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**ABSTRACT**

**Introduction:** We compared the effects of eccentrically-biased (EB) and conventional (CONV) resistance training on: muscle architecture, 1 repetition maximum (1RM), isometric strength, isokinetic force-velocity characteristics, functional capacity and pulse wave velocity (PWV) in older men and women.

**Methods:** Twenty-eight older adults participated in the study (mean±S.D; age 68±5 years). Of these, 13 were allocated to a wait-list control, 10 of whom progressed to training (CONV n=12; EB n=13). Training was twice a week for 16 weeks. EB involved three sets of 10 concentric lifts at 50% of 1RM with the eccentric portion of repetitions performed unilaterally, alternating between limbs with each repetition. CONV involved two sets of 10 repetitions at 75% of 1RM. EB and CONV were matched for total work. Isokinetic knee extensor strength was assessed across a range of velocities (0-360°s\(^{-1}\)). Functional capacity was assessed via 6 metre fast walk (6MFWT), timed up and go (TUG), stair climb and descent power and vertical jump tests. Vastus lateralis and gastrocnemius medialis architecture were assessed using ultrasonography.

**Results:** Both EB and CONV improved 1RM (Δ23-35%, P<0.01). Compared to the control group, both training regimens improved 6MFWT (Δ5-7%, P<0.01) and concentric torque at 60°s\(^{-1}\) and 120°s\(^{-1}\) (Δ6-8%, P<0.05). Significant improvements were evident in EB for: isometric and concentric torque at 240°s\(^{-1}\) and 360°s\(^{-1}\) (Δ6-11%, P<0.05), vastus lateralis thickness (Δ5%, P<0.05) and stair climb (Δ5%, P<0.01). TUG (Δ5%, P<0.01), stair descent (Δ4%, P<0.05) and
vertical jump (Δ7%, \(P<0.01\)) improved in CONV. PWV, pennation angle and fascicle length remained unchanged in both training groups.

**Conclusion:** EB appears superior to CONV at increasing torque at high contraction velocities while CONV appears more effective at improving some functional performance measures and vertical jump. This has important implications for preserving functional capacity.

**Key Words:** Elderly; Exercise; Strength; Function.
INTRODUCTION

Paragraph Number 1 Muscular strength and power declines with age, the proposed major reasons for this being changes to the neuromuscular system and muscle architecture, and skeletal muscle atrophy. The decline in power rather than the concurrent loss of strength per se, appears to have the most profound impact on functional capacity in older adults as it is associated with a slowing of walking speeds and increased risk of falling. As a means of combating these declines, training interventions using conventional high intensity resistance training, which involves both concentric and eccentric muscle actions performed against a constant external load, have been utilised and demonstrated to have significant positive effects on several aspects of performance and health. However, while typically very effective at increasing muscle mass and strength, this traditional mode of resistance training appears to be less effective at increasing muscle power generation during high-speed contractions, which are critical for the older adult. Therefore, the effectiveness of alternative strength and power training regimens require investigation.

Paragraph Number 2 One of these alternative modalities is eccentric resistance training, which has been reported to increase muscle fascicle lengths in elderly resistance trainers. This adaptation should also favourably alter the muscle’s force-velocity characteristics by increasing the maximum torque and power generation at higher contraction speeds. Additionally, there is evidence that eccentric resistance training provides a more effective stimulus for muscle growth than concentric training. So, given these proposed advantages, eccentric resistance training may be of particular value to older adults with regards to increasing walking speed, lowering the risk of falling and improving functional capacity.
Paragraph Number 3 Another aspect favouring eccentric resistance training is that it allows participants to perform the same amount of work at a lower rating of perceived exertion than traditional concentric training, a factor that may make it more attractive to those who have been sedentary for many years. From a cardiovascular perspective, there is reason to believe that eccentric training may have more favourable effects on arterial stiffness, at least in young people, than concentric training: thereby providing further advantages for its utilisation in a population group already prone to cardiovascular disease. The favourable effect of eccentric contractions may be mediated by lesser blood pressure responses than are seen in the concentric phase of conventional lifting. So underloading the concentric phase of resistance training, as occurs in many reported studies, may therefore have beneficial effects on cardiac afterload.

