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Effect of very low-intensity resistance training with slow movement on muscle size and strength in healthy older adults

Yuya Watanabe[1], Haruhiko Madarame[1], Riki Ogasawara[2], Koichi Nakazato[3] and Naokata Ishii[1]

[1]*Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Tokyo,* [2]*Department of Human and Engineered Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, Chiba, and* [3]*Graduate School of Health and Sport Science, Nippon Sport Science University, Tokyo, Japan*

Summary

We previously reported that low-intensity [50% of one repetition maximum (1RM)] resistance training with slow movement and tonic force generation (LST) causes muscle hypertrophy and strength gain in older participants. The aim of this study was to determine whether resistance training with slow movement and much more reduced intensity (30%1RM) increases muscle size and strength in older adults. Eighteen participants (60–77 years) were randomly assigned to two groups. One group performed very low-intensity (30% 1RM) knee extension exercise with continuous muscle contraction (LST: 3-s eccentric, 3-s concentric, and 1-s isometric actions with no rest between each repetition) twice a week for 12 weeks. The other group underwent intermitted muscle contraction (CON: 1-s concentric and 1-s eccentric actions with 1-s rest between each repetition) for the same time period. The 1RM, isometric and isokinetic strengths, and cross-sectional image of the mid-thigh obtained by magnetic resonance imaging were examined before and after the intervention. LST significantly increased the cross-sectional area of the quadriceps muscle (5·0%, $P<0·001$) and isometric and isokinetic knee extension strengths ($P<0·05$). CON failed to increase muscle size (1·1%, $P = 0·12$), but significantly improved its strength ($P<0·05$). These results indicate that even if the intensity is as low as 30% 1RM, LST can increase muscle size and strength in healthy older adults. The large total contraction time may be related to muscle hypertrophy and strength gain. LST would be useful for preventing sarcopenia in older individuals.

Correspondence
Yuya Watanabe, Laboratory of Applied Health Science, Kyoto Prefectural University of Medicine, 410 Nakagoryo-cho, Kamigyo-ku, Kyoto 602-0857, Japan
E-mail: yuya_watanabe80@yahoo.co.jp

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Introduction

Sarcopenia is defined as the ageing-related loss of muscle mass and/or strength (Evans, 1995; Rosenberg, 1997; Cruz-Jentoft *et al.*, 2010). In older individuals, the loss of muscle mass and/or strength has been shown to be a primary factor of frailty, falls and loss of independence (Wolfson *et al.*, 1995). Recent studies also reported that sarcopenia was associated with lifestyle-related diseases (Roubenoff, 2004; Karakelides & Nair, 2005; Schrager *et al.*, 2007), osteopenia (Walsh *et al.*, 2006) and mortality risk (Volpato *et al.*, 2004). Preventing sarcopenia would therefore be important for maintaining the quality of life in older individuals.

Resistance training has been considered the most effective intervention for increasing muscle mass and strength in older people (Borst, 2004). High-intensity resistance training has been used extensively to increase muscle mass and strength (American College of Sports Medicine position stand, 2009), whereas such training with an intensity lower than 65% 1RM (one repetition maximum) is considered less effective (McDonagh & Davies, 1984). Although there is no doubt that high-intensity resistance training causes muscle hypertrophy in older people (Frontera *et al.*, 1988; Fiatarone *et al.*, 1990; Harridge *et al.*, 1999), strenuous exercise with large mechanical stress may be associated with a risk of orthopaedic injury. In addition, high-intensity resistance exercise (95% 1RM) has been shown to markedly increase systolic blood pressure (arm flexion exercise, 255 mmHg; leg press exercise, 320 mmHg) in well-trained young men (MacDougall *et al.*, 1985). Even exercise at an intensity of 60% 1RM often causes increased systolic blood pressure (up to 180 mmHg) in older adults (Ajisaka, 2003).

