

Research article

Effects of Progressive Walking and Stair-Climbing Training Program on Muscle Size and Strength of the Lower Body in Untrained Older Adults

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Abstract

The purpose of the present study was to investigate the effect of the progressive walking program on lower limb muscle size and strength and evaluated whether the stair-climbing exercise provided additional training effects when combined with the walking program. Fifteen elderly subjects (age 69 ± 1 years, height 1.63 ± 0.02 m, body weight 64.5 ± 2.0 kg) were randomly assigned to a walking group or a walking and stair-climbing group. The progressive walking program comprised continuous (week 1-8) and interval (week 9-17) exercises. The walking and stair-climbing group also performed stair climbing. Muscle thickness, strength, and walking performance were evaluated before and 8 and 17 weeks after the start of the program. The muscle thickness of the anterior and posterior parts of the thigh significantly ($p < 0.05$) increased in both groups. There was also a significant ($p < 0.01$) main effect of time in isometric maximal strength and the values expressed relative to body mass for both knee extension and flexion. However, no group \times time interactions were noted. Furthermore, the percentage change of knee flexion strength after the training period was significantly ($p < 0.01$) correlated with the pre-intervention value. Seventeen weeks of the progressive walking program can increase thigh muscle size and strength for older adults; however, an added stair-climbing exercise may not provide additional training effects. Furthermore, the magnitude of improvement in knee flexion strength would depend on the pre-intervention value.

Key words: Aged, ambulation, muscles, strength, stair climbing.

Introduction

The skeletal muscle plays a crucial role in body metabolism and in the performance of activities of daily living (Helge et al., 2006; Holloszy, 2005). Skeletal muscle size and maximal voluntary force production reduce with age (Clark and Manini, 2008), which elevates the risk of developing a wide range of chronic disorders, including insulin resistance, hyperglycemia (Lee et al., 2011; Sanada et al., 2012), and atherosclerosis (Abe et al., 2012; Ochi et al., 2010), and results in disability, falls, and osteoporosis (Baumgartner et al., 1998; Walsh et al., 2006; Wolfson et al., 1995). One of the most notable problems is a decline of ambulatory ability resulting from a reduction in lower limb muscle mass. Therefore, strategies to increase or maintain

skeletal muscle mass and function, especially in the lower limbs, are important for overall health.

Endurance training such as walking is widely recommended as a major exercise modality for improving or maintaining aerobic capacity and cardiovascular health. Walking can also improve lower limb muscle size and strength in older adults when performed regularly for prolonged periods (i.e., over months rather than weeks) (Ozaki et al., 2015). For example, Kubo et al. investigated the effects of a 6-month progressive walking program. Subjects were instructed to perform 15 min of walking, three times per week, at a self-selected and comfortable pace in the first 2 weeks, to increase gradually the duration to the ninth week (40 min four times per week), and to maintain this level thereafter. As a result, muscle thickness (MT) in the knee flexors and dorsiflexors, and strength in the knee flexors, dorsiflexors, and plantar flexors increased; however, a significant effect was not observed in the knee extensors (Kubo et al., 2008). Other studies compared the training effects between high-intensity interval walking and continuous walking at moderate intensity (Nemoto et al., 2007; Okazaki et al., 2013). Five months of high-intensity interval walking significantly increased knee extension strength as well as knee flexion strength, and the effects were greater than that of the continuous walking program. These mean that muscle adaptation increased with increased walking speed. For high-intensity interval walking, a small but significant muscle hypertrophy of the quadriceps muscle was also observed (Okazaki et al., 2013). Although subjects in these previous studies performed interval walking at the start of the training period, developing a progressive walking program from continuous exercise to interval exercise and investigating the training effects should provide beneficial information regarding the usefulness of the program. Furthermore, because the training periods of the above studies lasted 5-6 months and measurements were obtained only before and after the training period, it is unclear whether walking training can induce muscle hypertrophy and strength gain in less than 5 months.