Paragraph Number 4 The eccentric resistance training typically employed in human studies involves loads being raised by research assistants or machines and then lowered (eccentrically) by the participants. Whilst this form of training can be undertaken in research contexts, it is impractical in fitness centres where the general population typically exercise. Therefore a more practical way of obtaining overload during the eccentric portion of exercises needs to be utilised. One of these is ‘eccentrically-biased’ resistance training, during which the loads are lifted (concentrically) with two limbs and then lowered (eccentrically) with one. This form of training is therefore eccentrically-biased, as it involves a relatively underloaded concentric phase and an overloaded eccentric phase. An example would involve lifting ~50% of the bilateral one repetition maximum (1RM) and then lowering it unilaterally, which in doing so would equate to ~100% of the unilateral 1RM. To date, however, there are no studies comparing the effectiveness of eccentrically-biased training to conventional resistance training in older adults.
Paragraph Number 5 We hypothesized that eccentrically-biased resistance training (EB) would lead to a greater increase in fascicle length and muscle thickness of the knee extensors and plantar flexors while also increasing concentric knee extensor strength of older adults at fast contraction speeds to a greater extent than conventional resistance training (CONV). We also sought to compare the effects of EB and CONV on functional capacity and pulse wave velocity (PWV).

METHODS

Participants

Paragraph Number 6 Twenty-eight community-dwelling older adults (17 males and 11 females) participated in this study. Of these, seven males and six females were assigned to the wait-list control group (mean ± S.D. age, 67 ± 5 years; body mass, 78.7 ± 13.7 kg; height, 167.0 ± 8.6 cm), 10 of whom progressed to one of the two training groups. Seven males and five females performed CONV (age, 68 ± 5 years; body mass, 77.8 ± 15.5 kg; height, 168.3 ± 11.6 cm), and eight males and five females performed EB (age, 68 ± 5 years; body mass, 77.4 ± 13.4 kg; height, 167.8 ± 8.8 cm). Participants were excluded from the study if they had relevant cardiovascular or orthopaedic problems or if they had undertaken any resistance training in the preceding six months. Written informed consent was obtained from all participants before entry into the study, which was approved by the local Human Research Ethics Committee.

Study Design

Paragraph Number 7 A randomised controlled design was used for this study. To reduce any potential bias of sex and age, participants were stratified according to age (60 to 70
and 71 to 80 years old) and gender before being randomly assigned to CONV, EB or a wait-list control group. Participants randomised to EB and CONV underwent pre-training testing of isometric and isokinetic knee extensor strength, quadriceps and medial gastrocnemius muscle architecture, arterial stiffness and functional capacity. Prior to baseline testing participants attended the laboratory on two occasions to be familiarised with the isometric and isokinetic strength and functional capacity tests. The familiarisation sessions and test session were separated by seven to 14 days. Participants then commenced the 16-week resistance training program, after which they underwent post-training testing. Participants randomised to the wait-list control group underwent pre-control testing and were then instructed to maintain their regular level of physical activity and avoid heavy resistance training for 16 weeks before post-control testing. They were then randomised to either EB or CONV and performed 16 weeks of resistance training before post-training testing.

**Resistance Training**

**Paragraph Number 8** EB and CONV participants performed resistance training twice weekly on non-consecutive days for 16 weeks. Both programs consisted of the 45° leg press, toe press, bench press and latissimus dorsi pulldown exercises. For the toe press, participants sat on the leg press machine with knees fully extended and with the balls of their feet on the bottom edge of the foot-plate, lifted and lowered the resistance with the plantar flexors. Bench press was performed using a Smith machine and lat-pulldowns were performed on a pin-loaded machine with a ‘V-bar’ handgrip, comprising of two parallel handles approximately 9 cm apart.

**Paragraph Number 9** At the first training session, participants were familiarised with each exercise and were instructed on proper technique. Participants then performed a 1RM test
for each exercise. After each successful lift, participants were given at least one minute to recover before the next attempt. No more than five lifts were needed to determine 1RM. 1RM tests were repeated two weeks later, then every three weeks subsequently and training weights were adjusted accordingly. When 1RM tests were performed, one less set than usual of each exercise was performed.