Several studies have reported that, in young, untrained men, relatively low-intensity (50–60% 1RM) resistance training with slow movement and tonic force generation (LST: 3-s eccentric, 3-s concentric and 1-s isometric actions with no rest between repetitions) caused significant increases in muscle size and strength, as did conventional high-intensity (80–90% 1RM) resistance training (Tanimoto & Ishii, 2006; Tanimoto *et al.*, 2008). Our recent study has shown that 50% 1RM LST is effective for muscle hypertrophy and strength gain in older participants (66·8 ± 3·8 years), whereas 50% 1RM resistance exercise with normal speed is less effective for muscle hypertrophy (Watanabe *et al.*, 2013).

Kumar *et al.* (2012) showed that six sets of unilateral leg extension exercise at 40% 1RM stimulated myofibrillar protein synthesis in older participants, but three sets of the exercise did not. Thus, we hypothesized that resistance training at much lowered intensity may induce muscle hypertrophy if it is conducted with a long total contraction time. Because the LST protocol has a longer total contraction time than resistance exercise with normal movement speed, it is expected to induce muscular hypertrophy even at a much lower intensity (i.e. 30% 1RM).

The aim of the present study was to investigate the effects of a 12-week protocol of LST with 30% 1RM on muscle size and strength in older adults. In addition, to evaluate acute physiological responses to LST in older adults, the electrical activities of the agonist muscle, blood lactate concentration and systolic blood pressure were measured during and after a single bout of exercise.

Methods

Participants

Eighteen older adults (60–77 years of age) who were active but not engaged in regular resistance exercise were recruited. They volunteered as participants after a medical screening. None of them had coronary risk factors, symptoms of cardiovascular diseases, definitive osteoporosis with the associated risk for compression fracture, uncontrollable hypertension or any other medical problems that might affect the results of the study. All participants were fully informed about the experimental procedures and the purpose of the study. They gave written informed consent before the study began. This study was approved by the Ethics Committee for Human Experiments, Graduate School of Arts and Sciences, The University of Tokyo.

Participants were subsequently divided into two groups (Table 1 LST and CON, described below) in random order but balanced to match physical parameters such as height, weight, cross-sectional area (CSA) of the quadriceps muscle and knee extension strength (1RM, isometric and isokinetic strengths) between groups.

Table 1 Physical characteristics of the participants.

	LST (*n* = 9:7 men and 2 women)	CON (*n* = 9:7 men and 2 women)
Age (years)	69·0 ± 4·7	69·9 ± 5·1
Height (cm)	158·4 ± 10·2	159·8 ± 10·9
Body mass (kg)	60·8 ± 13·2	58·3 ± 13

LST, low-intensity (30% 1RM) resistance training with slow movement and tonic force generation; CON, low-intensity (30% 1RM) resistance training with normal speed.

Resistance training protocol

Participants in each training group performed low-intensity (30% 1RM) knee extension exercise with a seated weight-stack knee extension machine (Galaxy Sport, Germany). The range of knee joint motion was 0°–90° (0° representing full extension). Participants were assigned to one of the two experimental groups. One group (*n* = 9) exercised with the LST method (3-s eccentric, 3-s concentric and 1-s isometric actions with no rest between each repetition: LST group). The other group (*n* = 9) exercised at normal speed (1-s concentric and 1-s eccentric actions with 1-s rest between each repetition: CON group). Participants in both groups repeated their movements at constant speed and frequency with the aid of a metronome. In this study, we matched the intensity of the exercise and the work volume (total repetitions) to make LST and CON protocols different only in exercise movement. The exercise session consisted of three sets of 13 repetitions with a between-set rest period of 60 s. The exercise volume (intensity × repetitions) of this study was matched to that in our previous report (50% 1RM, 8 repetitions × 3 sets) (Watanabe *et al.*, 2013). The exercise was performed twice a week for 12 weeks. The exercise intensity was 30% of 1RM, which was tested every 4 weeks.

