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ORIGINAL ARTICLE

Effects of a 12-week, short-interval, intermittent, low-intensity, slow-jogging program on skeletal muscle, fat infiltration, and fitness in older adults: randomized controlled trial

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Abstract
Purpose We developed a short-interval, low-intensity, slow-jogging (SJ) program consisting of sets of 1 min of SJ at walking speed and 1 min of walking. We aimed to examine the effects of an easily performed SJ program on skeletal muscle, fat infiltration, and fitness in older adults.
Methods A total of 81 community-dwelling, independent, older adults (70.8 ± 4.0 years) were randomly assigned to the SJ or control group. The SJ group participants were encouraged to perform 90 min of SJ at their anaerobic threshold (AT) intensity and 90 min of walking intermittently per week. Aerobic capacity at the AT and sit-to-stand (STS) scores were measured. Intracellular water (ICW) in the legs was assessed by segmental multi-frequency bioelectrical impedance analysis. Subcutaneous (SAT) and intermuscular (IMAT) adipose tissue and muscle cross-sectional area (CSA) were measured at the mid-thigh using computed tomography.
Results A total of 75 participants (37 SJ group, 38 controls) completed the 12-week intervention. The AT and STS improved in the SJ group compared with the controls (AT 15.7 vs. 4.9 %, $p < 0.01$; STS 12.9 vs. 4.5 %, $p < 0.05$). ICW in the upper leg increased only in the SJ group (9.7 %, $p < 0.05$). SAT and IMAT were significantly decreased only in the SJ group ($p < 0.01$).
Conclusion The 12-week SJ program was easily performed by older adults with low skeletal muscle mass, improved aerobic capacity, muscle function, and muscle composition in older adults.

Keywords Jogging · Randomized controlled trial · Aerobic capacity · Muscle hypertrophy · Muscle composition

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Abbreviations

AHS1	Amplitude of the first heart sound
ANOVA	Analysis of variance
AT	Anaerobic threshold
CSA	Cross-sectional area
CT	Computed tomography
DPBP	Double product breakpoint
EMG	Electromyography
HR	Heart rate
ICW	Intracellular water
IMAT	Intermuscular adipose tissue
LDMA	Low-density muscle area
LT	Lactate threshold
METs	Metabolic equivalents
MRI	Magnetic resonance imaging
NDMA	Normal-density muscle area
RPE	Rate of perceived exertion
SAT	Subcutaneous adipose tissue
SJ	Slow jogging
S-MFBIA	Segmental multi-frequency bioelectrical impedance analysis
SMI	Skeletal muscle index
STS	Sit-to-stand
$\dot{V}O_{2max}$	Maximum oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
WRT	Walk−run transition

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Introduction

Regular exercise and physical activity helps maintain health-related physical fitness in older adults, including cardiorespiratory fitness, body composition, muscle strength and power, and standing balance. Running and jogging are popular forms of exercise, and their popularity is increasing yearly, even among those ≥65 years of age. The physiological demands of jogging at slow velocity with very short strides ("slow jogging, or SJ": <7 km/h) have a linear relation between velocity and metabolic equivalents (METs), even when moving at a very slow speed (Fig. 1a) (Kitajima et al. 2014). Although the METs were approximately 1.6 times higher for jogging than for walking at the same speed (3–6 km/h), the rate of perceived exertion (RPE) did not significantly differ between the two types of locomotion (Fig. 1b). Humans tend to transition from walking to running (walk-run transition, or WRT) at speeds of about 6–7 km/h (Hreljac 1993; Farinatti and Monteiro 2010). We defined SJ as jogging at a velocity slower than that of the WRT. Quadriceps muscle activity as measured by electromyography (EMG) is significantly greater during SJ than walking, and this increased load may enhance muscle function (Gazendam and Hof 2007). Older adults who have a low fitness level can easily perform SJ during their everyday life because the RPE of SJ is similar to that of normal walking.