**Paragraph Number 10** CONV participants performed two sets of each exercise, with three minute rests between sets. Each set involved 10 completely bilateral repetitions at 75% of the 1RM. For EB, participants performed three sets of each exercise, with three minute rests between sets. Each set involved 10 concentric lifts performed bilaterally with 50% of the 1RM. Participants then lowered the weight unilaterally, alternating between left and right limbs with each repetition, thus performing five unilateral eccentric contractions per limb per set. The difference in the number of sets employed by CONV and EB in the current study was necessary to match the volume of work performed by each training group. The training protocols were designed to ensure that participants in EB and CONV performed the same amount of work for each limb relative to individual 1RMs (see Table 1). Actual total concentric work for each limb was calculated by multiplying the actual relative intensity (% of 1RM) by the number of repetitions performed in each set, then summing concentric work performed in each set over the whole training period. Actual total work (concentric and eccentric) for each limb was calculated by multiplying actual concentric work by 2.

**Rating of Perceived Exertion**

**Paragraph Number 11** Borg’s Rating of Perceived Exertion (RPE) Scale with values from 6 – 20 was used to obtain RPE after each set of exercise throughout the 16 weeks. Mean
RPE for each exercise for each participant was then calculated. Mean RPE for each exercise in weeks 4, 8, 12 and 16 of training was also calculated.

**Pulse Wave Velocity**

**Paragraph Number 12** Arterial stiffness was quantified from the pulse wave velocity (PWV) prior to strength and functional capacity tests. Reliability analyses on the data from the control group revealed an ICC (95% CI) of 0.835 (0.427 – 0.953) and 95% ratio LOA (limits of agreement) of 23.29%. Participants lay supine for 20 minutes before digital pulse detectors were strapped to their right index finger and right second toe. A three-lead electrocardiogram was obtained concurrently to use as a reference point for each pulse. Data were collected for 15 minutes and sampled at 1000Hz. The difference between the distances from the sternal notch to the index finger and the sternal notch to the second toe was taken as the distance travelled by the pulse wave. Five pulse waves, separated by 3 minutes, were selected for analysis. The mean time taken for the five separate pulse waves to travel from the finger to the toe was used to calculate PWV. Timing was made from the ‘foot’ of the waveforms. All PWV data were analysed by a single investigator.

**Muscle Architecture**

**Paragraph Number 13** Real-time B-mode ultrasonography (LOGIQ I, GE Healthcare, Wauwatosa, Wisconsin, USA) with a 42 mm long, 10 MHz linear-array transducer, was used to measure fascicle pennation angle, fascicle length and muscle thickness of the vastus lateralis (VL) and medial gastrocnemius (GM) muscles on a single randomly chosen limb. The reliability of the following protocol for measuring VL and GM architecture has been previously
demonstrated by our laboratory. A single investigator acquired the images from all participants. A second investigator, who was blinded to the identity of the participants, was then employed to analyse the images.

**Paragraph Number 14** Ultrasound images were obtained from sites 62.5% along the length between the anterior superior iliac spine and the superior aspect of the patella in the mid-sagittal (VL site 1) and mid-coronal (VL site 2) planes of the thigh. Participants were seated on the edge of the bench with knee angles fixed at 90°, a position associated with minimal fascicle curvature.

**Paragraph Number 15** Medial gastrocnemius architecture and thickness were measured 30% of the distance between the lateral malleolus of the fibula and the lateral condyle of the tibia while participants lay prone on the bench with their feet hanging off the edge in a modified night splint that fixed the ankle at 15° of dorsiflexion. Consistent positioning of the ultrasound transducer before and after training was obtained by use of a transparent plastic sheet onto which the examination sites and any permanent skin blemishes were marked. Three ultrasound images from each site were recorded digitally and analysed using freely available software (ImageJ 1.38x, National Institutes of Health, USA).

**Paragraph Number 16** Quadriceps thickness was defined as the distance between the superficial aponeurosis and the femur, and medial gastrocnemius muscle thickness was defined as the distance between the superficial and deep aponeuroses. Pennation angle was determined between the muscle fascicles and the deep aponeurosis, and fascicle length was measured between its insertions on the superficial and deep aponeuroses. Where the fascicles extended beyond the recorded image, their length was estimated from muscle thickness and fascicle pennation angle using the equation:
$L_f = T \times \sin\theta^{-1}$

where $L_f$ is fascicle length, $T$ is muscle thickness and $\theta$ is pennation angle.

