

The effectiveness of a combined exercise intervention on physical fitness factors related to falls in community-dwelling older adults

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Abstract: This study aimed to evaluate the effectiveness of an innovative exercise program on muscle strength, balance, and gait kinematics in elderly community-dwellers. The exercise program included strength and balance training and the 8-form Tai Chi Chuan. The measurements were carried out at baseline and 12 weeks, and consisted of four physical performance tests, joint isokinetic strength tests, and three-dimensional gait analysis. Fifty-six community-dwelling older adults aged 60–80 years old were randomly assigned to an intervention or control group. After 12 weeks, the intervention group showed a 17.6% improvement in the timed up and go test, accompanied by a 54.7% increase in the 30-second chair stand test score. Significant increases in the score of star excursion balance tests, and the strength of the extensor and flexor muscles at knee and ankle joints were also observed. In addition, the intervention group walked at a faster speed with a longer step length, shorter support phase, and a greater sagittal plane range of motion at the hip and ankle joints. No statistical improvements were seen in the control group. This study provided an effective, evidence-based falls prevention program that can be implemented in community settings to improve physical fitness and reduce fall risks among community-dwelling older adults. The star excursion balance test could be a sensitive measure of physical performance for fall risk assessment in older people.

Keywords: Tai Chi Chuan, resistance training, balance, fall prevention, fall-related risk factors

Introduction

Older people are more likely to experience falls due to the effect of aging on cognitive and physiological functioning.¹ Since the 1990s, falls by the elderly have been reported as a major health concern in Asian countries.^{2,3} Over 32% of community-dwelling older Chinese people suffer at least one fall over a 1-year period.⁴ In Japan, more than 70% of hip fractures were reported to be caused by simple falls.⁵ Falls and fall-related symptoms have become a great challenge to the sustainability of the public health care system worldwide. It is therefore essential to investigate potential intervention programs to help prevent falls from occurring.⁶

Studies have reported extensively on the effectiveness of multifactorial fall prevention programs involving education, environmental modification, exercises, and psychological intervention.^{7,8} Exercise intervention is one of the most important components in multifactorial fall-prevention programs.⁹ Although both group exercise and Tai Chi training targeting strength, balance, and flexibility can largely reduce the fall rate and fall-related injuries among community-dwelling older people,^{8,10,11} previous studies on group exercise and Tai Chi training have examined the effect on physical performance

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with conflicting results.^{8,12-14} For example, a recent randomized controlled trial has reported that both 12-month Tai Chi and group resistance training did not demonstrate any improvements in muscle strength and balance in older people.¹² A more significant beneficial effect of a combined exercise intervention that contains multiple types of exercises may be expected. It is essential that the program be feasible and enjoyable for older people to achieve health benefits from exercises.¹² However, few randomized controlled trials have been carried out to investigate the effect of combined group exercises and Tai Chi with special consideration for individual differences, cultural diversity, and social customs in older community-dwellers.

Therefore, the purpose of this study was to evaluate the effectiveness of an innovative exercise-based intervention program for older Chinese community-dwellers. The 12-week program combines balance exercises, muscle strength training, Tai Chi, and flexibility/stretching exercises. It was hypothesized that the program could improve physical performance and gait parameters, which indicate the risk of falls.

Material and methods

Subjects

A total of 249 older people between 60 and 80 years old, living in the Kongjiang community (Shanghai) were recruited for eligibility screening by advertisements posted in the local community and hospital. All potential participants received a comprehensive explanation of the proposed study, its benefits, inherent risks, and expected time commitment of those involved. Medical information (health status and medication) was obtained from the database of local community hospitals with participant permission. Subjects were excluded if they were not able to walk without a cane or other assistive device, had known medical conditions and musculoskeletal problems limiting safe participation in an exercise program, and were unable to finish the study because of frailty or illness. The decision to include or exclude participants was made by research staff based on a medical doctor's recommendation. This study was approved by Ethics Advisory Committee of Shanghai University of Sport. All participants gave their written informed consent before the study.

A total of 56 participants met the criteria and completed the baseline measurements. All participants were then randomized to either the intervention group or the control group using envelope-based randomization by a person independent of the investigators. Participants in the intervention group were required to undergo a customized 12-week exercise training program. Participants in the control group were

asked to maintain their usual level of physical activity for 12 weeks. Demographics of the participants are shown in Table 1. The outline of the trial and the randomization process are shown in Figure 1.