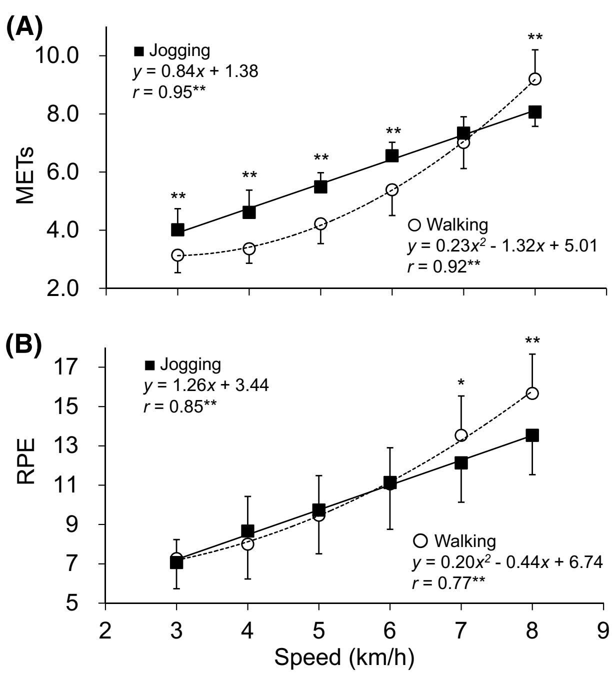

Fig. 1 Relations between speed and **a** metabolic equivalents (METs) and **b** the rate of perceived exertion (RPE) during walking (*open circle*) and jogging (*filled square*). Reproduced from Kitajima et al. (2014, in Japanese with English abstract) with permission of the copyright owner. $*p < 0.05$ and $**p < 0.01$, compared with the corresponding walking value

In this study, we developed an SJ program consisting of 1 min of SJ alternating with 1 min of walking. The program was designed so older adults could perform it easily. In a recent review, Miyashita et al.(Miyashita et al. 2013) concluded that an accumulation of short bouts of exercise during daily life lowers postprandial triacylglycerol concentrations. No studies, however, have examined the effects of multiple, short-interval, intermittent bouts of SJ on physical fitness in older adults. We hypothesized that running at a speed equal to or slower than the usual walking speed would improve aerobic capacity, physical function, and leg muscle composition in older adults. The purpose of this randomized controlled trial was to examine the influence of SJ training on physical fitness in a geriatric population.

Methods

Participants

A total of 81 community-dwelling, independent older adults [70.8 ± 4.0 (66–85) years of age] who had participated in the Fukuoka-Nakagawa Study were recruited for this study. The participants were randomly assigned to the SJ group ($n = 40$) or the control group ($n = 41$). Participants in the control group were instructed to maintain their usual lifestyle during the 12-week intervention period, whereas those in the SJ group were instructed to maintain their usual lifestyle except for adding the SJ exercise program. Potential participants with a history of serious conditions such as cardiac disease, stroke, diabetic complications, dementia, acute arthralgia, musculoskeletal disorder, and nervous symptoms during the previous 6 months, or those who would have difficulty regularly attending a class, were excluded. The purpose, procedures, and risks of the study were explained to each participant, and all gave their written informed consent before participating in the study. The Ethics Committee of Fukuoka University (Fukuoka, Japan) approved the study (11-04-01). The study was registered with the University Hospital Medical Information Network center (UMIN000005799).

Experimental procedures

Aerobic capacity: a sub-maximum graded bench stepping test Participants performed a sub-maximum graded stepping exercise test on a step bench to determine each individual's anaerobic threshold (AT) before and after the 12-week intervention. The details of the protocol for this bench stepping test were described in a previous study (Mori et al. 2006). The AT was determined by the breakpoint of the double product (DP) of the heart rate (HR) and the amplitude of the first heart sound (AHS1), as described previously (Tanaka et al. 2013). The AHS1 exhibits an increase similar to the early systolic wave of the first derivative of left ventricular pressure, a major determinant of myocardial oxygen demand. The DP of the HR and AHS1 reflects myocardial oxygen demand and blood lactate and catecholamine concentrations. The DP breakpoint is equal to the AT (Tanaka et al. 2013).

The bench stepping test consisted of 2-min periods of stepping with 1.5-min rest intervals between them. The workload of the test was adjusted by altering the bench height and step cadence until 75 % of the estimated maximum HR and/or an RPE of 17 (very difficult) was attained. A bench height of 10 cm was used until the cadence reached 100 steps/min, at which point the bench height increased in 2.5- to 5.0-cm increments. The step cadence was initially set at 60 steps/min and was increased by 10 steps/min for each subsequent 2-min stepping interval to a maximum of 100 steps/min. The HR and AHS1 were recorded using a multiple wireless transmission system (Nikoniko-Step; Kyusyu Keisokki Co., Ltd., Fukuoka, Japan) immediately after each 2-min interval. The double product break point as a marker of AT was determined as the point corresponding to the first sharp increase in DP after logarithmic transformation of both exercise intensity and DP. This point was determined by three researchers, and its average value was calculated (Tanaka et al. 2013).

