revealed that the significant agility increases were attributable to the SSE program (Table 2). The exercise group experienced a decrease of 0.39 seconds in this measurement. Walking round two cones and sit-and-reach had significant group-by-time interactions ($p<0.05$). Participants in the exercise group had a significant decrease in walking time (–1.4 s) and a significant increase in sit-and-reach (+5.8 cm). Kolmogorov-Smirnov tests revealed that data for chair-stand in 10 seconds and single-leg balance with eyes closed could not be assumed to be normally distributed. Therefore, Wilcoxon signed-rank tests were applied to these data, in which scores for chair stand (+1.8 n/10 s) and single-leg balance (+4.6 s) increased significantly in the exercise group. The control group exhibited no significant improvement in any of the five measures.

Correlation coefficients between baseline data and changes in each test are shown in Table 3a. They range from –0.45 to 0.27, accounting for 1.4-20.3% of variance; none achieved significance level ($p<0.05$) except for sit-and-reach. Correlation coefficients between the change in one test and the change in another test were not statistically significant. All coefficients were 0.37 or less in absolute value (Table 3b), which accounted for approximately 13.7% or less of each variance.

DISCUSSION

These results demonstrate improvements in agility, leg power, locomotion speed, flexibility and balance resulting from the six-month regimen of our square-stepping

Table 2 - *Functional fitness at pre- and post-treatment and comparison of changes in variables.*

Functional fitness related to risk of falls	Measurement item	Control group Pre	Control group Post	Exercise group Pre	Exercise group Post
Agility	Standing up from a lying position (s)	3.26±0.93	3.70±1.42	3.39±1.20	3.00±0.90[*a]
Leg power	Chair-stand in 10 seconds (n)	8.8±2.6	7.6±4.3	7.5±2.2	9.3±2.6[*b]
Locomotion speed	Walking round two cones (s)	22.6±3.4	22.9±4.8	21.2±3.5	19.8±3.6[*a]
Flexibility	Sit-and-reach (cm)	3.2±8.8	4.2±11.0	3.7±13.9	9.5±11.0[*a]
Balance	Single-leg balance with eyes closed (s)	11.0±15.5	6.7±9.1	9.3±11.7	13.9±15.6[*b]

Significances by Kolmogorov-Smirnov test were found in leg power and balance; Group-by-time interactions were found in agility, locomotion speed and flexibility by ANOVA; [*a]Significant main effect of time; [*b]Significant difference by Wilcoxon signed-rank test.

Table 3 - *Correlation coefficients: (a) between baseline data and change in each test and (b) between change in one test and change in other test.*

	(a)	(b) 1	(b) 2	(b) 3	(b) 4	(b) 5
1. Standing up from a lying position	0.27	1	0.27	0.21	0.37	0.16
2. Chair-stand in 10 seconds	–0.12		1	0.17	0.30	–0.14
3. Walking round two cones	0.24			1	0.17	0.15
4. Sit-and-reach	–0.45*				1	0.06
5. Single-leg balance with eyes closed	0.12					1

Spearman's correlation coefficients were calculated when sit-and-reach or single-leg balance with eyes closed were included as independent variables; Other coefficients calculated by Pearson's analysis; *$p<0.05$.

exercise (SSE) program. In addition, the attendance rate was relatively high and there were no accidents during the SSE program. Therefore, we believe that it is an effective, practical means of decreasing the risk factors for falling in apparently healthy elderly people.

Standing up from a lying position, which we defined as agility, was significantly improved. This task requires a combination of quick response and whole-body movement. Whole-body movement during the test needs control over the center of gravity of the body, or dynamic balance. There are no published reports of changes in time or dynamic balance in standing up from a lying position as a result of an exercise intervention in the elderly, but it has been hypothesized that reaction time (2, 7) and dynamic balance (6, 16, 17) are major determinants of this test item. In previous studies, increases in reaction time are associated with high risk factors for falls (2, 7). The twelve-month prospective study of Nevitt et al. (2) found that those who had an increase in 0.75 or more seconds in hand-reaction time showed 1.8 times the relative risk of falls than those who had an increase of 0.74 seconds or less. In addition, anterior body mass carriage following a trip needs dynamic balance to control the whole body to avoid falling (6, 16, 17). Therefore, improving agility (standing up from a lying position) probably provided some reduction in risk factors for falls.