Although muscle hypertrophy and strength gain of knee extensors induced by walking training seem relatively small as previously mentioned (Kubo et al., 2008; Okazaki et al., 2013), age-related changes in muscle size occur in a site-specific manner; the muscle size of the knee extensors particularly decreases with age (Abe et al., 2014). Stair

climbing is a common daily physical activity and induces greater activation in the knee extensors compared to walking (Takai et al., 2008). Thus, when stair climbing is combined with the above progressive walking program, additional training effects may be observed in the knee extensor muscles.

Therefore, this study aimed to investigate the effect of the progressive walking program on lower limb muscle size and strength and to evaluate the additional training effects of the stair-climbing exercise.

Methods

Participants

Fifteen elderly subjects (age 69 ± 1 years, height 1.63 ± 0.02 m, body weight 64.5 ± 2.0 kg) volunteered to participate in this study. They were recruited through printed advertisements and by word of mouth. None of the subjects had participated in any regular high-load resistance training for at least 1 year. All participants were free of any overt chronic disease, as determined by a medical history assessment, not past or current smokers, and not taking any medications or female hormone supplements. All subjects were informed about the methods, procedures, and risks of this study and provided informed consent before enrolling. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee for Human Experiments of Juntendo University (Approval Number: 27-10), Chiba, Japan. The participants were randomly assigned to either a walking (W) group (5 men and 3 women) or a walking and stair-climbing (WS) group (4 men and 3 women). They were evaluated for MT, strength,

and walking performance before (PRE), and 8 weeks (MID) and 17 weeks (POST) after the start of the training program.

Training program

The W group performed the walking program and the WS group performed the stair-climbing program in addition to the walking program. As shown in Table 1, the progressive walking program consisted of continuous (week 1-8) and interval (week 9-17) exercises. All subjects were instructed to walk at a self-selected, faster pace than usual, for 20-25 min, 3 days per week, during the first and second week, and walk at an intensity of 55-60% of the heart rate reserve (HRR) for 30-45 min, 3-5 days per week, during week 3-8. After 8 weeks of the continuous walking program, they performed the interval walking program consisting of 5-8 sets of 3-min high-intensity (65-80% HRR) walking followed by a 2-min low-intensity walking (self-selected pace), 4-5 days per week. Every 2 weeks, all subjects visited a laboratory and walked on a treadmill to confirm the intensity (pace) of walking.

Subjects in the WS group participated in the stair-climbing program in addition to the walking program. They climbed stairs, 25 steps per session, 3 days per week. Subsequently, the number of steps was increased by 5 steps per week.

Muscle thickness

MT was measured via a B-mode ultrasound using a 5 to 18-MHz scanning head (Noblus; Aloka, Tokyo, Japan) in four locations: the anterior and posterior aspects of the right thigh (AT and PT, respectively) at 50% of the thigh's

Table 1. Training Program. Data are presented as mean \pm standard deviation.

Week	Type	Walking		Stair climbing (steps)	Frequency
		Intensity	Duration		
1	Continuous Exercise	RPE: 13	20 min / day	25 steps / day	3 days / wk
2		RPE: 13	25 min / day	30 steps / day	3 days / wk
3		55-60% HRR	30 min / day	35 steps / day	3 days / wk
4		55-60% HRR	35 min / day	40 steps / day	4 days / wk
5		55-60% HRR	40 min / day	45 steps / day	4 days / wk
6		55-60% HRR	40 min / day	50 steps / day	4 days / wk
7		55-60% HRR	45 min / day	55 steps / day	5 days / wk
8		55-60% HRR	45 min / day	60 steps / day	5 days / wk
9	Interval Exercise	3 min (65-75% HRR) 2 min (Self-selected pace)	5 sets / day	65 steps / day	4-5 days / wk
10		3 min (65-75% HRR) 2 min (Self-selected pace)	6 sets / day	70 steps / day	4-5 days / wk
11		3 min (65-75% HRR) 2 min (Self-selected pace)	7 sets / day	75 steps / day	4-5 days / wk
12		3 min (65-75% HRR) 2 min (Self-selected pace)	8 sets / day	80 steps / day	4-5 days / wk
13		3 min (65-75% HRR) 2 min (Self-selected pace)	8 sets / day	85 steps / day	4-5 days / wk
14		3 min (65-75% HRR) 2 min (Self-selected pace)	8 sets / day	90 steps / day	4-5 days / wk
15		3 min (65-80% HRR) 2 min (Self-selected pace)	8 sets / day	95 steps / day	4-5 days / wk
16		3 min (65-80% HRR) 2 min (Self-selected pace)	8 sets / day	100 steps / day	4-5 days / wk
17		3 min (65-80% HRR) 2 min (Self-selected pace)	8 sets / day	100 steps / day	4-5 days / wk

