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ORIGINAL ARTICLE

# Comparison between eccentric and concentric resistance exercise training without equipment for changes in muscle strength and functional fitness of older adults

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## Abstract

**Purpose** The present study tested the hypothesis that resistance exercise training focusing on eccentric muscle contractions would improve muscle strength and functional physical fitness more than concentric contraction-focused resistance training in older adults.

**Methods** Healthy older adults (65–84 years) were placed into eccentric (ECC; $n=9$) or concentric training group (CON; $n=8$). They performed 4–6 basic manual resistance exercises focusing on either eccentric or concentric muscle contractions once at a community centre and at least twice at home a week for 8 weeks. Muscle thickness of the quadriceps femoris (MT), knee extensor maximal voluntary isometric contraction strength (MVC), 30-second chair stand (CS), 3-metre timed up and go (TUG), 2-minute step (2MS), sit and reach (SR), and static balance with eyes open and closed (Bal-EC) were assessed before and 7 days after the last community centre session.

**Results** Changes in MT (ECC: 21.6 ± 9.2% vs CON: 6.7 ± 7.1%), MVC (38.3 ± 22.6% vs 8.2 ± 8.4%), CS (51.0 ± 21.7% vs 34.6 ± 28.3%), TUG (16.7 ± 9.9% vs 6.3 ± 7.7%), 2MS (9.9 ± 6.0% vs 6.0 ± 7.3%) and Bal-EC (35.1 ± 6.7% vs 8.8 ± 16.2%) from baseline were greater ($P < 0.05$) for the ECC than the CON group.

**Conclusion** These results show that the eccentric manual resistance exercise training was more effective for improving lower limb strength, mobility, and postural stability of older adults when compared with the concentric training. This suggests the significance of emphasising eccentric muscle contractions in movements to maintain and improve physical function.

**Keywords** Maximal voluntary isometric contraction strength · Muscle thickness · 30-second chair stand · 3-metre timed up and go · 2-minute step · Static balance

### Abbreviations

| | |
|---|---|
| ADL | Activities of daily living |
| BM | Body mass |
| BMI | Body mass index |
| CV | Coefficient of variation |
| CON group | Concentric resistance exercise training group |
| DBP | Diastolic blood pressure |
| ECC group | Eccentric resistance exercise training group |
| HR | Heart rate |
| MVC | Maximal voluntary isometric contraction |
| QOL | Quality of life |
| RPE | Rating of perceived exertion |
| SBP | Systolic blood pressure |
| TMT | Trail making test |

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## Introduction

It is predicted that the number of people aged 65 years and older will increase to 236 million globally in the next 10 years, and will reach 1.6 billion by 2050 (He et al. 2016). It should be noted that frailty increases with advancing age, and 20–30% of the elderly population over 75 years of age have disabilities that affect their daily activities (Topinková 2008). Considering that life expectancy exceeds 80 years in most developed countries (Wang et al. 2017), it is necessary to reduce the disability rate and extend the health span, and for this, there is no doubt that exercise is the key. A previous study has reported that leg extension strength is independently associated with most physical functions required for everyday activities such as walking and balance in older adults (Bouchard et al. 2011). Therefore, resistance exercise training to maintain and increase lower limb muscle strength is necessary for older adults to be independent.

In most exercises, both concentric (shortening) and eccentric (lengthening) muscle contractions are included. Generally speaking, concentric muscle contractions are more emphasised in resistance exercises, and less focus is given to eccentric muscle contractions, in which muscles producing force are lengthened, such as lowering a dumbbell slowly or squatting down slowly. Several studies have shown that exercise training focusing on eccentric muscle contractions is more effective for increasing muscle strength and muscle mass, when compared with resistance training focusing on concentric muscle contractions (Chen et al. 2017a, b; Gremeaux et al. 2010). For example, Theodorou et al. (2013) reported that 6 weeks of stair descending training (mainly consisting of eccentric muscle contractions) increased maximal voluntary isometric contraction (MVC) torque of the knee extensors more than stair ascending training (concentric muscle contractions). Chen et al. (2017a) also showed that descending stair walking improved physical function such as MVC strength of the knee extensors, 30-second chair stand, 2-minute step, 8-foot up and go and one-leg stand, and insulin sensitivity and blood lipid profile greater than ascending stair walking in elderly obese women who performed the exercise twice a week for 12 weeks. It appears that low-intensity eccentric muscle contractions are effective for improving physical function and health. Thus, it is possible that focusing on eccentric muscle contractions in daily activities such as sitting down in a chair slowly is beneficial for maintaining and improving muscle and physical function in older adults. However, no previous study has compared eccentric and concentric contraction-focused basic manual resistance exercises without using any equipment (e.g., squat, sit-up, push-up) for their effects on muscle and physiological function of older adults.