Electromyographic signals during exercise

Electromyographic (EMG) signals were recorded from the left vastus lateralis muscle using pre-amplified, bipolar electrodes (20-mm interelectrode distance) (model SX230; Biometrics, Gwent, UK) during weeks 6–7 of the intervention period. Before electrode placement, the skin was shaved, cleaned with alcohol and abraded to reduce electrode impedance. All EMG signals were band-pass filtered (20–450 Hz). They were digitized at a sampling rate of 2 kHz using a data acquisition system (PowerLab/16SP; ADInstruments, Bella Vista, NSW, Australia).

The muscle activation level – evaluated according to the root mean square (RMS) of the EMG signals – was shown as a percentage of 5-s isometric maximum voluntary contraction at 60° of the anatomical knee angle. A goniometer (SOT-Giken, Kyoto, Japan) was positioned on the leg extension machine, and the angle variation of each repetition was identified.

Measurement of blood lactate concentration

Blood lactate concentration was measured before and after a single bout of exercise during weeks 8–9 of the intervention period. Blood samples were collected before, immediately after, and 2 and 5 min after the exercise. A pre-exercise blood sample was obtained after resting for a 10 min (sitting on a chair). At each collection, approximately 5 μl of blood was obtained from the fingertip via a disposable lancet and analysed with a lactate analyser (Lactate Pro; Arkray, Kyoto, Japan).

Measurement of blood pressure

Blood pressure at the left radial artery was measured continuously during the exercise with arterial tonometry (JENTOW-7700; Colin, Tokyo, Japan) during weeks 10–11 of the intervention period. An adjustable table supported the arm during measurements. The upper body was kept relaxed and immobilized on the machine during the exercise to minimize the mechanical effects of contractions of upper body muscles and change of posture.

Measurement of muscle cross-sectional area

Cross-sectional images of the right thigh were obtained using a 0·3-T magnetic resonance imaging system (AIRIS mate; Hitachi Medical, Tokyo, Japan). The coil covered the whole thigh, including markers attached to the skin. Spin-echo and multi-slice sequences were used with a repetition of 450 ms and an echo time of 14 ms. For each participant, a range of serial sections were selected on longitudinal images along the femur to obtain sections of identical portions before and after the intervention. Cross-sectional images of three portions near the mid-thigh were obtained, and their mean value was used for measurement of the CSA of the muscle. An outline of the quadriceps was traced on each cross-sectional image, and the traced images were transferred to a computer for calculation of the anatomical CSA using digitizing software (Image J 1·44p; National Institutes of Health, Bethesda, MD, USA). The evaluations were repeated three times for each image, and the mean value was used. The images were obtained before and after the 12-week training period. The postintervention measurement was made 4–7 days after the final exercise session. The intra-class correlation coefficient and mean coefficient of variation for the repeated evaluations were 0·99 and 1·2%, respectively.

Measurement of muscle strength

Muscle strength was evaluated with the 1RM test and isometric and isokinetic muscle strength tests. 1RM was defined as the largest weight that the participants could lift at one time through a full range of motion without noticeable countermovement. It was determined as previously described (Watanabe *et al.*, 2013) and was tested at 0, 4, 8 and 12 weeks of the intervention.

Isometric and isokinetic strengths were measured using an isokinetic dynamometer (Biodex Medical Systems; Shirley, NY, USA) before and after the 12-week intervention period. After brief leg muscle stretching (approximately 15 s), the participant sat on a chair with the back upright and the right leg firmly attached to the lever of the dynamometer. A pivot point of the lever was accurately aligned with the rotation axis of the knee joint. Isometric peak torque was measured at a knee angle of 60°. After participants were familiarized with the test procedure, two trials at maximum effort were made with a 2-min recovery period. The higher value obtained was used for analysis. Isokinetic torque was measured at angular velocities of 90 and 180° s^{-1}. The range of angular movement of the knee joint was limited between 0 and 100° of the anatomical knee angle. Peak torque was measured regardless of where it developed within the range of movement. There were three trials at maximum effort, and the highest value obtained was used for analysis. Isometric and isokinetic strengths were measured before and after the 12-week training period. The postintervention measurement was made 4–7 days after the final exercise session.