RPE; ratings of perceived exertion, HRR; heart rate reserve

length between the lateral condyle of the femur and the greater trochanter, and the anterior and posterior aspects of the right lower leg (AL and PL, respectively) at 30% of the lower leg's length between the lateral malleolus of the fibula and the lateral condyle of the tibia. Before all scans, the subjects rested in the sitting position for at least 30 minutes. To avoid the influence of fluid shifts within the muscle, the measurements were performed at about the same time. All measurements were performed by the same operator, with participants in the supine/prone position. The subcutaneous adipose tissue-muscle interface and the muscle-bone interface were identified on ultrasound images, and the distance between the two interfaces was recorded as the MT. The test-retest (inter-session) reliabilities were calculated using the intraclass correlation coefficient (ICC), standard errors of measurement (SEM), and minimal difference. These values (ICC, SEM, and minimal difference, respectively, for each location) were previously determined in 10 older men and women in terms of MT in the four locations (AT: 0.992, 0.37 mm, 1.03 mm; PT: 0.994, 0.37 mm, 1.03 mm; AL: 0.993, 0.21 mm, 0.58 mm; PL: 0.998, 0.22 mm, 0.61 mm).

Maximal isometric strengths

The maximal voluntary isometric strengths of the knee extensors and flexors were determined using a dynamometer (Takei, Tokyo, Japan). During testing, each participant was seated on a chair with the hip joint angle positioned at 90° flexion (0° equals full hip extension). The ankle was firmly strapped to the distal pad of the lever arm. Participants were then instructed to perform maximal isometric knee extension and flexion for about 5 seconds at a fixed knee joint angle of 90°. A knee joint angle of 0° corresponded to full knee extension. Several warm-up contractions (2–3 submaximal contractions and 1–2 near-maximal contractions) were performed before each testing. Two or three maximal efforts for each isometric measurement were performed, and each peak value was used in the data analysis. The test-retest (inter-session) reliabilities using ICC, SEM, and minimal difference were 0.945, 3.41 kg, and 9.45 kg, respectively, for knee extension strength and 0.921, 2.18 kg, and 6.04 kg, respectively, for knee flexion strength.

Walking performance

Walking performance was evaluated by timing each subject as he or she walked across a 10-m corridor on a hard-surfaced floor. The width of the corridor was set at 1 m. Subjects performed two timed trials and were encouraged to maintain a straight course. They were asked to walk down the corridor as fast as possible without running. Their times were measured using a digital stopwatch, and the best time was used in the data analysis. The test-retest (inter-session) reliabilities of the 10-m walking time using the ICC, SEM, and minimal difference were 0.833, 0.29 s, and 0.80 s, respectively.

Statistical analyses

All results are expressed as means and standard deviations. For all variables, a repeated measures ANOVA of time (PRE, MID, and POST) with a between-participant factor of group (W and WS) was used. Statistical significance was

set at $p < 0.05$.