In the present study, we instructed several eccentric or concentric basic manual resistance exercises (Fig. 1) to older adults who had not experienced any structured exercise training. They came to a community centre once a week for 8 weeks to perform basic manual resistance exercises, and they were instructed to perform some of the exercises at home at least twice a week. Changes in muscle and physical function, health-related quality of life as well as cognitive function were compared between the group of people who performed the resistance exercises emphasising eccentric muscle contractions and the group of people whose exercises emphasising concentric muscle contractions. It was

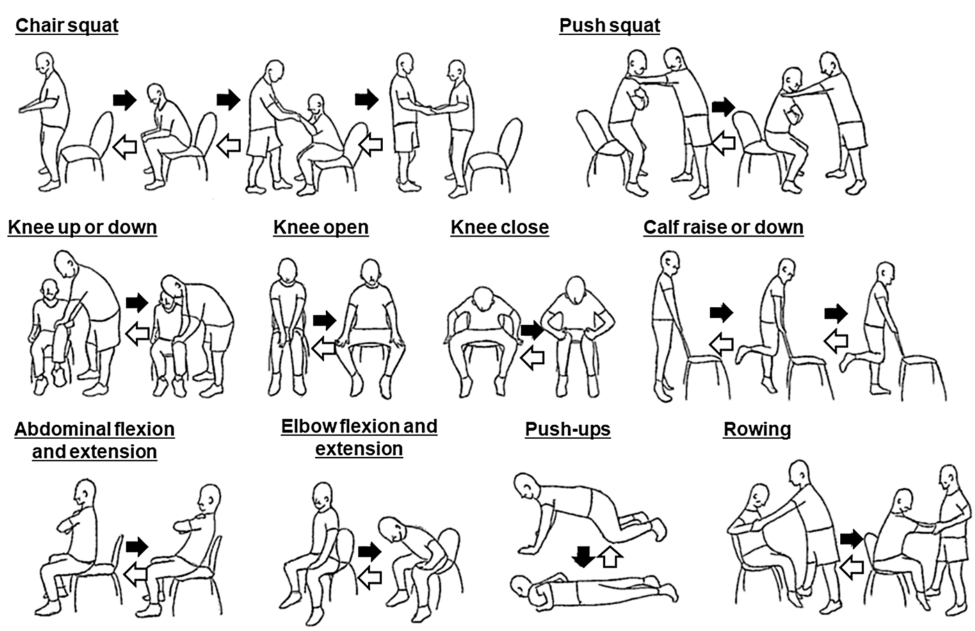


**Fig. 1** Eccentric and concentric resistance exercises performed in the training; chair squat, push squat, knee up or down, knee open, knee close, heel up or down, abdominal flexion or extension, elbow flexion or extension, push-up, and rowing. Black arrows indicate the sequence of movement in eccentric exercises, and white arrows indicate the sequence of movements in concentric exercises

hypothesised that the basic manual eccentric resistance training group would show greater improvement in muscle strength, muscle thickness of the knee extensors, physical function and balance when compared with the basic manual concentric resistance training group.

## Methods

### Participants

To recruit participants for the study, an advertisement was made in a large apartment complex of 360 households in a city in Japan, and after screening, 34 respondents were found to be eligible for the study based on their age to be over 65 years. After a medical check-up and an explanation of the details of the study, 22 participants participated in the study. Informed consent was obtained from all participants included in the study, which was approved by the Ethics Committee of Kogakuin University (no. H29-14). Five participants were excluded from the data analyses, since they missed the exercise session at the community centre more than three times. The number of participants who attended all of the community centre exercise sessions was 8, and who were absent from the session once or twice was 9. Thus, the total number of participants included in the analyses of the present study was 17, and their age ranged 65–84 years (average ± SD, 71.6 ± 5.6 years).

They were randomly assigned to one of the two groups based on the focus of muscle contractions in the exercise training: an eccentric resistance exercise training group (ECC group: 5 men, 4 women), and a concentric resistance exercise training group (CON group: 2 men, 6 women). No significant differences in physical characteristics were found between the groups at the baseline (Tables 1, 2, 3). Participants were instructed to avoid performing any vigorous physical activities or unfamiliar exercises, to perform some of the exercises that were instructed at the community centre