Measures

Physical performance

Standardized protocols were followed for one functional measure: the 30-second chair stand test (CS-30), the timed up and go (TUG) test, the functional reach test (FR), and the star excursion balance tests (SEBTs). The CS-30 test is a measure of lower-body strength and endurance and is a sensitive tool to predict the likelihood of falls among Chinese older adults.¹⁵ The TUG test demonstrated good inter-rater reliability for dynamic balance and functional mobility evaluation, with an intra-class correlation of 0.80.¹⁶ The FR test has been shown to have concurrent validity in the assessment of dynamic balance and predictive validity in identifying recurrent fallers in older populations.¹⁷ The SEBTs is also an assessment of dynamic balance with a high test-retest reliability (intra-class correlation coefficient ranging from 0.84 to 0.92) in younger adults.¹⁸

The TUG test measures the time taken to stand from a seated position in a chair with arms; walk 3 meters, turning around a cone; and return to a seated position as quickly as possible. This test demonstrated good inter-rater reliability for dynamic balance and functional mobility evaluation, with an intra-class correlation of 0.80.¹⁶ The TUG test has been recommended as a key test for fall risk screening by many fall prevention guidelines, such as those of the American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons.¹⁹ Shumway-Cook et al²⁰ also reported that TUG is not only a sensitive and specific (sensitivity 87% and specificity 87%) indicator of elderly falls, but also a valid method for screening the level of functional mobility and risk for falls in community-dwelling older adults. They found that older adults who took 14 seconds to perform the TUG had an 83% probability of being a faller.²⁰

The FR test was first used in 1990, and has been demonstrated to be a strong predictor of falls risk.²¹ The concurrent

Table 1 Demographics of subjects in two groups (mean \pm standard deviation)

Characteristic	Intervention group	Control group
Male/female	7/15	7/21
Age (years)	66.3 \pm 4.89	65.4 \pm 3.97
Height (cm)	155.7 \pm 5.62	156.6 \pm 5.42
Weight (kg)	60.2 \pm 5.45	59.8 \pm 6.84