SJ exercise program The SJ intervention was continued for 12 weeks. A single set in the program consisted of 1 min of jogging and 1 min of walking. Participants in the SJ group were encouraged to perform 90 sets of the program (total of 180 min) per week. We held a supervised SJ class once a week that included warm-up and cool-down phases. SJ group participants were instructed to: (1) strike with the forefoot (not the heel), (2) keep a straight back, (3) raise the chin slightly with the eyes looking at the horizon, (4) avoid kicking the ground, and (5) maintain a cadence of 180 steps/min while controlling their speed with their stride length. Individual jogging speed was calculated from the METs at AT using the following formula:

Prescribed jogging speed (m/min) = (METs at AT $\times$ 3.5 $-$ 3.5)/0.2.

During the supervised class, we set distance indicators at 10-m intervals on the jogging course and measured the jogging speed of each participant to make sure he/she understood his/her optimum speed. The HR was recorded simultaneously. Participants in the SJ group self-reported their exercise times in a diary. Daily physical activity and step counts of participants in both groups were monitored using accelerometers (Kumahara et al. 2004) before and after the intervention. In addition, the physical activity and step counts of the SJ group participants were monitored. This information was then provided to the SJ group participants as weekly feedback throughout the intervention period.

Anthropometric measurements

Body weight was measured to the nearest 0.1 kg on an electronic scale. Height was measured to the nearest 0.1 cm. Skeletal muscle index (SMI) was calculated using the bioelectrical impedance analysis (BIA) equation of Janssen et al. (Janssen et al. 2000). Segmental intracellular water (ICW) in the upper and lower limbs was assessed by segmental multi-frequency bioelectrical impedance analysis (S-MFBIA), as described previously (Miyatani et al. 2001; Yamada et al. 2013, 2014a). Impedance was obtained with an eight-channel, battery-operated, multi-frequency impedance instrument (Physion Z, Kyoto, Japan). Impedance measurements were obtained with the participants in a relaxed supine position on a padded bed, arms slightly abducted from the body, forearms pronated, and legs slightly apart. Participants were instructed to refrain from exercise including slow-jogging and vigorous physical activities for 24 h, and to refrain from eating or drinking more than 0.5 L of water for 3 h prior to the experiment. Room temperature was adjusted to maintain a thermoneutral environment. Impedance was measured within 5–10 min of rest. This rest period was necessary to avoid the immediate (1–2 min) effect of transition from a standing to a supine position on the shift in body fluid from the extremities to the thorax, and to avoid the slow phase of this shift that continues for up to 3–12 h (Kushner et al. 1996; Slinde et al. 2003). Limb ICW measured by S-MFBIA is a marker of segmental muscle cell mass, which excludes extracellular water and solids and is strongly related to muscle strength.

Randomly selected participants (14 SJ group, 15 controls) underwent computed tomography (CT) (Aquilion TSX-101A Scanner; Toshiba Medical Systems, Tokyo, Japan), as previously described (Yoshimura et al. 2011). Subcutaneous adipose tissue (SAT), intermuscular adipose tissue (IMAT), and the muscle cross-sectional area (CSA) were assessed at the mid-thigh in both legs. A low-density muscle area (LDMA: 0–29 HU) and normal-density muscle area (NDMA: 30–100 HU) were also quantified (Goodpaster et al. 2000; Yoshimura et al. 2014). Low-density muscle is considered lipid rich, whereas normal-density muscle has a lower lipid content.

Measurement of physical function

Physical function was measured as previously described (Ikenaga et al. 2014; Kimura et al. 2012). Briefly, participants ran 10 m, and the maximum gait speed was determined for the middle 6 m after the initial 2 m of acceleration and before the final 2 m of deceleration. Each participant completed two trials, and the average maximum gait speed was calculated for each.