Statistical analysis

Statistical analyses were performed with R software, version 2.13.2 (http://www.r-project.org/) and Microsoft Office Excel 2007 (Microsoft, Edmond, WA, USA). All values are expressed as means ± SD. All variables except the blood lactate concentration were analysed with a repeated two-way analysis of variance (ANOVA) (group × time) with a Holm post hoc procedure (Chan *et al.*, 2007). The blood lactate concentration data were analysed with a repeated two-way ANOVA (group × time) with a false discovery rate procedure (Curran-Everett, 2000). Differences between two variables within the same group were examined with Student's paired t-test. For all statistical tests, $P<0{\cdot}05$ was considered significant.

Results

All participants completed the training program. The exercise adherence rate in this study was 100% (18/18). There were no orthopaedic injuries associated with resistance exercise throughout the intervention period.

Muscle electrical activity

Figure 1a shows typical examples of EMG signals from the vastus lateralis muscle during the LST and CON protocols. The EMG exhibited continuous activity throughout the movements in the LST group and the intermittent activity in the CON group.

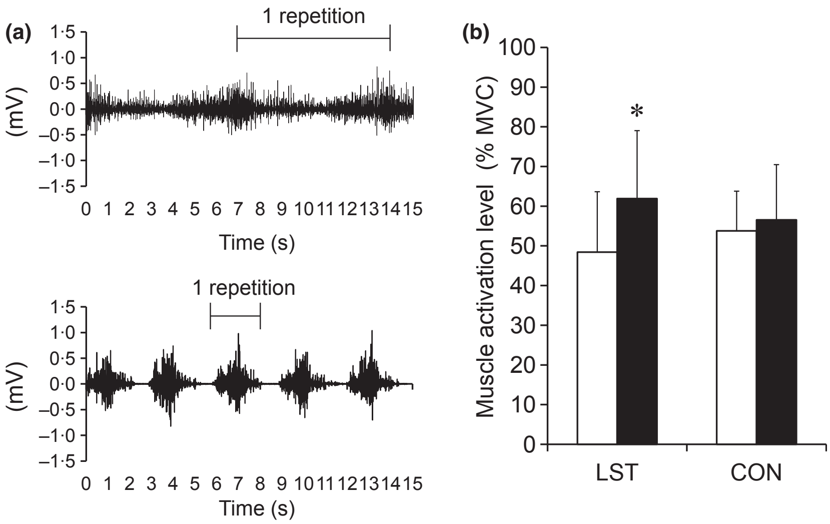

Figure 1 (a): Typical examples of electromyographic (EMG) signals from the left vastus lateralis muscle recorded during very low-intensity (30% 1RM) resistance training with slow movement and tonic force generation (LST) (upper panel) and very low-intensity (30% 1RM) resistance training with normal speed (CON) (lower panel). (b): Changes in activation level evaluated as the root mean square (RMS) of the EMG signals. □, first repetition of the first set; ■, last repetition of the third set. *, P<0·05, first repetition versus last repetition.

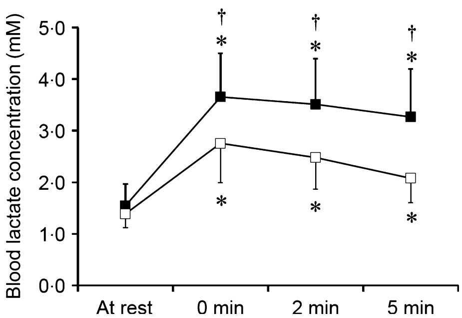

Figure 2 Blood lactate concentrations measured at rest, immediately after exercise (0 min), and 2 and 5 min after exercise. □, CON; ■, LST. *, P<0·05, versus at rest; †, P<0·05, LST versus CON.