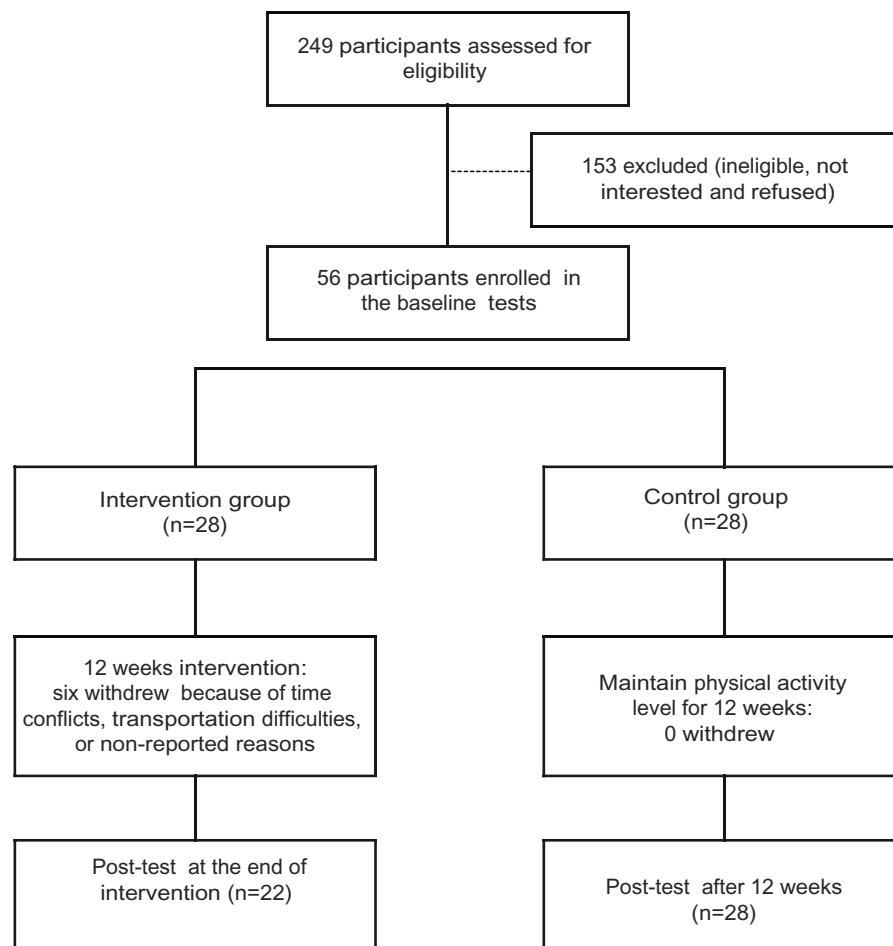


Figure 1 Flow chart of subjects through the study.

validity of the FR test in the assessment of dynamic balance, and the predictive validity in identifying recurrent fallers in older population were also reported.¹⁷ This test measures the participants' balance with a tape measure horizontally on the wall and the participant reaching forward as far as possible from the waist without losing their balance. The Berg Balance Scale (BBS) is the most commonly used balance assessment tool. Although the BBS is reliable and valid,²² a study has shown that the BBS has limited ability to predict elderly falls.²³

In the SEBTs, participants are required to stand at the center of a grid placed on the floor, with eight lines extending at 45° increments from the center of the grid. Participants place a single leg in the center of the grid, with the opposite leg reaching as far as possible along the eight defined directions. Participants are required to touch the furthest point on the floor as lightly as possible so as to avoid using the reach leg for support, and then return to the center of the grid without losing balance. The distance from the center of the grid to the point that the participant had reached is measured.

The CS-30 test is a measure of lower-body strength and endurance. Participants were asked to sit in a standard-height chair with their arms crossed over the chest, then stand fully and sit down again as many times as possible within 30 seconds.²⁴ A recent study showed that the CS-30 is a sensitive tool to predict the likelihood of falls among Chinese older adults.¹⁵ To decrease the effect of learning, all tests began with 3–5 practices.

Isokinetics

Maximal isokinetic torque tests for the flexor extensors of knee and ankle were performed on an isokinetic dynamometer (Con-Trex Multi-joint Module, CMV AG, Switzerland), using an angular velocity of 60°/s. Peak torque was measured in one set of five maximal repetitions. The highest peak torque was used for analysis.

Gait analysis

All participants were required to walk along a 15 m track at self-preferred speed with a set of reflective markers on

the skin, using the Cleveland Clinic marker set (OrthoTrak 4.2 Reference Manual; Motion Analysis Corporation, Santa Rosa, CA, USA). The markers' positions were recorded using an eight-camera VICON motion analysis system (Oxford Metrics, Oxford, UK) at a sampling rate of 100 Hz. Following the data collection, three-dimensional gait analysis was undertaken. A low-pass filter with a cutoff frequency of 6 Hz was applied to the three-dimensional segment trajectories by using a fourth-order zero-lag Butterworth filter. A custom Bodybuilder (Oxford Metrics) program was used to determine spatiotemporal gait parameters and joint range of motions (ROM) at hip, knee, and ankle.

Combined exercise intervention

The intervention group received 60-minute exercise classes three times per week for 12 weeks in the community center. The intensity of the exercise was increased gradually over time to help participants achieve success. Each class started with a 5-minute warm-up, followed by 15 minutes of balance exercises, 15 minutes of muscle-strength training, 15 minutes of 8-form Yang style Tai Chi Chuan, and ending with 10 minutes of flexibility/stretching and cool-down. The warm-up consisted of light walking, joint rotation (neck, shoulder, hip, knee, and ankle), arm and leg stretching, and other related exercises. The balance exercise included single limb stance, staggered stance, heel-to-toe walking, knee marching, and star-excursion. A chair was used to provide a safe support when needed. The strength training targeted the lower extremities and posture muscles, involving standing on toes, bodyweight squat, side leg, shank lift, standing up from a chair, hip flexion (raising one leg while lying on the back), abdominal exercises (raising legs and bending hip while lying on the back), and back exercises (raising the upper body while lying on the stomach). All the movements used the participant's bodyweight as mechanical stress and required no special equipment to perform. A rubber mat was provided while lying on the floor. Tai Chi Chuan is a series of gentle dance-like forms performed in a smoothly flowing sequence. It has been used worldwide as a health-enhancing exercise for all age groups.²⁵ The 8-form Tai Chi Chuan was developed from the traditional Yang style by Tai Chi masters. The movements involve weight-shifting, body alignment, and coordinated movements performed in a slow, continuous, circular, and flowing manner, without compromising the fundamental principles of traditional Tai Chi.²⁶ The eight techniques are: 1) commencing form and repulse monkey, 2) curving back arms (brush knee twist step), 3) stepping sideways and moving