The increase in the test of chair-stand in 10 seconds probably reflected the improvement in participants' leg power (14) even though it was not assessed directly. A number of studies have identified a lack of muscular strength or power as risk factors for falling (18, 19), especially trip-induced falls (20). For example, being unable, or taking more than 2 seconds, to rise from a chair without using one's arms was associated with an increased risk of injury (2); fallers show a significant decrease in the strength of knees and ankles compared with non-fallers (21). Hip flexion joint torque from a sitting to standing position, which is related with leg power, may also be an important factor for quick chair-stand movement (22).

A low walking speed is also considered as a risk factor for falling (23-25). In the prospective study of Taylor et al. (25), a decrease of 0.22 m/sec in maximal walking speed over ten years was associated with an increase in hip fracture risk (RR 1.25, 95% CI 1.17-1.33). In the present study, the speed of walking round two cones changed from 0.79 m/sec before the program to 0.85 m/sec at the end of the program. Although a decrease in falls in itself cannot be attributed to a change of only 0.06 m/sec, the improvement in this test probably provided some improvement in risk factors for falls. Also, this improvement may play a distinct role in falls, by improving neuromuscular function, so that the SSE program influences an individual's speed, coordination and protective responses during a fall (23).

Increases in hip joint flexibility, which was measured by the sit-and-reach test in this study, should result in decreasing the risk factors for falls (13). The increase in the present study (about 6 cm) was slightly higher than our expectations, because some recent reports have found that exercise intervention that did not focus on flexibility showed an increase of about 3 cm; in these, exercise frequency or duration were not very different from those of our study (26, 27). This improvement may be due to the leg and hip stretching exercise that was provided in every warm-up period. We also told participants that doing sufficient stretching could prevent falls and injuries from occurring in the SSE program, which made them concentrate on stretching and thus improving sit-and-reach scores. A previous study (13) showed that those who had fallen three or more times in the previous year had significantly lower hip-joint flexibility than those who had had no falls. It is probable that hip-joint flexibility is related to stability and mobility in the elderly. Those with lower hip joint flexibility could not walk smoothly with a certain stance, and had great difficulty in maintaining their stability and placing the foot as a support for their bodies when a trip occurred.

Postural instability has also been cited as a risk factor for falls in the elderly (2, 12, 13, 16, 25, 28). It was hypothesized that single-leg balance with eyes closed, defined as balance, would be improved due to the stepping imposed by the SSE program with raised heels. Raised heels, which for safety reasons was not added until participants were familiar with a step pattern, probably afforded neuromuscular stimulation to the exercisers. Shigematsu et al. (29) demonstrated increases in single-leg balance with eyes closed in women aged 72-87 years who participated in a three-month dance-based aerobic exercise. They performed movements that extended, flexed, abducted, adducted and rotated the leg and foot, such as side-stepping, fast walking, forward-backward stepping and heel rises. Participants in the present study performed steps similar to those of the dance movements of Shigematsu et al.

These findings indicate that individuals in the exercise group were able to move their whole body more quickly and accurately after the exercise program. This may have clinical meaning, given that the leg movement in the front, side or oblique directions after tripping or slipping is appropriately carried out, and the center of gravity of the body is controlled to avoid falls. Since only 1.4-20.3% of the variance of the changes in each test could be explained by the initial levels, it is suggested that all persons, independently of their initial performance on any test, could benefit from our SSE program in at least one fitness element.

The present study was conducted with non-randomized allocation of participants. However, it may be difficult for persons who are transitioning to frailty or who are already frail to attend an SSE program. Therefore, our results may not be generalizable to a wider population, although they do appear to demonstrate that the SSE program is applicable as a primary prevention strategy. Only data concerning some functional fitness elements according to risk factors were used, so that other functional fitness elements, such as maximum step length or rapid stepping ability (30) and the effect of the SSE program on fall occurrence were not determined. However, these results clearly indicate that apparently healthy individuals aged 60-80 with no regular exercise habits can reduce their risk factors for falling by undertaking a square stepping exercise program once a week for six months.

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