**Table 1** Physical characteristics (age, body mass: BM, body mass index: BMI, percent body fat: Fat and height) of the participants and their baseline values (mean ± SD, range) of muscle thickness of quadriceps femoris (MT), maximal voluntary isometric contraction strength of the knee extensors (MVC, average of the right and left legs), 30-second chair stand test (CS), 3-metre timed up and go test (TUG), 2-minute step test (2MS), sit-and-reach test (SR), static balance ability with eyes open (Bal-EO) and eyes closed (Bal-EC) for the movement distance of the centre of gravity (mm), of the participants in the eccentric (ECC group) and concentric resistance exercise training group (CON group)

| | ECC group | CON group | *t* test |
|---|---|---|---|
| Age (years) | 72.0 ± 6.6 (65–84) | 71.1 ± 4.5 (65–77) | n.s. |
| BM (kg) | 60.3 ± 9.8 (47.6–77.0) | 55.4 ± 5.4 (45.4–62.6) | n.s. |
| BMI (kg/m$^2$) | 23.5 ± 4.5 (16.3–30.3) | 22.9 ± 1.5 (20.7–25.1) | n.s. |
| Fat (%) | 25.6 ± 12.5 (3.0–43.1) | 27.4 ± 6.2 (16.7–34.6) | n.s. |
| Height (cm) | 160.8 ± 10.9 (140.2–177.1) | 155.5 ± 5.5 (146.4–161.0) | n.s. |
| MT (mm) | 17.4 ± 1.9 (14.8–19.0) | 17.5 ± 1.5 (15.4–19.5) | n.s. |
| MVC (kg) | 38.5 ± 9.9 (22.5–54.0) | 37.5 ± 8.3 (24.8–49.5) | n.s. |
| CS (times) | 13.7 ± 2.6 (11–19) | 16.8 ± 4.4 (10–24) | n.s. |
| TUG (s) | 7.2 ± 0.7 (6.1–8.5) | 6.2 ± 1.3 (4.5–8.3) | n.s. |
| 2MS (times) | 88.4 ± 4.2 (83–96) | 99.9 ± 18.2 (67–119) | n.s. |
| SR (cm) | 34.4 ± 8.9 (22.0–44.0) | 38.9 ± 10.7 (20.0–51.0) | n.s. |
| Bal-EO (mm) | 330.5 ± 81.3 (229.3–441.8) | 367.9 ± 97.5 (280.2–567.2) | n.s. |
| Bal-EC (mm) | 422.1 ± 158.0 (199.7–692.0) | 465.3 ± 117.3 (296.7–605.8) | n.s. |

*n.s.* no significant ($P > 0.05$) difference between groups based on *t* test

**Table 2** Changes in resting heart rate (HR), systolic (SBP) and diastolic (DBP) blood pressure taken before (pre) and after (post) the 8-week training for the eccentric (ECC group) and concentric resistance exercise training group (CON group)

| | ECC group | | CON group | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| HR (beats/min) | 70.6 ± 8.1 | 68.0 ± 6.2 | 71.8 ± 12.7 | 68.2 ± 9.6 |
| SBP (mm/Hg) | 149.1 ± 15.5 | 133.7 ± 15.2* | 139.8 ± 13.6 | 128.1 ± 15.2* |
| DBP (mm/Hg) | 83.7 ± 6.9 | 75.2 ± 7.6* | 82.9 ± 10.3 | 76.6 ± 10.1 |

*A significantly ($P < 0.05$) different from the pre-value

**Table 3** Changes in activities of daily living (ADL), health-related quality of life (QOL) based on short-form health survey score for physical functioning, role physical, bodily pain, general health, vitality, social functioning, role emotional and mental health, and trail making test A (TMT-A) and B (TMT-B) before and after the 8-week training for the eccentric (ECC group) and concentric resistance exercise training group (CON group)

| | ECC group | | CON group | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| ADL (point: 14–51) | 35.4 ± 7.0 | 38.2 ± 6.0* | 39.0 ± 5.7 | 40.3 ± 4.7 |
| QOL (point: 0–100) | | | | |
| Physical functioning | 46.6 ± 10.7 | 51.4 ± 7.2* | 46.1 ± 12.0 | 50.2 ± 7.6 |
| Role physical | 47.2 ± 8.3 | 53.1 ± 5.2* | 46.6 ± 8.5 | 49.5 ± 9.5 |
| Bodily pain | 53.2 ± 7.8 | 55.4 ± 5.7 | 51.8 ± 9.5 | 51.6 ± 8.7 |
| General health | 48.4 ± 8.9 | 51.8 ± 7.2* | 49.0 ± 7.4 | 50.4 ± 5.9 |
| Vitality | 53.0 ± 10.4 | 55.9 ± 5.9* | 49.8 ± 7.9 | 54.2 ± 6.6* |
| Social functioning | 53.4 ± 5.7 | 53.4 ± 4.7 | 53.0 ± 5.9 | 54.6 ± 4.8 |
| Role emotional | 51.0 ± 5.4 | 54.2 ± 4.2 | 51.4 ± 9.3 | 51.9 ± 8.6 |
| Mental health | 53.9 ± 6.5 | 56.6 ± 3.7 | 51.2 ± 10.2 | 53.5 ± 5.5 |
| TMT-A (s) | 75.8 ± 13.7 | 82.8 ± 15.9 | 82.0 ± 15.4 | 91.5 ± 24.3 |
| TMT-B (s) | 98.8 ± 24.0 | 94.3 ± 23.4 | 99.5 ± 15.9 | 104.3 ± 22.6 |

*A significantly ($P < 0.05$) different from the pre-value

at home, and to maintain their normal life style including food intake during the experimental period.