arms (part wild horse's mane), 4) wave hands like clouds, 5) standing on one leg, 6) diagonal strides (heel kick), 7) grasp swallow's tail, and 8) cross hands and closing form. The controlled, progressive Tai Chi movements challenged each participant's limitations in postural control and gait. All of the exercises were performed under the supervision of qualified exercise instructors and monitored by a medical doctor from the local community health service center.

The exercise intervention itself was designed to reduce fall risk by improving balance and muscle strength. The exercises include a set of strength movements focusing on the lower extremities and balance training. The effectiveness of these movements has been previously reported by other studies.^{27–29} In addition, an 8-form simplified Tai Chi Chuan was integrated into the 12-week program. The effectiveness of 8-form Tai Chi had been established previously and suggested to be used as an exercise regimen for interventions designed to promote strength, balance, flexibility, and improved overall physical functioning among older adults.²⁵ Taylor et al¹ also suggested that Tai Chi may prove particularly useful for increasing strength as well as balance and coordination in combination with strength training exercises. More importantly, Tai Chi is a traditional Eastern form of exercise that has been practiced in eastern Asia for hundreds of years, with somewhat similar improvements in physical functioning reported when compared with exercises developed in Western countries.³⁰ The reduced complexity of 8-form Tai Chi is easy to perform and is enjoyable. Thus, the design of this intervention is expected to be more suitable for Chinese community-dwelling older adults.

Data analysis

All variables are presented as means and standard deviations. A two-way analysis of variance (ANOVA) with repeated measures was conducted to determine the effect of intervention on measures of physical fitness, gait, and isokinetic tests. Group (intervention versus control) was used as the between-subjects factor, and time of measurement (baseline versus 12 weeks) as a within-subjects factor. *F*-statistic, eta-squared (η^2), and *P*-values are reported. The alpha level was adjusted to <0.025 to control for Type I errors using the Bonferroni method. If an interaction was significant, a one-way ANOVA was performed for the time factor. A conservative cutoff of *P*-value of <0.01 was used to determine statistical significance for the one-way ANOVAs. All data were analyzed using the Statistical Package for the Social Sciences (SPSS, version 15.0; IBM Corporation, Armonk, NY, USA).

Results

Physical performance

There were no statistically significant differences between groups in terms of participant characteristics at baseline. Significant interaction effect was found in the CS-30 test and the TUG test (Table 2). The results showed an improvement of 15.3% in the CS-30 score, $F(1, 21)=21.617$, $P<0.001$, $\eta^2=0.507$, and 17.6% in the TUG test, $F(1, 21)=79.286$, $P<0.001$, $\eta^2=0.791$. There was no significant interaction for the FR test. The SEBT results are shown in Figure 2 (see Table S1 for the statistical results). There were significant interactions for all directions except the medial direction of the right limb stance. However, the main effect of time was significant, $F(1, 21)=8.816$, $P=0.004$, $\eta^2=0.143$. One-way repeated-measures ANOVAs showed significant improvements in reaching distance among the eight directions of the SEBTs for both legs. The improvement ranged from 13.4% (medial) to 40.7% (posterior) for the right limb stance, and from 12.9% (medial) to 40.0% (posterior) for the left limb stance. The changing tendencies of left and right legs were similar. In the control group, there was a decreasing trend in physical performance after 12 weeks. Only two variables of the SEBTs reached significance. There was significant reduction after 12 weeks for the left limb stance in the distance reached in the lateral direction, $F(1, 27)=13.539$, $P<0.001$, $\eta^2=0.297$, and medial direction, $F(1, 27)=25.004$, $P<0.001$, $\eta^2=0.439$.