Maximum knee extension strength was measured with the participant sitting on a dynamometer chair (TKK5715 and TKK5710e; Takei Scientific Instruments Co. Ltd., Niigata, Japan) with their knees flexed at 90° (Kimura et al. 2012). The participants sat with their arms folded and their bodies stabilized by a belt around the waist. After familiarization with the test, participants were encouraged to produce their maximum knee extension force. The peak torque was estimated from the product of force and distance between the attachment of the dynamometer (at the lateral malleolus) and the center of rotation of the knee joint. Two maximum-effort trials were conducted, and the highest recorded value was accepted as the result.

The sit-to-stand (STS) test was performed using a standard chair height of 0.4 m. Participants were asked to rise from the chair as quickly as possible five times with their arms folded across their chests. Static balance was assessed using the one-leg-stand test with the eyes open. The participants had to stand on one leg with eyes open and hands resting on hips. The time at which the raised leg touched the ground or the standing leg, or a hand left the hip, was recorded.

Statistical analyses

All results are presented as mean ± standard deviation (SD). Log-transformation was applied to achieve normal distribution when appropriate. Baseline characteristics were compared between the two groups using unpaired *t* tests. Within-group differences were assessed using paired *t* tests. The significance of between-group differences in pre-intervention and post-intervention values was assessed using repeated-measures analysis of variance (ANOVA). In addition, the SJ group participants were divided into low-SMI and normal-SMI groups to compare the differences in the change in physical fitness between subjects who had normal SMI and low SMI using repeated-measures ANOVA. A value of $p < 0.05$ was considered to indicate statistical significance. All statistical analyses were performed using SPSS Statistics for Windows version 20.0 (IBM Corp, Armonk, NY, USA).

Results

Participant characteristics and exercise compliance

A flow diagram of the study design is shown in Fig. 2. One participant in the SJ group dropped out because of worsening knee osteoarthritis pain. A married couple in the SJ group also dropped out because their car was rear-ended while driving to a destination unrelated to the intervention. One participant in the control group dropped out because of long-term hospitalization. Another two participants in the control group did not complete their post-intervention assessment because of a schedule conflict. Prior to the intervention, there were no significant between-group differences in any of the variables for the participants who completed the study (37 SJ group, 38 controls) (Table 1). The attendance rate at the weekly, supervised SJ classes was 90.2 ± 12.0 %. The average self-reported time spent on SJ training per week was 188.6 ± 102.4 min, and 56.8 % of the participants reached the recommended training quantity goal of >150 min/week.

Changes in aerobic capacity and physical function

The AT improved 15.7 % in the SJ group ($P < 0.01$) and 4.9 % in the control group ($p < 0.05$). There was a significant interaction between the group and time for this parameter ($p < 0.01$) (Table 2). The STS performance improved 12.9 % in the SJ group ($p < 0.05$) and 4.5 % in the control group ($p < 0.05$). The interaction between the group and time was also significant for STS performance ($p < 0.05$). Static balance also significantly improved in the SJ group after training ($p < 0.05$) and did not change in the control group. In this case, however, the interaction between group and time was not significant ($p = 0.064$). Knee extension strength was not significantly altered after 12 weeks of training in either group.

Changes in body composition

Changes in body composition during the experimental period are presented in Table 2. Upper leg ICW significantly increased only in the SJ group, and the percent change was significantly greater in the SJ group than in the control group (9.7 vs. 3.4 %, $p < 0.05$), with a significant interaction between group and time ($p < 0.05$).

CT measurements of mid-thigh composition before and after the experimental period are shown in Table 3. Both SAT and IMAT significantly decreased from pretraining levels only in the SJ group ($p < 0.01$), and the interaction between time and group was significant for both variables ($p < 0.01$ and $p < 0.05$, respectively). The NDMA did not change during the experiment. The LDMA was lower after training only in the SJ group ($p < 0.05$), but the time-group interaction was not significant ($p = 0.19$).