## Exercise training

The training session at the community centre in the apartment complex was scheduled once a week for 8 weeks, and was held on a different day of the week for each group (ECC group: Tuesday, CON group: Saturday). All sessions were supervised by the investigators. In addition, the participants in both groups were instructed to perform some of the exercises performed at the community centre on following days before the next community centre training session at least twice a week. Each exercise training session at the community centre was 90 min for both groups including 10 min of warm-up exercises with stretching, 10–15 min of coordination exercises (e.g., arm and leg movements, ball catch, rhythmic movements), 60 min of main exercises focusing on either the eccentric or concentric basic manual resistance exercises described below, and a 5-min cool-down.

In a training session at the community centre, participants performed 4–6 exercises from the list of 10 exercises shown in Fig. 1. Each exercise consisted of 2–5 sets of 10–15 repetitions. For the ECC group, the load for the concentric phase (e.g., standing up from a chair) was minimised, whereas the load for the eccentric phase (e.g., sitting down to a chair) was minimised for the CON group. The exercises for lower limb muscles such as the chair squat and the push squat were included in all community centre training sessions, but other exercises were chosen for each session by the investigator. A home-based exercise training programme manual (detailing the 10 exercises performed in the community centre) was provided to each participant, who was instructed to perform 2–3 exercises of the lower limb muscles such as chair squat 2–3 sets of 10–15 repetitions on each day at least 2 days a week. They were asked to record the home exercises on a training log book. The participants were instructed not to perform any exercises after the last (8th) community centre training session; thus, post-training measures were taken without a home-based training for a week.

A Borg's rating of perceived exertion (RPE) scale from 6 to 20 (Borg 1970) was used to assess subjective intensity of exercise immediately after each exercise in the community centre. The exercise intensity was gradually increased over the 8 sessions from low intensity (RPE: 6–11) for the first couple of weeks to moderate (RPE: 12–17) to high intensity (RPE: more than 18) for the last couple of sessions.

All participants were asked to record muscle soreness of the lower limb muscles on a visual analogue scale (VAS) with a 100-mm straight line; the left end of which indicated "not sore" and the right end "very sore" after each community centre training session for 3 days.

## Outcome measurements

Outcome measures consisted of body mass, body mass index and percent body fat, resting heart rate, systolic and diastolic blood pressure, muscle thickness of the quadriceps femoris, muscle strength of the knee extensors, 30-second chair stand, 3-metre timed up and go, 2-minute step, sit and reach, static balance, questionnaires on daily activities and health-related quality of life, and a trail making test. These measurements were taken at 14 and 7 days before the first training session and 7 days after the last (8th) training session at the community centre by the same investigator. Based on the measures taken at 14 and 7 days before the training session, the test–retest reliability of the measurements was determined.

### Body mass (BM), body mass index (BMI) and percent body fat

Height and BM were measured by a standard method, and BMI was calculated. Body fat was measured using a bioelectrical impedance analyzer (BC-118; Tanita Corporation, Japan).

### Resting heart rate (HR) and systolic (SBP) and diastolic blood pressure (DBP)

HR and SBP and DBP were measured by an automatic sphygmomanometer (HEM-7122; Omron Healthcare Co., Ltd, Japan). Participants sat quietly in a chair for at least 5 min before the measurement.

### Muscle thickness of the quadriceps femoris (MT)

MT of the sum of the rectus femoris and the vastus intermedius was measured by a B-mode ultrasonographic apparatus (SonoSite 180 II Ultra Sound System; SonoSite, Inc, USA). MT was measured at 15 cm above the superior border of the patella of the dominant (kicking) leg (Bemben 2002). Each participant sat in a chair with the knee joint of the dominant leg at 90° of flexion for about 5 min before the measurement, and the ultrasound image was recorded from the site by placing the probe on the skin gently using enough acoustic gel.

### Maximal voluntary isometric contraction (MVC) strength of the knee extensors

MVC strength was measured using a chair equipped with a load cell (T.K.K.5710 m; Takei Scientific Instruments Co., Ltd, Japan) in a seated position with a knee joint angle of 75° flexion (Katsura et al. 2011). Knee extension force of each leg was measured twice with 45 s between trials, and the average of the higher value of each leg was recorded for further analysis.