Results

Before training, there were no significant differences between the two groups regarding age, anthropometric variables, MT, strength, and walking performance. All 15 participants completed the training program. The mean values of self-reported walking time per session and training frequency per week throughout the training period in each group were as follows: 37.4 ± 3.3 min/session and 3.76 ± 0.49 days/wk, respectively, in the W group, and 37.5 ± 3.6 min/session and 3.52 ± 0.79 days/wk, respectively, in the WS group. There were no significant differences in these values between both groups. The mean values of the self-reported number of steps per session and training frequency per week throughout the training period were 61.6 ± 12.4 steps/session and 3.07 ± 0.78 days/wk, respectively, in the WS group. For body weight and body mass index, significant changes were not observed after the training period.

For MT of the lower body, significant ($p < 0.05$) increases were observed in all variables except for MT of the anterior lower leg (Figure 1). There was a significant ($p < 0.01$) main effect of time in isometric maximal strength and the values expressed relative to body mass for knee extension and flexion (Figure 2). Similarly, a significant ($p < 0.05$) main effect of time was observed in walking performance. A significant ($p < 0.05$) increase was observed at MID (after 8 weeks) only in knee flexion strength (both absolute and relative values) and walking performance. However, no group \times time interaction was noted. Furthermore, the percentage change of knee flexion strength after the training period was significantly ($p < 0.01$) correlated with the value at PRE (Figure 3).

Discussion

This is the first study demonstrating that the progressive walking program significantly increased maximal isometric knee flexion strength at 8 weeks and thigh muscle size and knee extension strength at 17 weeks after the start of training. There were no significant differences in training effects between the W and WS groups, suggesting that the stair-climbing exercise provided no additional training effects. Furthermore, the percentage change of knee flexion strength after the training period was significantly correlated with the value at PRE.

Regarding the muscle hypertrophy induced by walking training, Kubo et al. demonstrated that MT in knee flexors and dorsiflexors significantly increased after 6 months of the progressive walking program (Kubo et al., 2008). The exercise duration and frequency were gradually increased and mean walking duration was 45 min per day, and frequency was 5.4 days per week throughout the training period, although the exercise intensity was not reported (Kubo et al., 2008). In the present study, muscle hypertrophy was observed in the anterior and posterior aspects of the thigh and in the posterior part of the lower leg after 17 weeks of the progressive walking program. The exercise intensity, duration, and frequency were gradually increased