**Isokinetic and Isometric Testing**

**Paragraph Number 17** Isokinetic and isometric knee extensor strength of a randomly chosen limb was determined on a Biodex System 4 Quick Set dynamometer (Biodex Medical Systems, Shirley, New York, USA). Reliability analyses on 23 healthy community-dwelling older adults (13 men and 10 women, average age 67.2 ± 5.6 years), 13 of whom participated in the current study, revealed that the ICCs (95% CI) for the dynamometer strength tests were: Isometric = 0.991 (0.978 – 0.996); 60°s$^{-1}$ = 0.976 (0.943 – 0.990); 120°s$^{-1}$ = 0.982 (0.958 – 0.992); 240°s$^{-1}$ = 0.984 (0.962 – 0.993); 360°s$^{-1}$ = 0.984 (0.960 – 0.993). 95% ratio LOAs for the isometric, 60°s$^{-1}$, 120°s$^{-1}$, 240°s$^{-1}$ and 360°s$^{-1}$ dynamometer tests were 9.87, 20.28, 20.92, 18.21 and 14.91% respectively (previously unpublished data).

**Paragraph Number 18** Participants sat upright in the dynamometer secured by waist and torso straps. The dynamometer’s axis of rotation was visually aligned with the lateral epicondyle of the femur. The dynamometer’s ankle pad was positioned above the medial malleolus. The position of the seat base, seat back and length of lever arm were recorded at the first familiarisation session and replicated for the subsequent familiarisation and testing sessions. Participants were instructed to hold onto handles positioned on either side of the seat during contractions.

**Paragraph Number 19** A standard warm-up of the quadriceps, involving two sets of six concentric efforts at 30°s$^{-1}$ was carried out before each session. Participants rested one minute between the warm-up and the commencement of the test. The test consisted of maximal
concentric contractions at 60, 120, 240 and 360º s\(^{-1}\), and isometric contractions \((0º s^{-1})\). One of five different test sequences, each with a different order of contraction speeds, was randomly assigned to participants at the first familiarisation session and used for all subsequent sessions. Isokinetic contractions were performed between knee joint angles of 105º to 5º, with 0º representing full extension. Isometric contractions were performed at a knee joint angle of 60º. Participants performed five contractions at each speed with 30 seconds rest between each contraction and one minute rest between speeds. Participants were given loud verbal encouragement, and visual feedback of the torque signal in each repetition.

**Paragraph Number 20** Torque, corrected for limb weight, was sampled at a frequency of 1000Hz (PowerLab 4/25; AD Instruments, Bella Vista, New South Wales, Australia) and stored on computer. Only torques from the isokinetic portion of each dynamic contraction were analysed on a computer software program (Chart 5; ADInstruments, Bella Vista, New South Wales, Australia). The torque data from the five contractions performed at each velocity were averaged and used for statistical analysis.

**Functional and Vertical Jump Tests**

**Paragraph Number 21** Five functional tests were undertaken. They were: the 6 metre fast walk test (6MFWT), the Timed Up and Go test (TUG), stair climb and stair descent power tests, and the vertical jump test. Reliability analyses on 23 healthy community-dwelling older adults (13 men and 10 women, average age 67.2 ± 5.6 years), 13 of whom participated in the current study, revealed that the ICCs (95% CI) were: 6MFWT = 0.952 (0.886 – 0.980); TUG = 0.979 (0.951 – 0.991); Stair climb = 0.997 (0.992 – 0.999); stair descent = 0.989 (0.974 – 0.995); vertical jump = 0.988 (0.971 – 0.995). 95% ratio LOAs for the 6MFWT, TUG, stair climb, stair
descent and vertical jump tests were 14.32, 10.36, 7.28, 13.72, and 13.53% respectively (previously unpublished data).

**Paragraph Number 22** The 6 metre fast walk test, performed between two sets of light gates, involved the timing of participants as they walked as quickly as possible.

**Paragraph Number 23** The Timed Up and Go test measures the time taken for an individual to rise from a chair, walk 3 metres to touch a marker on a wall, turn 180 degrees, return to the chair, and sit down. Time was recorded by stopwatch. Participants were instructed not to use their hands when rising from or sitting back down on the chair.