### 30-second chair stand (CS)

In the CS, each participant sat in the middle of a chair with each hand being placed on the opposite shoulder and two arms being crossed at the chest, and was instructed to stand up and sit down as many times as possible in 30 s (Rikli and Jones 1999). The number of repetitions completed in 30 s was recorded. The measurements were taken twice, and the better value of the two was used for further analysis.

### 3-metre timed up and go (TUG)

In the TUG, the time required for the participant to stand up from a chair, walk a distance of 3 m, walk back to the chair, and sit down was measured by a stop watch (Rikli and Jones 1999). The measurement was taken twice, and the better value of the two was used for further analysis.

### 2-minute step (2MS)

The participant stood straight with their back to a wall with a tape indicating the level midway between the patella and iliac crest, and marched in the place for 2 min, lifting the knees to the height of the tape. The total number of times the knee reached the tape level in 2 min was recorded (Rikli and Jones 1999). The measurement was taken twice, and the better value of the two was used for further analysis.

### Sit-and-reach test (SR)

Using a digital flexibility testing device (T.K.K.5112; Takei Scientific Instruments Co., Ltd, Japan), each participant sat on the floor with legs being held straight out in front and put both hands on the device, with arms being held straight in front of the body to initially set the zero point of the device. Then, the participant was asked to bend their trunk forward slowly and reach as far forward as possible, and the distance from the zero point was recorded (Yamamoto et al. 2009). The measurement was taken twice, and the better value of the two was used for further analysis.

### Static balance ability with eyes open (Bal-EO) and closed (Bal-EC)

To assess balance, the total distance of the centre of pressure movement in millimetres was recorded by a force platform system (T.K.K.5810; Takei Scientific Instruments, Japan) for 60 s, once with eyes open and then again with eyes closed while standing on two legs (Fukusaki et al. 2016). The measurement was taken twice for each condition, and the better value of the two was used for further analysis.

### Activities of daily living (ADL)

The ADL test consists of 14 items such as "maximum walking time without rest", "widest ditch you can step over" and "a method to climb stairs", and a total of 51 points were distributed among the 14 items based on the participant's performance (Katsura et al. 2011).

### Health-related quality of life (QOL)

QOL was assessed with the Short-Form Health Survey version 2 (SF-36v2) which consists of 36 questions categorised to assess either the physical or mental domains of physical functioning, role physical, bodily pain, general health, vitality, social functioning, role emotional and mental health. A norm-based score, ranging from 0 to 100, was calculated within each of the eight subdomains (Underbjerg et al. 2018).

#### Trail making test (TMT)

The TMT is one of the most widely used neuropsychological assessment instruments and is the most common instrument for the assessment of attention (Rabin et al. 2005). The trail making test consists of two parts (A and B). Part A requires an individual to connect randomly located numbers (1–25) in numerical order as quickly as possible, and Part B, which contains both numbers and letters, requires the participant to connect the numbers and letters, alternating between them. The time required to complete the task was measured by a stop watch for each part of the test (Hiyamizu et al. 2011).

### Test–retest reliability of the measurements

The test–retest reliability of some of the measures (MVC, CS and 2MS) was determined by coefficient of variation (CV). The CV for MVC, CS and 2MS was 6.3%, 4.2% and 2.3%, respectively.

### Statistical analyses

Baseline values of each variable were compared between groups by *t* tests. Changes in each variable before and after the 8-week training period were compared between groups by a mixed-design two-way analysis of variance (ANOVA). The normalised changes in the variables from pre- to post-training (% changes) were also compared between the groups by a *t* test. Statistical significance was set at $P \leq 0.05$. The effect size for the difference in the normalised change in each variable between the ECC and CON groups was calculated using Cohen's *d*, and was considered 0.2, 0.5, and 0.8 as a small, medium, and large effect, respectively (Cohen 1988).

## Results

### Baseline values

No significant differences between the ECC and CON groups were evident for any of the variables at the baseline (Tables 1, 2, 3). Regarding MVC strength, no significant difference was found between the right and left legs for both groups; thus, the average of the legs is shown in the table.