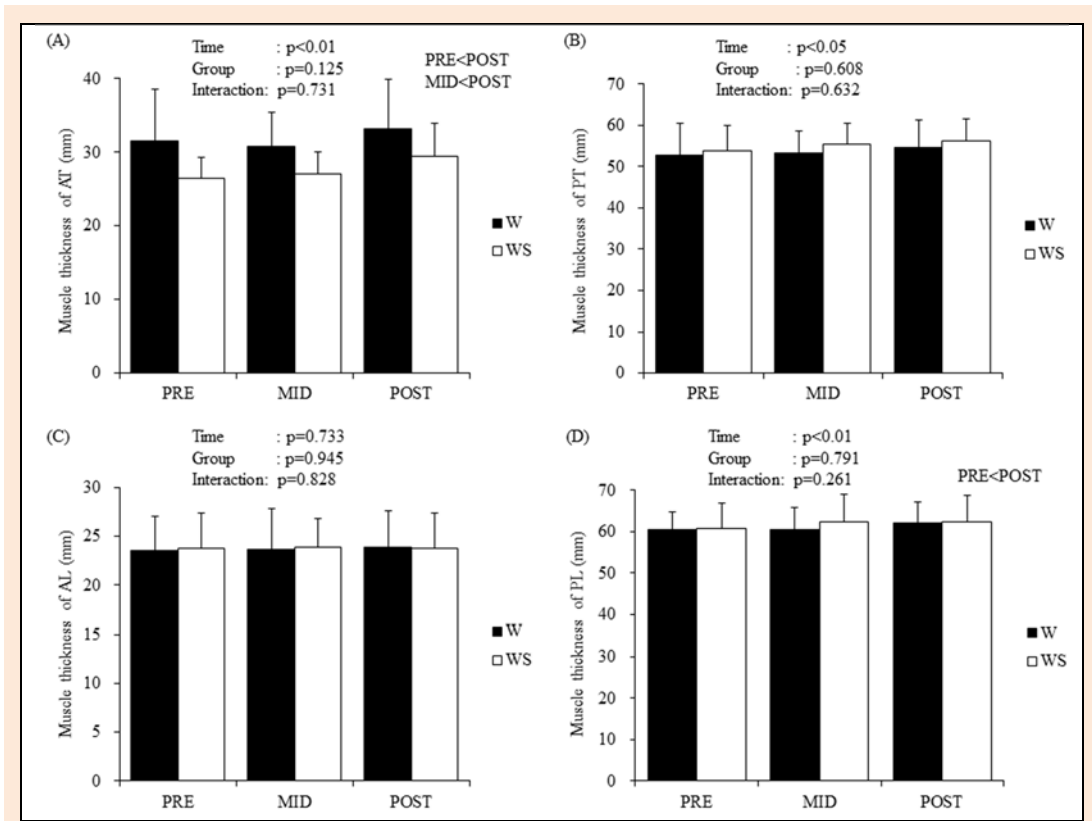


Figure 1. Changes in muscle thickness of the lower limbs in both groups. Data are presented as mean ± standard deviation. (A) AT; anterior aspect of the thigh, (B) PT; posterior aspect of the thigh, (C) AL; anterior aspect of the lower leg, (D) PL; posterior aspect of the lower leg.