Table 2 Systolic blood pressure measured at rest and during exercise.

LST (n = 9)		CON (n = 9)	
At rest	During exercise	At rest	During exercise
131·1 ± 13·5	171·9 ± 31·8*	128·4 ± 12·0	165·0 ± 17·1*

Blood pressures are expressed in millimetres of mercury. LST, low-intensity (30% 1RM) resistance training with slow movement and tonic force generation; CON, low-intensity (30% 1RM) resistance training with normal speed.
*P<0·05 versus at rest.

Figure 1b shows the changes in the muscle activation level between the first repetition of the first set and the last repetition of the third set. A significant increase in the muscle activation level was observed in the LST group (P<0·001), whereas no such change was observed in the CON group (P = 0·44).

Blood lactate concentration

Figure 2 shows the blood lactate concentrations measured at rest as well as immediately after and 2 and 5 min after a single bout of exercise with the LST and CON protocols. For both protocols, the blood lactate concentration increased significantly after exercise, although the mean values were significantly higher after LST than after CON at each time point measured (P<0·05), despite the same intensity and mechanical work during LST and CON protocols.

Blood pressure

Table 2 shows the systolic blood pressure measured before and during (peak value) exercise. Systolic blood pressure increased significantly to a similar extent in the both groups. There was no significant difference in peak systolic pressure between LST and CON (P = 0·60) groups.

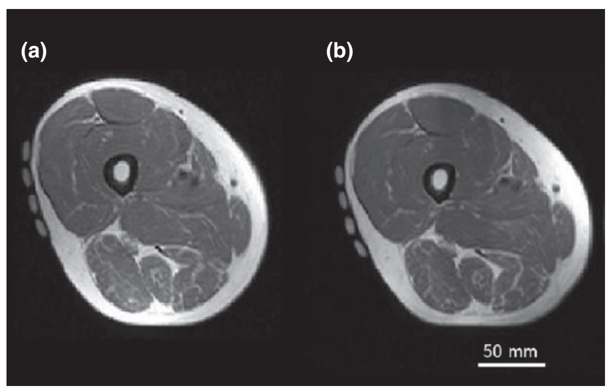

Figure 3 Typical magnetic resonance images showing transverse sections of the thigh taken before (a) and after (b) LST intervention for 12 weeks.

Changes in muscle cross-sectional area

Figure 3 shows typical examples of cross-sectional magnetic resonance images of an identical portion of the thigh. These

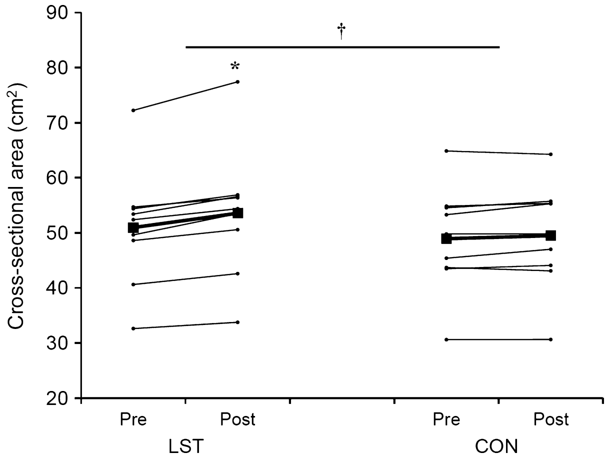

Figure 4 Cross-sectional area (CSA) of the quadriceps muscle measured before and after LST and CON interventions for 12 weeks. Each participant's value was presented by thin line, while mean value was presented by bold line. LST, low-intensity (30% 1RM) resistance training with slow movement and tonic force generation; CON, low-intensity (30% 1RM) resistance training with normal speed.*, P<0·05, versus preintervention. †, P<0·05, LST versus CON.

images were taken before and after LST training for 12 weeks. The CSA of the quadriceps muscle significantly increased after LST training (P<0·001), whereas no such change was observed after CON training (P = 0·12). When relative change in CSA was compared between groups, it was significantly greater in LST than in CON (P<0·001) (Fig. 4). The percentage increases in CSA of the quadriceps muscle were 5·0 ± 1·6% after LST training and 1·1 ± 1·7% after CON training.