### Exercise training

The attendance rate (attended number of sessions) over 8 training sessions at the community centre was 88.0 ± 16.5% (6–8 times) for the ECC group and 75.2 ± 8.4% (6–8 times) for the CON group. The average (range) number of the training at home for the ECC and CON group was 23.7 ± 3.3 (17–29) times and 22.4 ± 4.7 (13–28) times, respectively, without a significant difference between groups. In the ECC group, eight of the nine participants performed eccentric exercise training more than three times a week at home, and the average was 3.4 ± 1.1 times per week. For the CON group, seven out of eight participants performed resistance training more than three times a week at home, and the average was 3.2 ± 1.2 times per week, which was not significantly different from that of the ECC group. The exercise intensity was gradually increased over the 8 sessions at the community centre as indicated by the RPE increasing from the first week (6.5 ± 0.7) to the last week (18.4 ± 0.7). Some participants in both groups experienced minor muscle soreness after the community centre training sessions. The average of peak muscle soreness indicated by the VAS recorded at 1 or 2 days after each session for the 8 sessions was 10.0 ± 3.0 mm for the ECC group and 14.0 ± 4.0 mm for the CON group, without a significant difference between the groups.

### Changes in outcome measurements

#### Physical characteristics, resting HR, SBP, and DBP

No significant changes in BM, BMI and body fat were evident after training when compared with the baseline (Table 1) for both groups. As shown in Table 2, resting HR did not change significantly after the training, but both groups showed a significant ($P < 0.05$) decrease in SBP after training, and DBP decreased significantly ($P = 0.019$) after training only for the ECC group.

#### MT, MVC, physical function tests (CS, TUG, 2MS and SR), and static balance

A significant interaction effect or group effect was found for all measurements except for SR and Bal-EO (MT: $P = 0.027$, MVC: $P = 0.040$, CS: $P = 0.049$, TUG: $P = 0.045$, 2MS: $P = 0.024$ and Bal-EC: $P = 0.041$). Figure 2 shows normalised changes in the variables from pre- to post-training for the participants in the ECC and CON group separately, and compared between the groups. For each variable, a large variability among the participants for their responses was seen. Both groups showed significant ($P < 0.05$) increases in MT after training, but the increase was greater ($P = 0.002$) for the ECC group (21.6 ± 9.2%) than the CON group (6.7 ± 7.1%). Increases in MVC after training were also found for both groups ($P < 0.05$), and the magnitude of increase (average of the two legs) was greater ($P = 0.003$) for the ECC group (38.3 ± 22.6%) than the CON group (8.2 ± 8.4%). When

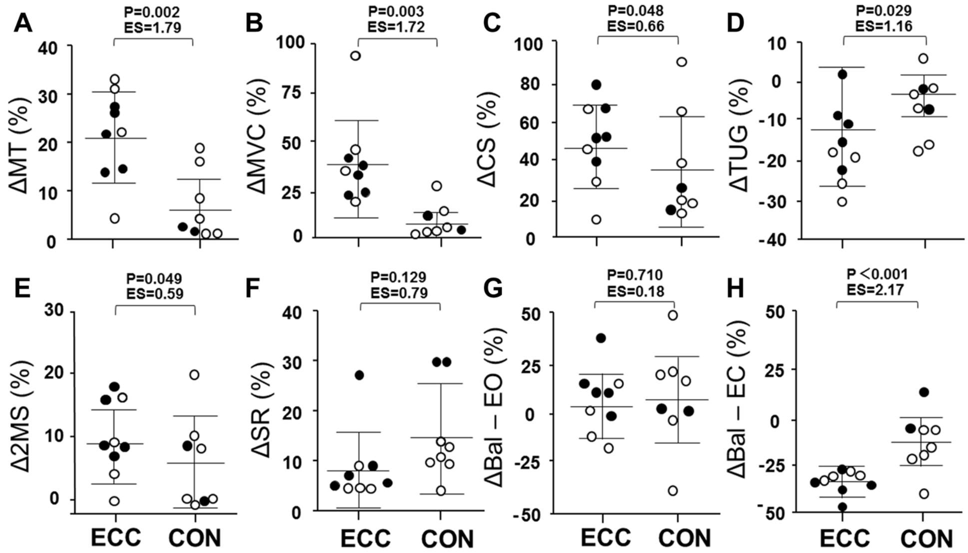


**Fig. 2** Normalised change from baseline to the post-training for muscle thickness of quadriceps femoris (MT, **a**), maximal voluntary isometric contraction strength of the knee extensors (MVC, **b**), 30-second chair stand (CS, **c**), 3-m timed up and go (TUG, **d**), 2-minute step (2MS, **e**), sit and reach (SR, **f**) and static balance ability with eyes open (Bal-EO, **g**) and close (Bal-EC, **h**) for the eccentric resistance exercise training group (ECC group) and concentric resistance exercise training group (CON group). open circle: women, closed circle: men, *a significant ($P<0.05$) difference between groups. Effect size (ES) for the difference between ECC and CON groups is shown under the $P$ value

looking at each leg, the increase was greater ($P=0.004$) for the ECC group (36.6 ± 22.8%) than the CON group (7.3 ± 8.8%) for the right (dominant) leg, and the increase in the left leg was also greater ($P=0.003$) for the ECC group (40.2 ± 22.7%) than the CON group (9.1 ± 10.3%).