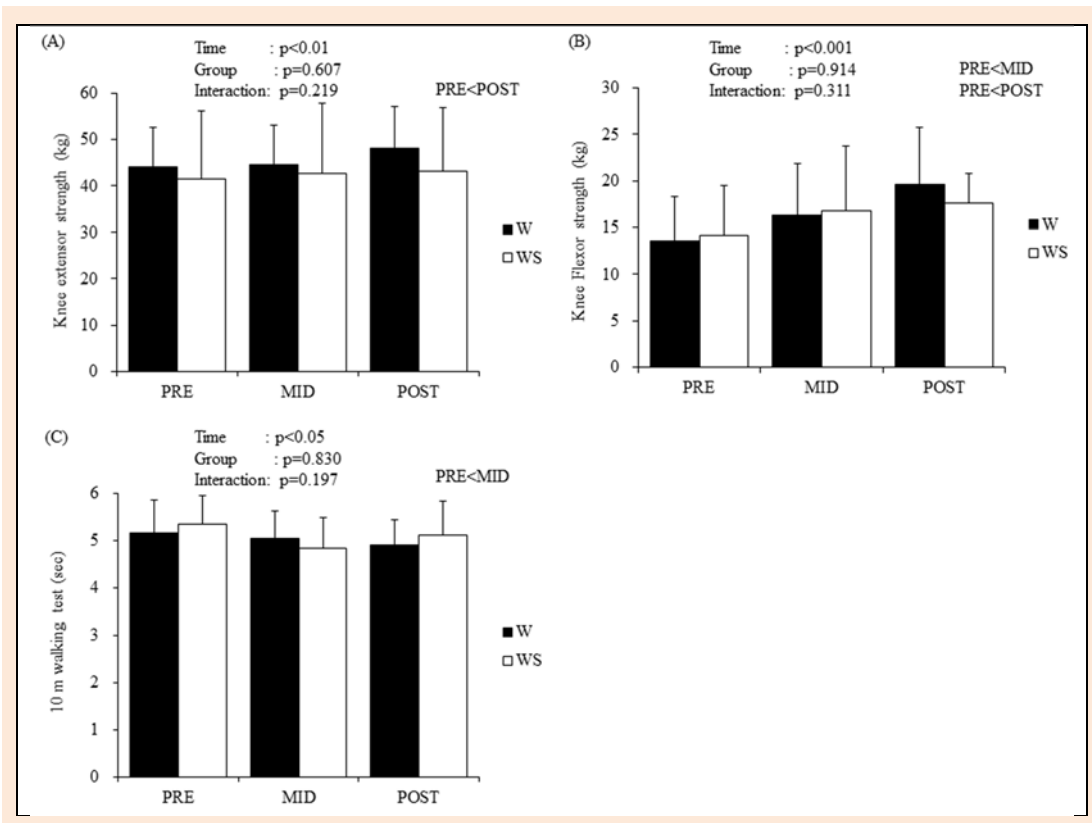


Figure 2. Changes in muscle strength of the lower limbs and physical fitness in both groups. Data are presented as mean ± standard deviation. (A) Knee extension strength. (B) Knee flexion strength. (C) 10-m walking test.

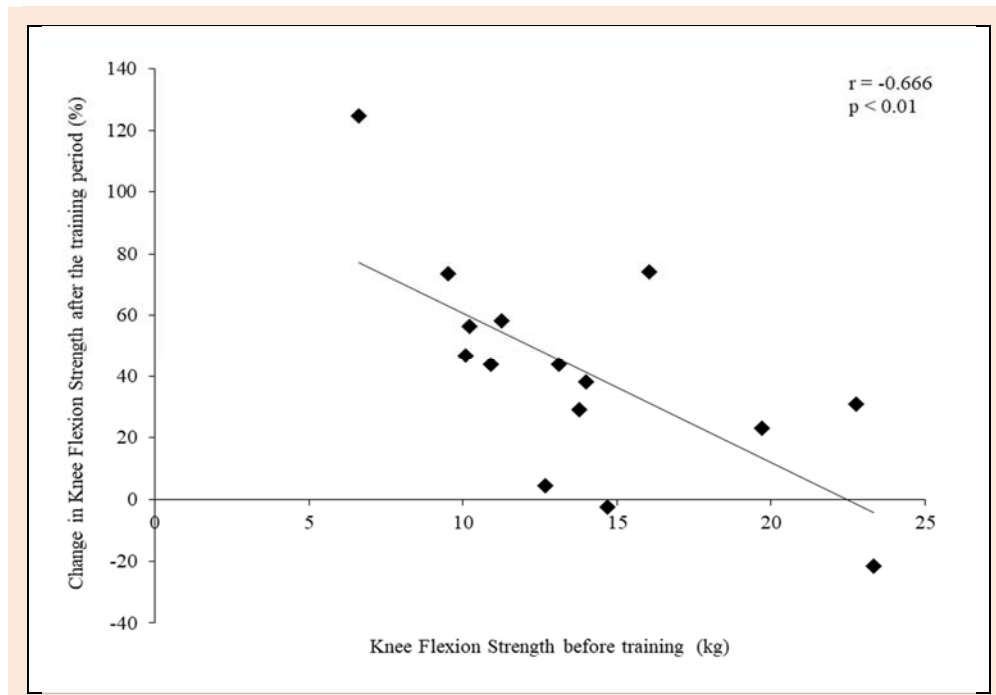


Figure 3. The relationship between knee flexion strength before training and change in knee flexion strength after the training period.

as shown in Table 1. However, the mid-thigh muscle cross-sectional area did not increase after 10 weeks of walking training in older adults in the previous study (Ozaki et al., 2011). The exercise intensity, duration, and frequency were 45% HRR, 20 min per session, and 4 days per week, respectively, and these training variables were constant throughout the training period. Furthermore, Sipila and Suominen demonstrated that endurance training including walking twice a week and step aerobics once a week did not increase the thigh muscle cross-sectional area in older women, even after 18 weeks of training (Sipila and Suominen, 1995). Although the exercise intensity increased from 50% HRR to 80% HRR, the exercise duration and frequency were constant throughout the training period. Based on these studies, it appears that significant muscle hypertrophy was observed approximately 4 months after the start of the walking training when exercise intensity, duration, and frequency appropriately increased throughout the training period.