Comparison of low-SMI and normal-SMI groups

There were no significant differences in the changes in AT or STS performance between the low-SMI and normal-SMI

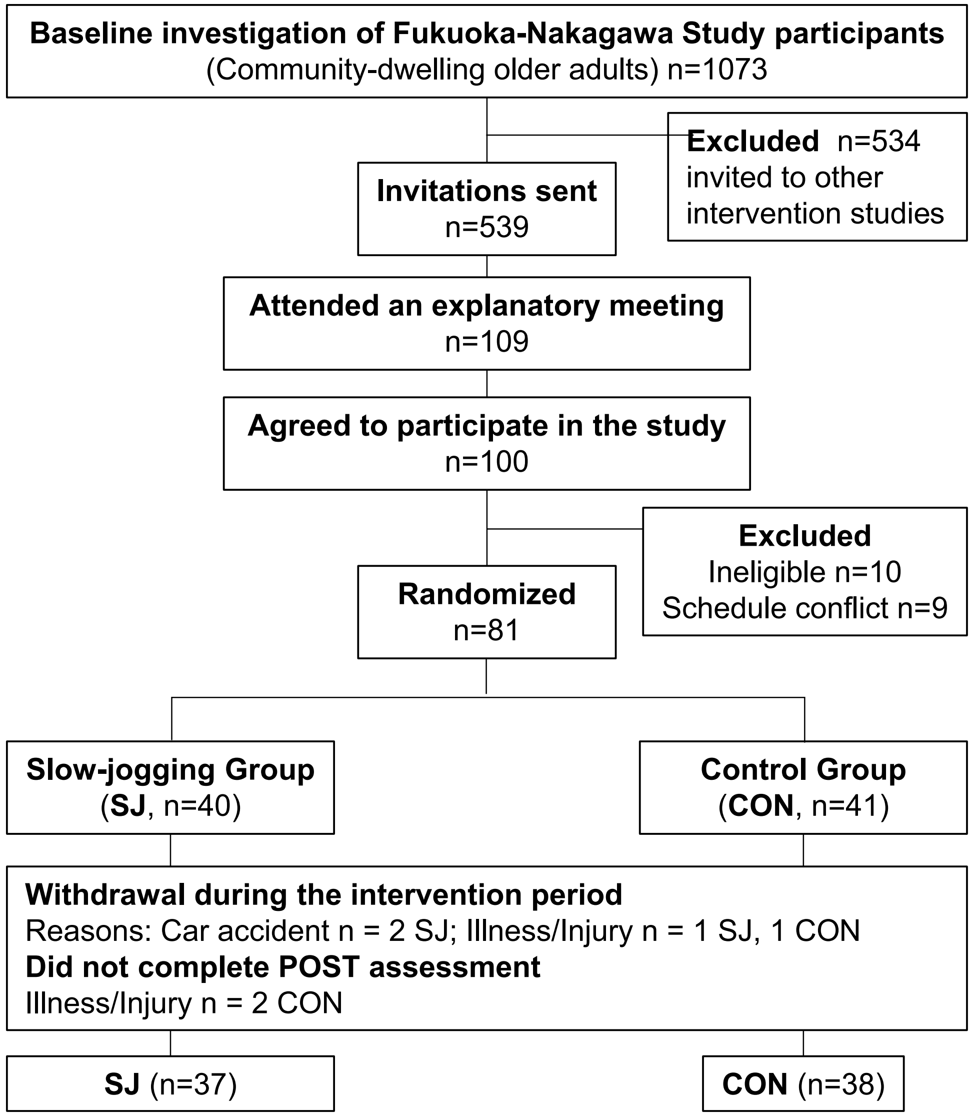

Fig. 2 Flow diagram for the study

Table 1 Participant characteristics and physical activity before and after training

	SJ ($n = 37$)			CON ($n = 38$)		
	PRE	POST	% Change	PRE	POST	% Change
Age, years	70.4 ± 4.1	–	–	71.3 ± 3.9	–	–
Gender, M/F	18/19	–	–	16/22	–	–
Height, cm	157.8 ± 9.1	–	–	156.9 ± 9.3	–	–
Body weight, kg††	57.6 ± 10.7	56.6± 10.2**	−1.5 ± 2.3	56.6 ± 8.6	56.7 ± 8.9	0.1 ± 1.9
BMI, kg/m^{2††}	23.0 ± 2.8	22.7 ± 2.6**	−1.3 ± 2.4	23.0 ± 2.4	23.0 ± 2.4	0.1 ± 2.1
Abdominal circumference, cm†	85.1 ± 8.9	83.4 ± 8.7**	−1.9 ± 2.9	85.1 ± 7.5	85.2 ± 7.3	−0.1 ± 3.5
Body fat, %	33.9 ± 8.1	34.3 ± 6.1	1.8 ± 8.3	35.6 ± 6.7	36.6 ± 6.6	3.3 ± 6.3
Step counts, steps/day††	7467 ± 2844	9330 ± 3905**	29.8 ± 49.4	7347 ± 3699	6515 ± 3399	−4.5 ± 31.7
Exercise time, min/week	–	189 ± 100	–	–	–	–