Both groups showed significant ($P<0.01$) increases in CS after training, and the increase from baseline was greater ($P=0.048$) for the ECC group (51.0 ± 21.7%) than the CON group (34.6 ± 28.3%). The time to complete the TUG decreased ($P=0.001$) only for the ECC group (− 16.7 ± 9.9%), and the change was greater for the ECC than CON group ($P=0.029$). Both groups showed significant ($P<0.05$) increases in 2MS after training, and the increase was greater ($P=0.049$) for the ECC group (9.9 ± 6.0%) than the CON group (6.0 ± 7.3%). SR was improved after training for the ECC group (8.6 ± 7.2%) and the CON group (15.2 ± 9.6%) similarly ($P=0.129$).

Improvement of balance with eyes closed (Bal-EC) was found only for the ECC group, which showed 35.1 ± 6.7% less movement of the centre of pressure after training compared to the baseline, and this was greater ($P < 0.001$) than that for the CON group. However, no such improvement or difference was shown by the test with eyes open (Bal-EO).

### ADL, QOL, and TMT

As shown in Table 3, ADL showed significant ($P=0.01$) improvements only for the ECC group after training. Regarding QOL, physical functioning, role physical, and general health improved ($P<0.05$) only for the ECC group, but vitality improved for both groups similarly. Neither group showed a significant change in TMT-A and B after training.

## Discussion

The participants in the ECC group showed better improvement in DBP, MT, MVC, CS, TUG, 2MS, and Bal-EC when compared with the participants in the CON group. These results supported the hypothesis that the manual eccentric resistance exercise training would improve muscle strength, physical function and balance greater than the manual concentric resistance exercise training.

As shown in Fig. 2, the inter-individual variability in responses to the training was large. A similar level of individual differences in response to resistance training was reported in previous studies (Kanda et al. 2018; Stadnyk et al. 2017). It should be noted that the test–retest reliability of the measurements was reasonable, and the magnitude of the changes in the variables after training was comparable to that of the previous studies (Chen et al. 2017a, b). With regard to sex differences, no specific differences in the responses to the training were evident. Although the number of male and female participants was not the same between the groups, it does not appear that this affected the findings. No significant differences between groups were evident for any of the dependent variables before the training (Tables 1, 2, 3). The participants in both groups attended the community centre training sessions similarly and the total number of home-based training sessions was not significantly different between groups either. Thus, the difference in the variables between groups at post-training was likely to reflect the difference in the muscle contraction types focused in the training sessions; eccentric versus concentric muscle contractions. It should be noted that both groups showed improvement in many of the outcome measures. These suggest that the training intervention in the present study, which did not require any equipment, was effective for improving fitness and health of older adults. Importantly, it seems that the training focused on eccentric muscle contractions was more effective in comparison to that focused on concentric muscle contractions.

In the present study, BM, BMI and body fat did not change after the training, although Chen et al. (2017a) reported small but significant decreases in these variables after 12 weeks of descending (eccentric) or ascending (concentric) stair walking training. They also reported greater decreases in resting HR and SBP after descending than ascending stair walking. The present study found decreases in SBP in both groups similarly, but a significant decrease in DBP was evident only for the ECC group. However, no significant change in DBP for the CON group was likely due to a larger variability among the participants (Table 2). It is important to note that SBP was decreased by both eccentric and concentric resistance exercises in the present study. It appears that the exercises prescribed in the present study are effective to reduce blood pressure.

It should be noted that all participants showed an increase in MT (the sum of the rectus femoris and vastus intermedius), and some participants in the ECC group showed more than 20% increase (Fig. 2a). Suetta et al. (2008) showed that 12 weeks of progressive resistance training with knee extension and leg press exercises (8–20 RM) performed 3 times a week, increased muscle thickness of vastus lateralis of patients (60–86 years) with hip osteoarthritis by 15%. The present study found a similar magnitude of increase in muscle thickness in a shorter training duration and a lower-intensity resistance training emphasising eccentric contractions.