Isokinetics

A significant interaction effect was found for all isokinetic variables (Table 3). However, the effect of time was not significant for knee flexor strength and ankle extensor strength. For the intervention group, knee flexor and extensor strength significantly increased by 19.4% and 20.2% respectively. Ankle extensor strength improved 43.1%, which was a far greater improvement than for the ankle flexor's 13.6%. No significant changes were seen in the control group for these measures.

Gait analysis

Gait speed, cadence, and step length increased significantly at the post-test session in the intervention group. The percentage of the double support phase reduced from 24.1% to 21.1% of the gait cycle, $F(1, 21)=19.164$, $P<0.001$, $\eta^2=0.477$. The dynamic ROM of the ankle and hip joint increased significantly by 8.2% and 6.5%, respectively. The knee also showed a tendency for larger ROM, although neither interaction effects nor the effect of time were significant (Table 3).

Discussion

The aim of this study was to determine the effects of an exercise intervention program on the measures associated with the risk of falls (balance, muscle strength, and gait performance) in older people. The results showed that a 12-week combination exercise program improved fall-related physical performance and gait parameters, indicating a reduced risk of falls.

The effect of exercise intervention on physical performance

Four clinical tests were used to determine the effect of exercise intervention on balance and muscle strength. Our results substantiated the effectiveness of the 12-week exercise intervention for improving functional mobility and physical performance in older adults. The findings are in broad agreement with similar prior intervention trials on the evaluation of physical function.^{28,31}

There is strong evidence that the CS-30 test has good test-retest reliability and provides a safe and effective method to test lower-body strength in older populations.²⁴ A 54.7% increase in CS-30 scores is consistent with a previous study that found a 66% increase after 10 weeks of lower-body resistance training.³¹ Significant but smaller improvements were also found by two other research groups, which found 13.5% and 20% improvements respectively in the CS-30 test after 12 weeks of exercise interventions.^{28,32} The results provide

Table 2 Changes in physical performance parameters (mean \pm standard deviation)

Variable	Baseline		Change after 12 weeks		Group \times time		
	Intervention	Control	Intervention	Control	$F(1, 48)$	P	η^2
FR (cm)	30.80 \pm 5.05	35.42 \pm 4.35	1.48 \pm 1.50	-0.58 \pm 2.42	0.089	0.767	0.002
CS-30 (times/30 seconds)	17.52 \pm 4.71	15.91 \pm 3.80	9.64 \pm 5.08 ^a	-0.05 \pm 3.54	100.061	<0.001	0.654
TUG (seconds)	8.40 \pm 2.04	7.73 \pm 0.91	-1.48 \pm 1.50 ^a	0.29 \pm 0.90	30.219	<0.001	0.363

Notes: For the one-way repeated-measures ANOVA, alpha was set at 0.01. In the two-way repeated-measures ANOVA for the group \times time interaction, alpha was set at 0.025. ^a $P<0.001$.

Abbreviations: ANOVA, analysis of variance; CS-30, the 30-second chair stand test; FR, functional reach test; TUG, time up and go test.

SEBT results (cm)