Changes in muscle strength

Figure 5 shows changes in 1RM for knee extension exercise at 0, 4, 8 and 12 weeks of the intervention. Although both

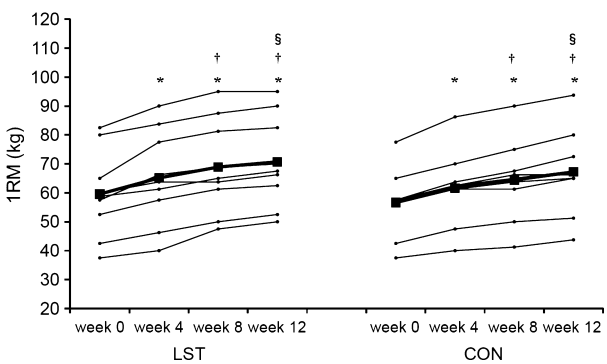

Figure 5 One repetition maximum at 0, 4, 8 and 12 weeks of the intervention. Each participant's value was presented by thin line, while mean value was presented by bold line. LST, low-intensity (30% 1RM) resistance training with slow movement and tonic force generation; CON, low-intensity (30% 1RM) resistance training with normal speed. *, P<0·05 versus week 0; †, P<0·05 versus week 4; §, P<0·05 versus week 8.

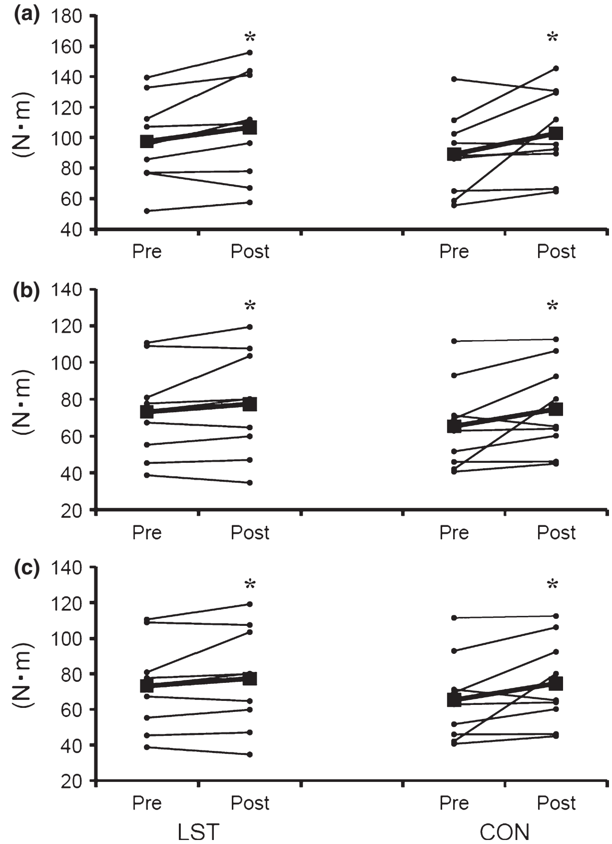

Figure 6 (a): Isometric strength measured before and after the intervention. (b): Isokinetic strength at 90° s^{-1} measured before and after the intervention. (c): Isokinetic strength at 180° s^{-1} measured before and after the intervention. Each participant's value was presented by thin line, while mean value was presented by bold line. LST, low-intensity (30% 1RM) resistance training with slow movement and tonic force generation; CON, low-intensity (30% 1RM) resistance training with normal speed. *, P<0·05 versuspreintervention.

protocols significantly increased 1RM after 12 weeks of training, there was no significant difference between groups. The percentage increases in 1RM were 19·7 ± 7·9% after LST training and 18·5 ± 4·3% after CON training.