**Paragraph Number 24** The stair climb and descent power tests involved participants climbing and descending a flight of stairs as quickly as possible. Stair climb and descent time were assessed separately using a stopwatch. The flight of stairs utilised in this study comprised of 16 steps, each with a height of 15cm. The participants were not allowed to hold the handrails during this test. Stair climb and descent power were calculated using the following equation:

\[
Power(W) = \frac{m \times g \times d}{t}
\]

Where \( m \) is the mass (kg) of the participant, \( g \) is acceleration (m·s\(^{-2}\)) due to gravity, \( d \) is vertical displacement (m) and \( t \) is stair climb or descent time (s).

**Paragraph Number 25** The vertical jump test was performed on a force plate (Kistler Type 9286AA, Kistler Instruments, Winterthur, Switzerland). Participants were instructed to stand on the force plate with both feet shoulder width apart, perform a counter-movement by bending the knees, then jump as high as possible. Arm swing was allowed during performance of the jump. Vertical jump height and peak jumping power were estimated from vertical take-off velocity derived from impulse data by means of data analysis software (BioWare 3, Kistler Instruments, Winterthur, Switzerland). Methods for signal sampling are described elsewhere.
Paragraph Number 26 Participants performed each functional and vertical jump test three times during familiarisation and test sessions. The average of the three results from each test was used for statistical analysis. All functional capacity and vertical jump tests were supervised by the same investigator.

Statistical Analyses

Paragraph Number 27 Normality of the data were determined using the Kolmogorov-Smirnov test, and non-normal data were natural log-transformed. One-way ANOVAs were used to evaluate whether there were any differences between groups for any of the variables at baseline. Repeated measures ANOVAs were used to evaluate differences in RPE for each exercise between weeks 4, 8, 12 and 16. Two-way (group * time) analyses of variance (ANOVA) were used to evaluate any effect of the exercise interventions on arterial stiffness, muscle architecture, isometric and isokinetic strength, angle of peak torque, functional capacity and 1RM. Two-way (group * velocity) analyses of variance (ANOVA) were also used to evaluate if the exercise interventions differed in their efficacy at differing isokinetic speeds. Post-hoc tests with a Bonferroni correction were used to further analyse significant main interactions. Two-tailed unpaired t-tests were used to evaluate whether there were any differences in RPE and work performed between training groups. Data are presented as mean ± standard deviation (SD). Results were considered significant at \( P < 0.05 \), and statistical analyses were performed using IBM SPSS Statistics 19.0 (IBM, Somers, NY). A priori power analysis based on the most conservative effect size of 0.34 with regards to dynamometer tests of strength (torque data at 60°s⁻¹) revealed that 13 participants were needed per group to obtain statistical power of 0.95.
RESULTS

Paragraph Number 28 Three participants assigned to the wait-list control group decided not to participate in the resistance training intervention. The other 10 participants from the wait-list control group were randomly assigned to either EB or CONV after the control period. There were no significant differences between the three groups with regards to any variables at baseline.

Resistance Training Data

Paragraph Number 29 Estimates of total work performed by each limb for leg press, toe press, bench press and latissimus dorsi pulldowns were not significantly different between EB and CONV (see Table 2). EB and CONV participants completed 95.9% and 95.8% of the total planned training sessions, respectively. Changes in 1RM as a result of training are summarised in Table 3. Significant time effects were observed for changes in 1RM for all exercises ($P < 0.01$). Post-hoc tests revealed significant differences ($P < 0.01$) between pre- and post-training 1RM for all exercises in both exercise groups. There were no significant group by time effects for 1RM between EB and CONV for any exercise, indicating that there was no significant difference between training modalities with regards to changes in 1RM.

Rating of Perceived Exertion

Paragraph Number 30 Mean RPE for each set tended to be higher in CONV than EB for all exercises. This difference was non-significant for leg press ($12.8 \pm 1.6$ versus $12.5 \pm 1.4$ respectively; $P = 0.59$) and toe press ($13.3 \pm 1.8$ versus $12.2 \pm 1.4$; $P = 0.11$), but significant for bench press ($14.8 \pm 2.0$ versus $13.3 \pm 1.4$; $P < 0.05$) and latissimus dorsi pulldowns ($15.1 \pm 2.2$
versus 12.8 ± 1.2; \( P < 0.01 \). RPE did not change significantly between weeks 4, 8, 12 and 16 in CONV for all exercises \( (P > 0.05) \). RPE did not change significantly between weeks 4, 8, 12 and 16 in EB for leg press, bench press and latissimus dorsi pulldowns. A significant time effect was observed for toe press in EB \( (P < 0.05) \). Post-hoc tests revealed that RPE was significantly lower in week 16 than week 4 for toe press in EB \( (11.8 ± 1.5 \text{ in week 16 versus } 12.6 ± 1.9 \text{ in week 4}) \).