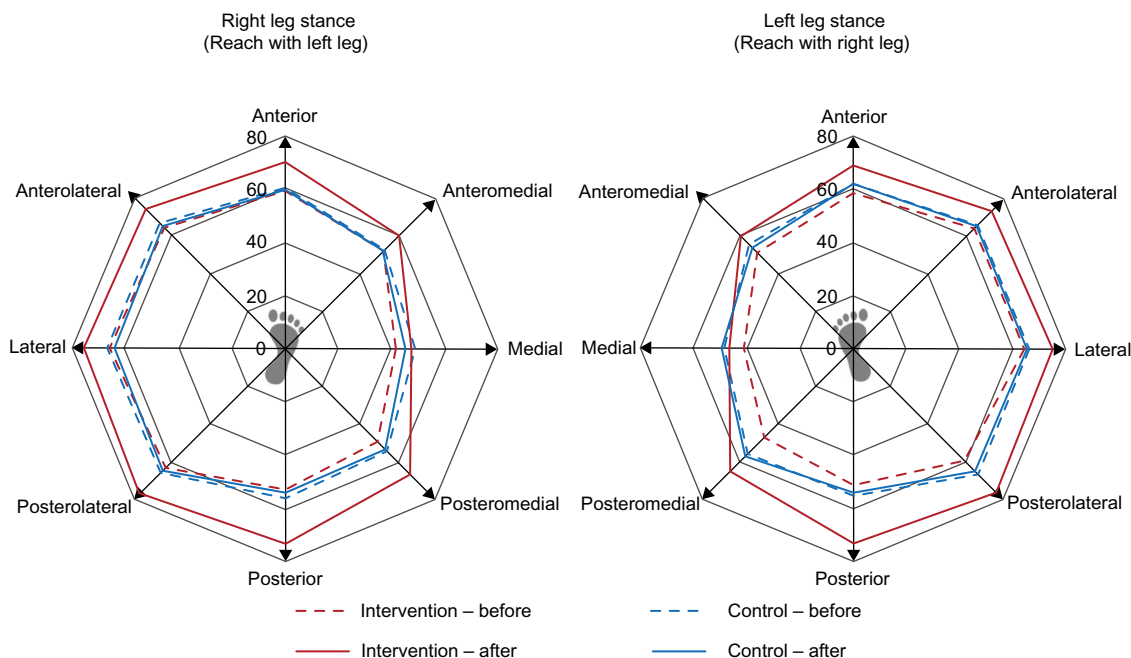


Figure 2 The star excursion balance test (SEBT) results for left and right leg stance.

strong evidence of an improvement in muscle strength, particularly the strength of muscle groups involved in hip extension, knee extension, and ankle plantar flexion.

Results of the TUG test suggested that there was significant improvement in the mobility and balance required for the performance of basic activities of daily living. Although the FR test is a reliable and valid measure for assessing balance

in geriatrics, this study found no significant change. It is noteworthy that this study applied the SEBTs to the assessment of postural control function in the older adults. The test challenges the subject to maintain the base of support during the dynamic task of reaching in eight directions with the opposite leg. The increases in SEBT scores indicated that the dynamic balance of the exercise group significantly

Table 3 Gait parameters and joint kinematics before and after 12 weeks (mean ± standard deviation)

Variables	Baseline		12 weeks		Group × time		
	Intervention	Control	Intervention	Control	F(1, 48)	P	η²
Isokinetic strength							
Knee flexor (Nm)	32.20±7.80	31.95±8.40	40.94±7.12 ^a	30.83±8.40	54.375	<0.001	0.506
Knee extensor (Nm)	57.03±14.85	53.55±14.95	68.91±18.18 ^a	52.42±15.17	32.971	<0.001	0.384
Ankle dorsiflexor (Nm)	34.08±7.07	33.78±9.01	40.81±5.96 ^a	33.41±9.81	19.300	<0.001	0.267
Ankle plantar flexor (Nm)	56.87±10.43	58.93±11.81	68.15±12.62 ^a	56.39±15.20	23.234	<0.001	0.305
Spatiotemporal parameters							
Speed (m/s)	1.10±0.18	1.07±0.18	1.29±0.22 ^a	1.08±0.22	21.854	<0.001	0.292
Cadence (step/minutes)	121.2±10.2	120.3±8.9	129.1±11.4 ^a	117.2±10.3 ^b	29.400	<0.001	0.357
Step length (m)	0.54±0.07	0.59±0.04	0.60±0.06 ^b	0.57±0.12	8.613	0.005	0.140
Double support (%)	24.10±5.10	24.78±4.17	21.08±3.99 ^a	24.08±4.79	7.685	0.008	0.127
Sagittal joint ROM							
Hip (°)	32.82±5.17	33.45±5.32	35.46±5.02 ^b	31.51±7.81	12.046	0.001	0.185
Knee (°)	57.09±5.33	55.87±5.33	57.98±5.15	55.98±4.78	0.803	0.374	0.015
Ankle (°)	27.81±5.04	29.45±4.78	29.61±4.79 ^b	28.18±6.58	9.741	0.002	0.155

Notes: For the one-way repeated-measures ANOVA, alpha was set at 0.01. ^aP<0.001; ^bP<0.01. In the two-way repeated-measures ANOVA for the group × time interaction, alpha was set at 0.025.