Figure 6 shows changes in isometric and isokinetic strengths for knee extension exercise before and after the intervention. In all measures, significant strength gains were observed after LST and CON interventions. When relative changes were compared between groups, there were no significant differences in any of the measures. The percentage increases in the isometric strength, isokinetic strengths at 90 and 180° s^{-1} were 15·3 ± 15·5%, 8·6 ± 10·8% and 4·9 ± 10·1% after LST training and 10·8 ± 13·5%, 18·7 ± 28·1% and 17·7 ± 28·0% after CON training, respectively.

Discussion

This study demonstrates three important findings: (i) the CSA of the quadriceps muscle increased after 12 weeks of very low-intensity (30% 1RM) resistance training with slow movement and tonic force generation (LST group); (ii) the strength of the knee extensors but not the CSA of the quadriceps muscle increased after 12 weeks of very low-intensity (30% 1RM) resistance training with normal speed (CON group); (iii) there were no differences in the peak systolic blood pressure during the LST and CON protocols. The primary factor responsible for the induction of muscle hypertrophy with the LST protocol has to be the continuous muscle action (3-s eccentric, 3-s concentric and 1-s isometric force generation), because the relative intensity and the amount of mechanical work were the same in both protocols (LST and CON).

Kumar *et al.* (2012) showed that a single bout of 40% 1RM resistance exercise with high volume (14 repetitions × 6 sets) stimulates myofibrillar protein synthesis in older participants, whereas the exercise with low volume (14 repetitions × 3 sets) did not. Our results are consistent with Kumar *et al.*'s study in that even at low intensity increasing the work volume may promote myofibrillar protein synthesis in older adults. In addition, the effect of LST in our study suggests that a long contraction time or a large mechanical impulse (force–time integral) may be important for inducing muscle hypertrophy in older participants.

Several studies have investigated the acute and chronic effects of very low-intensity resistance exercise in young participants. Burd *et al.* (2010) demonstrated that resistance exercise at 30% 1RM until volitional failure (24·0 ± 1·1 repetitions) stimulates mRNA expressions of MyoD and myogenin and muscle protein synthesis in young, well-trained men. The magnitude of the postexercise increase in myofibrillar protein synthesis was similar to that after high-intensity (90% 1RM) resistance exercise (Burd *et al.*, 2010). They also reported that very low-intensity resistance exercise with slow speed (30% 1RM, 6-s concentric and eccentric contraction) repeated until failure caused an increased muscle activation level at the end of the set and postexercise muscle protein synthesis in young, well-trained men (Burd *et al.*, 2011). Most recently, the same research group showed that resistance training at 30% 1RM with volitional failure (× 3 sets) caused muscle hypertrophy of knee-extensor muscles after a 10-week period in young, active men (Mitchell *et al.*, 2012). Another group also demonstrated that very low-intensity resistance exercise with high volume (15·5% 1RM, 36 repetitions × 10 sets) caused muscle hypertrophy in healthy young men (Holm *et al.*, 2008). These studies suggest that a long total contraction time leads to activation of a large number of motor units even at low exercise intensity and thus plays an important role in muscle hypertrophy.

In this study, blood lactate concentration measured after a single session of exercise was significantly greater in the LST group than in the CON group (Fig. 2). In addition, there was a significant correlation between the blood lactate concentration and percentage increase in quadriceps CSA ($r = 0·54$; $P = 0·02$). It has been speculated that metabolic stress-induced increases in circulating anabolic hormones play some roles in muscle hypertrophy (Schoenfeld, 2013). The LST has also been shown to cause acute elevation in plasma GH as well as blood lactate in young men (Tanimoto *et al.*, 2005). However, our recent study showed that LST with 50% 1RM load caused muscle hypertrophy without acute hormone responses in older participants (Watanabe *et al.*, 2013). Therefore, hormonal responses may not be associated with hypertrophic effect of LST in older participants, though we cannot make a definitive conclusion due to lack of hormonal data in this study.