**Pulse Wave Velocity**

*Paragraph Number 31* Pulse wave velocity data for the three groups are summarised in Table 4. The three groups did not differ significantly at baseline. No significant time \( (P = 0.38) \) or group by time \( (P = 0.30) \) effects were observed.

**Muscle Architecture**

*Paragraph Number 32* Muscle architecture data for all three groups are summarised in Table 5. The three groups did not differ significantly in any architecture measurements at baseline. A significant group by time effect was observed for VL site 1 thickness \( (P < 0.01) \). Post-hoc tests revealed that VL site 1 thickness increased significantly by 5% in EB \( (P < 0.05) \), while thickness did not change significantly in CONV \( (P = 0.41) \) and decreased significantly by 6% in the control group \( (P < 0.05) \). No significant main effects were observed for other muscle architecture measures in either muscle.

**Knee Extensor Torque-Velocity Relationship**

*Paragraph Number 33* The knee extensor torque data are presented in Table 6. Change in \( (\Delta) \) torque at each velocity in each group is illustrated in the Supplemental Digital Content.
(see Figure, SDC 1, Change in torque for knee extensors for conventional training [CONV], eccentrically-biased training [EB] and the control group. Values are means and SD. Asterisks indicate significant difference between pre- and post-training or post-control [*P < 0.05; **P < 0.01]).

. The main group effect for the mean change in torque (post – pre, for all velocities combined) showed a trend between the groups with (mean) Control = 1.6 Nm, CONV = 5.2 Nm, and EB = 7.6 Nm. The difference between these means bordered on being statistically significant between the control group and EB (P = 0.13).

**Paragraph Number 34** The main effect for the amount of change in torque (post – pre, Δ torque) differed between velocities. Essentially the 5 velocities formed 2 clusters. The three slower velocities (0, 60 and 120° s⁻¹) displayed a greater change in torque (mean of all 3 groups) than the two faster velocities (240 and 360° s⁻¹). The amount of change (Δ torque) was: 5.9, 6.3 and 6.3 Nm for the three slower velocities and 2.8 and 2.3 Nm for the two faster velocities. These differences were statistically significant (P < 0.05) between 120° s⁻¹ and the two faster velocities (240 and 360° s⁻¹). For the two other slower velocities (0 and 60° s⁻¹) the difference with the two faster velocities (240 and 360° s⁻¹) displayed the same trend (see means) but did not reach statistical significance.

**Paragraph Number 35** Further analyses revealed that the differences in the change in torque (i.e. the 3 slower velocities displaying greater overall increases in torque than the two faster velocities) were largely attributable to the differences in delta torque displayed at different velocities in CONV, where the differences between velocities within the group were statistically significant (P < 0.05). This was due to CONV producing relatively large changes at the three slowest velocities, but little or no improvement at the two fastest velocities. Conversely in EB
the $\Delta$ torque at different velocities did not differ statistically as they all displayed an improvement of similar and relatively large magnitude, and in the control group the $\Delta$ torque at different velocities again did not differ statistically, as the changes were also consistent but of small magnitude or non-existent across all velocities.

**Paragraph Number 36** Further analysis of the difference between groups, revealed a group by velocity interaction with the change in torque being statistically significant ($P < 0.05$) at $360^\circ \text{s}^{-1}$, with EB producing a greater change in torque at this fastest velocity than either CONV or control.

**Paragraph Number 37** With regards to the two-way (group * time) ANOVA performed using the absolute torque values, significant time effects were detected for torque during isometric contractions and all concentric contraction speeds ($P \leq 0.01$). A significant group by time effect was also detected for torque during concentric contractions at $360^\circ \text{s}^{-1}$ ($P < 0.05$). Post hoc tests revealed that for isometric contractions, torque increased significantly in ECC by 7% ($P < 0.01$). For contractions at $60^\circ \text{s}^{-1}$, torque increased significantly in both ECC and CONV by 6% and 7% respectively ($P < 0.05$). For contractions at $120^\circ \text{s}^{-1}$, torque increased significantly in both ECC and CONV by 7% and 8% respectively ($P < 0.01$). For contractions at $240^\circ \text{s}^{-1}$ and $360^\circ \text{s}^{-1}$, torque increased significantly only in ECC by 5% ($P < 0.05$) and 11% ($P < 0.01$) respectively.