Values are mean ± SD

SJ slow-jogging group, *CON* control group, *PRE* before training, *POST* after training, *n* number of participants, *BMI* body mass index

* $p < 0.05$ and ** $p < 0.01$, compared with corresponding PRE value; † $p < 0.05$ and †† $p < 0.01$, group × time interaction

Table 2 Aerobic capacity, body composition and physical function before and after training

	SJ ($n = 37$)			CON ($n = 38$)		
	PRE	POST	% Change	PRE	POST	% Change
AT, METs††	3.8 ± 0.5	4.4 ± 0.6**	15.7 ± 15.1	3.9 ± 0.5	4.1 ± 0.5**	4.9 ± 9.3
Upper leg ICW, kg†	3.7 ± 1.2	4.0 ± 1.3**	9.7 ± 12.6	3.6 ± 1.5	3.6 ± 1.3	3.4 ± 13.5
Lower leg ICW, kg	1.2 ± 0.3	1.2 ± 0.3	0.7 ± 6.8	1.1 ± 0.3	1.1 ± 0.3	−1.8 ± 5.9
Gait speed, m/s	1.33 ± 0.15	1.32 ± 0.18	−0.5 ± 13.0	1.38 ± 0.23	1.34 ± 0.20	−1.1 ± 15.5
Knee extension strength, Nm/kg	2.23 ± 0.70	2.30 ± 0.71	2.1 ± 12.2	2.08 ± 0.59	2.07 ± 0.61	−0.2 ± 9.8
STS, s†	8.1 ± 2.3	6.8 ± 1.5**	−12.9 ± 16.8	7.2 ± 1.6	6.7 ± 1.2*	−4.5 ± 19.1
One-leg-stand	1.57 ± 0.45	1.69 ± 0.43*	12.4 ± 24.9	1.57 ± 0.50	1.57 ± 0.50	1.3 ± 19.7

Values are mean ± SD

SJ slow-jogging group, *CON* control group, *PRE* before training, *POST* after training, *n* number of participants, *AT* anaerobic threshold, *ICW* intracellular water, *STS* sit-to-stand

* $p < 0.05$ and ** $p < 0.01$, compared with corresponding PRE value; † $p < 0.05$ and †† $p < 0.01$, group × time interaction

Table 3 CT measurements of midthigh composition before and after training

	SJ ($n = 14$)			CON ($n = 15$)		
	PRE	POST	% Change	PRE	POST	% Change
SAT, cm^{2††}	108.9 ± 52.9	103.3 ± 49.6**	−4.5 ± 6.1	112.0 ± 49.9	111.2 ± 51.3	2.3 ± 6.3
IMAT, cm^{2†}	8.1 ± 4.0	6.0 ± 2.5**	−21.8 ± 15.0	9.3 ± 6.9	9.1 ± 6.4	−3.0 ± 12.4
NDMA, cm^2	189.3 ± 38.1	190.6 ± 35.4	1.0 ± 4.0	169.7 ± 36.2	174.6 ± 37.9	−0.1 ± 3.0
LDMA, cm^2	33.3 ± 13.0	30.6 ± 16.0*	−11.5 ± 10.6	30.7 ± 16.5	32.0 ± 16.0	−2.8 ± 10.2

Values are mean ± SD

SJ slow-jogging group, *CON* control group, *PRE* before training, *POST* after training, *n* number of participants, *SAT* subcutaneous adipose tissue, *IMAT* intermuscular adipose tissue, *NDMA* normal-density muscle area, *LDMA* low-density muscle area

* $p < 0.05$ and ** $p < 0.01$, compared with corresponding PRE value; † $p < 0.05$ and †† $p < 0.01$, group × time interaction

groups in the SJ program (Table 4). In addition, the changes in thigh ICW did not significantly differ between the low-SMI and normal-SMI groups. The SJ program affected AT, STS, and muscle composition similarly in the low-SMI and normal-SMI groups.