Although the causal relationship between blood lactate and muscle hypertrophy remains unclear, we can at least consider that a larger number of muscle fibres, including type II fibres, would be activated during LST than during CON, because lactate is mainly produced in type II fibres. In fact, a significant increase in muscle activation level (RMS of the EMG signal) was only found during the LST protocol (Fig. 1b), and the increase was significantly correlated with peak blood lactate concentration after the exercise ($r = 0·53$; $P = 0·02$). Thus, it is conceivable that recruiting large numbers of motor units with a long total contraction time of LST stimulated myofibrillar protein synthesis and resulted in muscle hypertrophy in older participants.

If a large total contraction time is an important factor for muscle hypertrophy, normal low-intensity resistance training – CON in this study – may also cause muscle hypertrophy in older adults when it is performed until repetition failure in each set of exercise. In fact, increasing the exercise volume has been reported to stimulate myofibrillar protein synthesis even at an intensity of 40% 1RM in older individuals (Kumar *et al.*, 2012). Increasing a total contraction time in normal resistance training, however, is necessarily associated with an increase in work volume, resulting in metabolic and cardiovascular stress. Therefore, the LST protocol is considered more desirable for older adults, particularly when their physical strength is exceptionally low.

In this study, the exercise volume (30% 1RM, 13 repetitions × 3 sets) was matched to that in our previous report (50% 1RM, 8 repetition s × 3 sets) (Watanabe *et al.*, 2013), which showed a 6·5% increase in front thigh muscle thickness. The present training protocol also caused a 5·0% increase in CSA of the quadriceps muscle after a 12-week intervention. We cannot directly compare these two studies in terms of the muscle-hypertrophic effect because of the difference in hypertrophy measures (muscle thickness versus muscle CSA). It should be noted, however, that a period of resistance exercise with an intensity as low as 30% 1RM can induce muscle hypertrophy in older individuals, depending on the mode of movement and the exercise volume.

This study showed significant increases in all strength measures after both LST and CON training (Figs 5 and 6). Thus, it can be interpreted that normal resistance training at very low intensity (CON) can cause an increase in strength without muscle hypertrophy. This is probably because muscle strength is primarily related to the neural factors – that is, the ability to recruit motor units – in addition to muscle CSA (Ikai & Fukunaga, 1970). It is also possible that older individuals have greater trainability to generate a large force such as 1RM and isometric strengths because they have spent more time on low-level activities during their daily lives (Meijer *et al.*, 2001). In addition, 1RM strength is strongly subjected to the 'learning effect' of repeated exercise bouts (Rutherford & Jones, 1986). Several studies have reported that low-intensity resistance training (~50% 1RM) for leg muscles effectively increases 1RM strength in older people (Taaffe *et al.*, 1996; Vincent *et al.*, 2002). The present LST methodology, with a definite muscle-hypertrophic effect, should be even more desirable for preventing ageing-related loss of muscle size. It can be used as an introductory training programme for older individuals with low physical strength to make their daily lives more active.

Conclusion

This study showed that resistance training at an intensity of 30% 1RM with slow movement and tonic force generation is effective for gaining muscle size and strength in older adults. A long total contraction time included in the LST protocol may be an important factor for inducing muscle hypertrophy. As this type of exercise is not associated with generation of a large accelerating/decelerating force (Tanimoto & Ishii, 2006) or undesirable elevation of blood pressure (Table 2), it carries a lower risk of orthopaedic injury or a cardiac event. Thus, it is thought that the LST protocol is safe and effective for maintaining/developing muscle mass and preventing sarcopenia in older individuals who cannot perform conventional high-intensity resistance exercise.

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