**Paragraph Number 38** A significant group by time effect ($P < 0.05$) was detected for angle of peak torque during contractions at $240^\circ \text{s}^{-1}$. Post-hoc tests revealed that the angle of peak torque during contractions at $240^\circ \text{s}^{-1}$ decreased significantly ($\Delta 5\%, P < 0.05$) in the control group but did not change significantly in CONV ($P = 0.36$) or EB ($P = 0.225$). No significant main effects ($P > 0.05$) were observed for angle of peak torque at all other contraction speeds.
Functional and Vertical Jump Tests

Paragraph Number 39 Functional and vertical jump tests data are summarised in Table 4. Significant time ($P < 0.05$) and group by time ($P < 0.01$) effects were detected for the 6MFWT. Post-hoc tests revealed that 6MFWT time decreased significantly ($P < 0.01$) in both EB and CONV but increased significantly in the control group ($P < 0.05$). A significant time effect was detected for the TUG ($P < 0.01$). Post-hoc tests revealed that TUG time decreased significantly in CONV ($P < 0.01$) and approached significance in EB ($P = 0.08$). There was no significant change in the control group ($P = 0.25$). When data were pooled across experimental groups, a significant improvement in TUG performance (4.54s pre versus 4.41s post; $P < 0.01$) was observed from pre- to post-condition. A significant time effect was detected for the stair climb power test ($P < 0.01$). Post-hoc tests revealed that stair climb power increased significantly only in EB ($P < 0.01$) with no significant change in CONV ($P = 0.10$) or the control group ($P = 0.53$). When data were pooled across experimental groups, a significant improvement in stair climb power (417 W pre versus 430 W post; $P < 0.01$) was observed from pre- to post-condition. A significant time effect was detected for the stair descent power test ($P < 0.05$). Stair descent power increased significantly in CONV ($P < 0.05$) and approached significance in EB ($P = 0.06$). There was no significant change in the control group ($P = 0.96$). When data was pooled across experimental groups, a significant improvement in stair descent power (373 W pre versus 382 W post; $P < 0.05$) was observed from pre- to post-condition. A significant group by time effect was detected for the vertical jump height ($P < 0.05$). Post-hoc tests revealed that vertical jump height increased significantly in CONV ($P < 0.01$) but did not change significantly in EB.
(P = 0.33) or the control group (P = 0.22). No significant time (P = 0.83) or group by time (P = 0.525) effects were detected for peak jumping power.

**DISCUSSION**

**Paragraph Number 40** This is the first study to compare eccentrically-biased resistance training, a more practically applicable training modality than eccentric-only resistance training, and conventional training in older adults. The main findings are: (i) EB and CONV lead to similar increases in 1RM strength; (ii) EB leads to increases in strength across a range of isokinetic contraction velocities while CONV leads to strength gains only at slower contraction velocities; (iii) EB and CONV induce similar improvements to the performance of a number of functional capacity assessments but CONV was more effective than EB for increasing vertical jump height; (iv) EB and CONV seem to have no significant impact on arterial stiffness; (v) EB may be more effective than CONV at increasing muscle mass; (vi) RPE is similar to or lower in EB than in CONV training.