All participants also showed an increase in MVC, and the magnitude of increase was greater for the ECC than the CON group (Fig. 2b). It is interesting that one participant in the ECC group showed 94% increase in MVC, and the participant performed the largest number of home-based training sessions (29 times) over the 8-week period among all participants. In the resistance exercise programme, the knee extensors were mainly targeted, and the participants were encouraged to perform the leg exercises such as chair squat, push squat, and knee up or down (Fig. 1) at least twice a week at home. Thus, it seems reasonable to assume that the increased MVC reflected the effect of the resistance exercise training. Greater increases in the knee extensor muscle strength after eccentric than concentric resistance training have been also reported in previous studies (Chen et al. 2017a; Suetta et al. 2008). However, it is important to note that the intensity of the resistance exercises performed in the present study was not high, but the magnitude of the increase in the knee extensor strength was comparable to that reported in previous studies in which higher intensity eccentric training was performed (Chen et al. 2017b; Leong et al. 2014). The present study showed that eccentric resistance training using body weight was still effective for increasing in knee extensor strength of older adults. In the present study, the participants performed the resistance exercises at least three times a week at home in both groups. Thus, it may be that frequency of the training is an important factor determining the effects of the resistance exercises performed in the present study on muscle function of older adults.

Other physical functions (CS, TUG, 2MS and SR) showed improvement after the training for both groups, but the magnitude of the improvement was greater for the ECC than the CON group except SR. CS showed the largest change among the variables, but a large variability in the change was observed among the participants (Fig. 2c). It should be noted that the squat exercises were performed in every session in the present study, and the participants were instructed to perform the squat exercises at home. The magnitude of increase in CS by 30–50% after resistance training of older adults was also reported in previous studies (Chen et al. 2017a, b). Although some participants in the CON group also showed a large increase in CS, the ECC group showed significantly greater improvement than the CON group. This was probably due to the greater increase in the knee extensor strength for the ECC than the CON group (Fig. 2b). The magnitude of the change in TUG (Fig. 2d) and 2MS (Fig. 2e) was smaller than that of CS, which was also in line with the findings of Chen et al. (2017a). In average, TUG and 2MS improved by approximately 10% for the ECC group, but 5% for the CON group. These suggest that the resistance exercise programme was effective for improving agility and endurance, but the eccentric protocol was more effective. It is also important to note that both eccentric and concentric resistance exercise training improved SR (Fig. 2f). Barbosa et al. (2002) reported a similar increase in SR after 10-week whole body resistance training using a machine with free weights on flexibility in older adults. It is interesting that the resistance training was effective for improving flexibility.

Balance ability is important for prevention of falling in elderly individuals (Park 2018). Although different measures were used in different studies, improvement in balance after resistance exercise training of older adults has been reported previously (Ema et al. 2017; LaStayo et al. 2003). In the present study, no changes in the balance test with eyes open were found (Fig. 2g), but the balance test with eyes closed showed improvement in balance after the training, especially for the ECC group (Fig. 2h). Chen et al. (2017a) reported increases in balance ability assessed by an index quantifying sways over 30 s with both eyes open and closed conditions on firm or unstable surface after descending stair waling. It has been reported that the variance of body sway of eyes closed is larger than that of eyes open (Ledin et al. 2004), which was also observed in the present study (Table 1). It is not known why only the balance with eyes closed showed an improvement in the present study. However, it is possible that the calf muscle training especially with the eccentric contractions improved proprioception, which might contribute to the balance with eyes closed. Further study is required for investigating the effect of eccentric versus concentric resistance training on proprioception.

Regarding ADL, a significant improvement was found for the ECC group only, but the post-training score was similar between the groups (Table 3). Thus, the significant improvement in the ECC group was likely due to the lower pre-training score. Improvement of QOL was found after the training, but physical functioning, role physical, and general health were improved better for the ECC than CON group. This may be associated with the greater improvement of muscle and physical function for the ECC than CON group as discussed above.

Previous studies reported that the 12- to18-week resistance training and strength–balance–cognitive training improved the time of TMT in older adults (Tanne et al. 2005; van het Reve and de Bruin 2014). However, the present study did not observe any improvement of TMT. This may be due to the shorter intervention period (8 weeks) in the present study than that of the previous studies. It is interesting to extend the duration of the training period to see if any changes can be observed.

In conclusion, the resistance exercise programme focusing on eccentric contractions was more effective than that focusing on concentric contractions for improving muscle and physical function in addition to the thickness of quadriceps femoris muscle. These results show that muscle and physical function can be improved better by basic manual resistance exercise training with emphasising eccentric muscle contractions. To minimise the increase in the number of frail or disabled elderly individuals who are expected to increase more globally, advocating the efficacy of eccentric resistance exercises is important. It should be noted that implementing simple eccentric resistance exercises (sitting to a chair slowly) in daily activities may contribute to extend the health span.

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**Author contributions** YK and KN conceived and designed this research project; YK instructed the exercise sessions and took the measurements with HT, NT and ST, KN provided advice on the research process; YK analysed the data, all contributed to the discussion of the data; and YK and KN drafted the manuscript. All authors read and approved the final version of manuscript.

## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

**Ethical approval** All procedures performed in this study were in accordance with the ethical standards of the University Institutional Review Boards for Human Subjects and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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