Discussion

The primary findings from this study were that 12 weeks of accumulating short, intermittent (1 min) SJ training improved the sub-maximum aerobic capacity, decreased myocardial oxygen requirements and repetitive sit-to-stand speed, decreased SAT and IMAT in the thigh, and increased thigh ICW in older adults. One-leg standing balance and LDMA in the thigh changed significantly over the experimental period in the SJ group, but the interaction between time and group did not reach significance for these variables. The effects of the SJ program were comparable for the subjects who had a normal SMI and those with a low SMI.

We designed the SJ program to consist of 1 min of slow jogging alternating with 1 min of walking because older adults could perform this exercise easily. When compared with walking at the same speed, slow jogging at less than 6–7 km/h (WRT speed) induced greater oxygen consumption at an equal RPE (Kitajima et al. 2014). Regrettably, one participant in the SJ group dropped out because of knee osteoarthritis-related pain. All of the other participants completed the program, except for one couple who dropped out because of a car accident unrelated to the intervention. The average attendance rate at the weekly, supervised SJ classes was greater than 90 %, and the average self-reported time spent in SJ training was >180 min/week. Most of the participants enjoyed the SJ program. Although improvement was evident, only 56.8 % of the participants reached the recommended physical activity training goal of >150 min/week. We, therefore, speculate that perhaps less training time is needed to improve aerobic capacity, muscle function, and skeletal muscle composition in an older population. Although the SJ program was of low-to-moderate

Table 4 Changes before and after the SJ intervention in low and normal-SMI groups

	Normal SMI ($n = 18$)		Low SMI ($n = 19$)	
	PRE	POST	PRE	POST
Age, years	70.7 ± 4.0	–	70.1 ± 4.2	–
Gender, M/F	9/9	–	10/9	–
Body weight, kg	52.6 ± 8.0	52.4 ± 7.9	62.3 ± 11.3	60.6 ± 11.0**
Step counts, steps/day††	8439 ± 2769	8908 ± 3261	6089 ± 2576	8812 ± 4095**
Upper leg ICW, kg	3.7 ± 1.1	4.1 ± 1.1*	3.7 ± 1.3	4.0 ± 1.4**
AT, METs	3.7 ± 0.5	4.4 ± 0.6**	3.9 ± 0.4	4.5 ± 0.6**
STS, s	7.6 ± 1.8	6.5 ± 1.5**	8.6 ± 2.6	7.1 ± 1.6*

Values are mean ± SD

SJ slow-jogging group, *CON* control group, *PRE* before training, *POST* after training, *n* number of participants, *AT* anaerobic threshold, *ICW* intracellular water, *STS* sit-to-stand

* $p < 0.05$ and ** $p < 0.01$, compared with corresponding PRE value; † $p < 0.05$ and †† $p < 0.01$, group × time interaction

intensity with low RPE compared with most previous aerobic exercise training interventions, we found significant improvements in the cardiovascular fitness and physical function of the participants.