Several studies have observed increases in knee extension and flexion strength following walk training in older adults. Nemoto et al. reported that moderate-intensity (50% of maximal oxygen uptake [VO_2max]) continuous (≥ 8000 steps per day) walking increased isometric knee flexion strength alone in older men and women, whereas high-intensity interval walking (5-8 sets of 3 minutes of walking at approximately 40% VO_2max followed by 3 minutes of walking at $>70\%$ VO_2max) produced improvements in both isometric knee extension and flexion strength after 6 months of the training program (Nemoto et al., 2007). The magnitude of improvement in knee flexion strength is also significantly higher in high-intensity interval walking; however, this previous study evaluated the above strengths only before and after the training period. In the present study, significant main effects of time were

observed for maximal isometric strength in both isometric knee extension and flexion strength. For knee flexion strength, a significant increase was observed even at 8 weeks after the start of the training program. As shown in Table 1, the exercise intensity, duration, and frequency were increased gradually in the present study. However, isometric knee extension or flexion strength did not improve following 10 weeks of 20-min moderate-intensity (45% HRR) continuous walking in older adults (Ozaki et al., 2011). Given this evidence, walking training appeared to improve isometric knee flexion strength at 2 months and knee extension strength at 4 months after the start of training when the exercise intensity, duration, and frequency was properly set for strength gain and these variables appropriately increased throughout the training period. Increased maximal strength may have also contributed to the improvement in walking performance in the present study.

As previously mentioned, significant muscle hypertrophy and strength gain in the knee extensor muscles seem not to occur following only a moderate-intensity continuous walking training (Kubo et al., 2008; Nemoto et al., 2007). One previous study demonstrated that the activation of knee extensor muscles was higher in stair-climbing compared to normal walking (Takai et al., 2008), prompting us to investigate whether a stair-climbing training provided additional training effects in the knee extensor muscles when was combined with the walking program. Significant muscle hypertrophy and strength gain in the knee extensor muscles were not observed after 2 months of continuous walking training in the present study, which is consistent with previous results. However, MT and strength for the knee extensors significantly increased after the next 2 months, where subjects performed high-intensity interval walking, and there were no differences in the magnitude of these training effects between the W and WS groups.

Generally, the activation of the knee extensor muscles during walking increases with increasing speed (Koyama et al., 2012). Thus, because the knee extensor muscles are sufficiently activated for inducing muscle hypertrophy and strength gain during high-intensity walking, any additional effects provided by the stair-climbing exercise might not have been observed in the present study.

In exercise without adding any external load to the body mass, exercise intensity would be determined by the ratio of maximal strength in the working muscles to the subject's body mass. A previous study demonstrated that the magnitude of the improvement in the relative value of knee extension strength to body mass following a body mass-based resistance training was negatively correlated to the corresponding pre-intervention value (Yoshitake et al., 2011). Our previous study also showed the same result (Ozaki et al., 2017). Thus, we hypothesized that, in walking training, the magnitude of improvement in maximal strength also depends on the pre-intervention value. As expected, the percentage change in maximal knee flexion strength after the training period was negatively correlated with the value at PRE in the present study. Thus, these results suggest that exercise with an external load may be needed for muscular adaptations in the skeletal muscle, especially in physically fit subjects.

Conclusion

In conclusion, 17 weeks of the progressive walking program including both moderate-intensity continuous and high-intensity interval exercise can increase thigh muscle size and strength for older adults, which may contribute to improvement in walking performance. However, stair-climbing exercise may not provide additional training effects when combined with high-intensity walking exercise. Furthermore, the magnitude of improvement in knee flexion strength after the walking program would depend on the pre-intervention value.

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Key points

- Progressive walking program including both moderate-intensity continuous and high-intensity interval exercise can increase thigh muscle size and strength for older adults.
- The magnitude of improvement in knee flexion strength after the walking program would depend on the pre-intervention value.
- Stair-climbing exercise may not provide additional training effects when combined with high-intensity walking exercise.

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