Abbreviations: ANOVA, analysis of variance; ROM, range of motion.

improved after the intervention. Increasing the excursion distance requires a greater range of motion at the hip, knee, and ankle. The results suggested that neuromotor control and related muscle strength, such as knee extensor and ankle plantar flexor strength might also have improved, which allowed the participants to perform a greater range of motion at the hip, knee, and ankle while maintaining balance. Our finding is supported by the results of Gribble et al,³³ who found that the process of aging leads to a notable decrease in distance of all eight vectors of the SEBTs. However, previous studies have only investigated SEBTs in younger populations.¹⁸ Our study suggests that SEBTs also can be used in older individuals, and the results of the control group allowed us to assess its reliability. A comparison study between older fallers and non-fallers may help detect a correlation between SEBT performance and falls in the future.

The effect of exercise intervention on isokinetics and gait parameters

The strength of the flexor and extensor muscles of lower extremities is highly correlated with the capacity to execute mobility tasks.³⁴ Previous studies have shown that stronger knee extensor and flexor strength were associated with better balance,³⁵ and older people with a history of falling exhibited less plantar flexion during the push-off phase of the gait cycle. Weak ankle plantar flexors can cause a longer double support phase during walking, and a reduced double support phase was reported as a strong indication of improvement in movement stability.³⁶ Thus, our results indicate that increasing muscle strength in lower limbs can improve older individuals' ability to successfully perform daily tasks. In addition, the combined intervention integrated classical training movements with Tai Chi. This was expected to have more significant impacts on multi-joint muscle strength than the interventions using Tai Chi exercise only.^{37,38} However, a direct comparison between the combined intervention and Tai Chi exercise is ideally needed to make this conclusion.

Falls during walking are the primary cause of accidental injury in older individuals.³⁹ Gait analysis provided valuable information about the effectiveness of a fall prevention exercise program. Our findings showed that the strength gains and balance improvements were associated with positive changes in spatiotemporal measures and joint kinematics. This is consistent with the findings of other researchers.^{27,28,40} Lord et al²⁷ reported that 22 weeks of exercises could increase gait velocity and related parameters in older persons. Increased cadence and stride length were associated with improved ankle dorsiflexion strength and hip extension strength.

Rubenstein et al⁴⁰ showed that 12 weeks of strength and balance training increased isokinetic strength 21% for knee flexor and 26% for knee extensor, with increasing walking speed and reducing fall rates. The significant increase in hip and ankle ROM is also consistent with a previous study.²⁸ The increases in cadence and stride length can be explained by the increased strength in the knee and hip extensors, such as quadriceps femoris, gluteus maximus, and hamstrings.⁴¹ The significant reduction of the double support phase confirmed the finding seen in the isokinetics data, caused by increased ankle plantar flexor strength. These findings suggested that participants who could generate more muscle force to get a quicker push-off speed during the final instants of the stance phase, were also able to move their center of gravity further away from their base of support.

Limitation

The main limitation of this study is the lack of a follow-up. This prevents us from studying the effect of this intervention on actual rates of falling. In addition, subjects with certain medical conditions, who may have a higher risk of fall, were excluded from the study. We recognize that actual clinical relevance must be demonstrated definitively via future randomized controlled trials in high-risk older populations. In addition, cognitive function was not measured in this study. The positive gait outcomes in our study may suggest that the exercise intervention would benefit the cognitive function in older people. Previous studies have found the positive change in gait ability associated with the improvement in cognitive function,⁴² and concluded that regular physical activity is associated with significantly better cognitive function and less cognitive decline in older women.⁴³ Thus, direct determination of cognitive function deserves further investigation particularly under dual-task conditions. There were also too few males enrolled to compare the sex differences at baseline and after 12 weeks.

Future work

In light of the health benefits and reduced rates of falling associated with improvement of physical fitness in older adults, the significant change in physical performance, isokinetic strength, and gait performance in our study over only 12 weeks using this combined training program may lead to clinically important long-term benefits. A follow-up study is needed to provide insight into the long-term effects, and reinforce our current findings. It may also provide valuable information about the effect of intervention on actual fall rates. It is also important to compare the effect of this

combined intervention with other exercise interventions, such as Tai Chi training only or muscle strength training only. These comparisons will allow us to make a comprehensive conclusion of the effectiveness of the combined intervention. Future studies with large sample size and including the participants with a higher risk of falls are also needed to investigate the effect in different population groups (eg, sex differences and age differences) after intervention.