Several studies have shown the effects of moderate- to high-intensity aerobic exercise training on muscle hypertrophy (Lovell et al. 2010; Harber et al. 2009, 2012). Harber et al. demonstrated that 12 weeks of aerobic exercise on a cycle ergometer at 60–80 % of heart rate reserve significantly increased quadriceps muscle volume (12 %), as measured by magnetic resonance imaging in older women (Harber et al. 2009) and 6 % in older men (Harber et al. 2012). Lovell et al. (2010) reported that cycle ergometer training at 50–70 % maximum oxygen uptake ($\dot{V}O_{2max}$) three times weekly for 16 weeks significantly increased leg strength, leg power, and upper leg muscle mass. Nemoto et al. (2007) reported that 5 months of high-intensity interval walking training consisting of five or more sets of 3 min of low-intensity walking and 3 min of high-intensity walking at >70 % peak oxygen uptake ($\dot{V}O_{2peak}$) produced improvements in knee extension (13 %) and flexion strength (17 %). In contrast, moderate-intensity continuous walking (at approximately 50 % $\dot{V}O_{2peak}$) did not result in the same improvements in middle-aged and older adults. Additionally, 9–12 months of walking and jogging training resulted in increased types I and IIA fiber size in older adults (Coggan et al. 1992). Conversely, Sipila and Suominen (1995) reported that an 18-week walking program did not increase the quadriceps or thigh muscle CSA as assessed by CT. These different results might be due to the lengths of the intervention periods. In the present study, muscle CSA assessed by CT was not changed by the SJ program, but thigh ICW increased significantly in the SJ group. Previous studies have shown that leg ICW measured by segmental bioelectrical impedance spectroscopy is more strongly correlated with muscle power than is lean CSA, and relative expansion of extracellular water may mask muscle atrophy during aging or in mobility-impaired individuals (Yamada et al. 2010, 2013, 2014a). Therefore, thigh ICW may be a more sensitive marker of changes in skeletal muscle cell mass than muscle CSA (Yamada et al. 2013). The muscle water content measured in skeletal muscle biopsy specimens from older women increased after aerobic training (Harber et al. 2009) but decreased in the specimens from older men (Harber et al. 2012). These adaptations were associated with improved cell size and function. This discrepancy between the sexes has not been clarified. It is possible, however, that the cell size and function are tightly linked. Because of the prolonged stance phase during walking, muscle activity in the quadriceps is greater during slow jogging than walking, regardless of the speed (Gazendam and Hof 2007). In addition, the optimal absolute exercise intensity for improving aerobic capacity is different for young and old populations. In other words, for older people with a low fitness level, even slow jogging at about 3 METs constitutes relatively moderate-intensity exercise and so provides optimal stimulation. Thus, slow jogging was a workload sufficient to induce muscle cell hypertrophy in the thigh and increase leg muscle power. Another novel finding of this study was that SJ training decreased body weight and adipose tissue in the thigh. It can be assumed that the decrease in IMAT is linked to loss of body weight (Yaskolka Meir et al. 2016). Previous studies have shown that higher intramuscular adipose content (assessed by CT) is associated with lower knee extension strength (Goodpaster et al. 2001) and a greater risk of limited mobility in the future (Visser et al. 2005). These effects are independent of thigh muscle CSA. Yoshimura et al. reported that aerobic exercise training at the lactate threshold (LT) attenuated the loss of skeletal muscle (NDMA) during energy restriction (Yoshimura et al. 2014). Weight loss may limit muscle growth

(Yoshimura et al. 2014), although adequate exercise (e.g., slow jogging) contributes to reduced muscle atrophy and/or increased ICW. We found that the effects of the exercise program were similar for subjects who had normal or low SMIs. These results suggest that SJ training would be effective even in sarcopenic patients.

We prescribed exercise intensity individually based on the AT (determined by the breakpoint of the DP of HR and AHS1). The product of HR and AHS1 as an index of myocardial metabolic stress could reflect plasma adrenaline and lactate levels. Thus, the DP breakpoint can measure sub-maximum aerobic capacity, thereby providing information similar to that with the LT but in a noninvasive manner. In addition to decreasing inflammation and oxidative stress, aerobic exercise training improves mitochondrial biogenesis, insulin sensitivity, and protein synthesis in skeletal muscle. In addition, aerobic exercise training at the LT and/or higher intensities induces expression of co-activator peroxisome proliferator-activated receptor-γ co-activator-1α (PGC-1α), which plays an important role in enhancing mitochondrial function (Tobina et al. 2011). Previous research has also shown favorable effects of light-to-moderate intensity aerobic exercise training at the LT on hypertension (Kiyonaga et al. 1985), glucose intolerance (Nishida et al. 2001; Sakamoto et al. 1999), and lipid metabolism (Sunami et al. 1999).

Recently, researchers in the Copenhagen City Heart Study reported that light and moderate joggers at a slow or average pace (6 METs, <2.5 h/week) had lower mortality rates than sedentary non-joggers, whereas the mortality rate for strenuous joggers who maintained a fast pace (≥12 METs) was not statistically different from that of the sedentary group (Schnohr et al. 2015). This result highlights the importance of optimal exercise intensity prescriptions for safety. In the present study, the speed of slow jogging was 2.1–4.8 km/h, which was slower than the WRT speed. This short, intermittent, slow-jogging exercise at low-to-moderate intensity improved not only physical fitness but also muscle composition and muscle function in older adults, although the effect size for muscle hypertrophy was lower than has been achieved with progressive resistance training (Liu and Latham 2009).

In conclusion, the 12-week exercise intervention program based on short-interval, intermittent, SJ exercise at individually prescribed intensities improved aerobic capacity, muscle function, and muscle composition in older adults. SJ exercise may be a potentially useful method for improving health-related physical fitness. It may prevent sarcopenia and frailty in older people.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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