Conclusion

In summary, this study provided an effective, evidence-based falls prevention program that can be implemented in community settings to improve physical fitness and reduce fall risks among community-dwelling older adults. In addition, we found that SEBTs could be a sensitive measure of physical performance for older people. It is worth further exploring optimized SEBTs for fall risk assessment. It may be also hypothesized that the improvement can result in a reduction in fall rates in the future, while a follow-up study is needed to test this hypothesis.

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Disclosure

The authors report no conflicts of interest in this work, or connection to any products used in the study, or referred to in this paper.

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Supplementary material

Table S1 Changes in SEBT (mean \pm standard deviation)

Variable	Baseline		Change after 12 weeks		Group \times time		
	Intervention	Control	Intervention	Control	F(1, 48)	P	η^2
SEBTs – right limb stance							
Anterior (cm)	58.62 \pm 6.77	62.39 \pm 5.12	10.95 \pm 6.42**	-0.39 \pm 2.83	80.320	<0.001	0.602
Anterolateral (cm)	64.40 \pm 6.42	66.78 \pm 4.92	9.36 \pm 7.05**	-0.82 \pm 3.15	53.303	<0.001	0.501
Lateral (cm)	64.48 \pm 6.81	66.80 \pm 6.31	10.88 \pm 7.12**	-1.24 \pm 5.58	49.763	<0.001	0.484
Posterolateral (cm)	60.07 \pm 5.84	67.14 \pm 8.25	16.56 \pm 7.90**	-1.77 \pm 5.17	108.465	<0.001	0.672
Posterior (cm)	51.98 \pm 9.15	56.30 \pm 10.00	21.18 \pm 10.78**	-1.32 \pm 7.49	83.607	<0.001	0.612
Posteromedial (cm)	47.78 \pm 9.25	56.40 \pm 10.09	18.07 \pm 10.04**	0.94 \pm 7.36	53.307	<0.001	0.501
Medial (cm)	41.47 \pm 6.46	48.60 \pm 9.91	5.55 \pm 6.97*	0.95 \pm 8.54*	4.405	0.041	0.077
Anteromedial (cm)	51.47 \pm 5.83	55.50 \pm 5.18	8.52 \pm 7.02**	-1.21 \pm 4.25	41.139	<0.001	0.437
SEBTs – left limb stance							
Anterior (cm)	59.70 \pm 5.73	60.80 \pm 5.27	10.82 \pm 7.38**	-0.65 \pm 3.92	70.149	<0.001	0.570
Anterolateral (cm)	64.61 \pm 5.51	66.57 \pm 5.65	9.51 \pm 5.96**	-1.34 \pm 5.02	63.316	<0.001	0.544
Lateral (cm)	65.99 \pm 5.51	66.88 \pm 6.61	10.31 \pm 6.02**	-2.82 \pm 6.47*	64.705	<0.001	0.550
Posterolateral (cm)	63.53 \pm 7.46	66.20 \pm 9.84	13.61 \pm 8.29**	-0.94 \pm 6.26	69.209	<0.001	0.566
Posterior (cm)	52.66 \pm 7.53	56.36 \pm 9.26	20.52 \pm 11.36**	-2.00 \pm 5.36	84.664	<0.001	0.615
Posteromedial (cm)	49.53 \pm 8.61	54.75 \pm 8.19	17.68 \pm 10.84**	-1.05 \pm 2.95	78.903	<0.001	0.598
Medial (cm)	41.95 \pm 6.65	49.07 \pm 8.37	5.43 \pm 5.94**	-3.56 \pm 4.09**	32.997	<0.001	0.384
Anteromedial (cm)	51.92 \pm 6.22	52.91 \pm 5.75	8.29 \pm 6.44**	-0.97 \pm 2.77	59.994	<0.001	0.531

Notes: For the one-way repeated-measures ANOVA, alpha was set at 0.01. * $P < 0.01$; ** $P < 0.001$. In the two-way repeated-measures ANOVA for the group \times time interaction, alpha was set at 0.025.

Abbreviations: ANOVA, analysis of variance; SEBTs, star excursion balance tests.

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