**Paragraph Number 41** The changes to the torque-velocity relationship of the knee extensors after training confirm our hypothesis that EB would be more effective than CONV at increasing torque production during faster concentric contractions. The observed increase in torque production at isometric and slower concentric contractions (0, 60 and 120° s\(^{-1}\)) but not at the faster velocities (240 and 360° s\(^{-1}\)) in CONV is expected as the relatively heavy weights demanded that concentric contractions in all exercises, and specifically, the leg press, were performed at relatively slow speeds. This finding is consistent with the concept of velocity-specificity in resistance training. The significant increase in torque at fast concentric contractions (240 and 360° s\(^{-1}\)) is encouraging for its application to training programs for older
adults. This increased torque at fast contraction speeds may be an advantage when rapid
movements of the limbs are necessary, such as recovering from a stumble or trip. The increase
in torque across all concentric contraction velocities and during isometric contractions after EB
is intriguing as it does not conform to the concept of velocity-specificity. The previously
reported elongation of muscle fascicles after eccentric-only resistance training would
conceivably increase muscle force and power output at relatively high shortening velocities
although we did not observe increases in fascicle lengths. It is therefore difficult to pinpoint a
reason for the positive effects of eccentric resistance training on high velocity concentric strength
in EB. However, the increase in vastus lateralis thickness in EB may partly explain this
observation. One issue arising from the EB training modality is that of the bilateral strength
deficit. The influence of the bilateral strength deficit would mean that participants in the EB
group possibly performed slightly less work overall during the training program in the eccentric
phase, which was performed unilaterally, than those in the CONV group. This is because the
1RM tests were performed bilaterally, meaning that the unilateral 1RM may have been slightly
underestimated, especially at the start of the training program. Also, the bilateral strength deficit
is reduced with training and it may have declined less in the EB group, who performed the
bilateral concentric phase of exercises at 50% of 1RM compared to 75% of 1RM in the CONV
group. This could have potentially biased the bilateral tests towards the CONV group and the
unilateral tests towards the EB group. However, both groups performed bilateral concentric
phases so the effects of the training should not have differed too drastically between groups. To
illustrate this, torque still increased at all contraction speeds in EB while only increasing at slow
contraction speeds in CONV. In addition, 1RM strength, which was performed bilaterally,
increased to a similar degree in both EB and CONV groups.
Although more functional capacity measures improved significantly in CONV than EB, performance improvements in the TUG and stair descent power test in EB approached significance ($P = 0.08$ and $P = 0.06$ respectively) thereby suggesting that the two training modalities might be similarly effective at improving functional performance. It was surprising to observe a significant decline in 6MFWT performance in the control group after only 16 weeks in this healthy community-dwelling older adult population. However, similar declines in function have been observed in the control groups of other studies so this finding is not a unique anomaly and may be indicative of real functional declines. Another interesting observation was that the increase in knee extensor strength across all contraction velocities in EB did not translate into better performance in the vertical jump test than CONV. However, it should be noted that older adults perform vertical jumps with relatively low joint angle velocities and conventional resistance training has been shown to have a positive effect on vertical jump performance in older men. Also, participants in CONV lifted heavier loads in the concentric phase, which were possibly more specific to body mass, than those in EB, and vertical jump is a movement with a bilateral stretch shorten cycle which finishes with a concentric effort rather more similar to the CONV training than the EB. This may suggest that velocity and contraction mode specificity are important for this task. Nevertheless, it could be argued that the superior improvements in vertical jump performance, which is a bilateral method of assessing power, in CONV is more functionally significant than the increases in unilateral, isokinetic strength seen in the EB group.

The lack of familiarisation prior to 1RM testing is a limitation of the current study and may have over-estimated 1RM gains as a result of training. However, the percentage increase in leg press 1RM (23% for CONV and EB), for example, is similar to the
increase (23%) in leg press 5RM observed by Reeves, Maganaris, Longo and Narici after 14 weeks of conventional training in 9 older adults (average age 67 ± 2 years) with 2 weeks of familiarisation prior to 1RM testing. Also, the similar increases in 1RM strength in both training groups indicate that both modalities are equally effective at increasing maximal strength, and the improvements in isokinetic and isometric strength, and functional capacity measures in both groups independently illustrate the effectiveness of the CONV and EB training protocols employed in this study.

**Paragraph Number 44** Medial gastrocnemius (GM) and vastus lateralis (VL) muscle fascicle length and pennation angle did not change significantly in either training group. This is in contrast to the observations of Reeves et al., who reported increases in VL fascicle length and pennation angle following 14 weeks of either eccentric-only or conventional resistance training performed 3 times a week by older adults. However, there were significant decreases in GM pennation angle and VL thickness at site 1, and non-significant decreases in GM fascicle length, VL pennation angle and VL fascicle length in the control group in the current study. While the degree of deterioration in muscle architecture measures in the control group is surprising, the fact that the reliability of these muscle architecture measures has been recently demonstrated makes this observation difficult to explain. Also, the lack of change in angle of peak torque in the training groups supports our finding of a lack of change in fascicle lengths in CONV and EB. These observations may suggest that both training modalities had a protective effect against the potentially detrimental age-related changes in GM and VL muscle architecture, and that the increases in torque at fast contraction speeds in EB may be due to mechanisms other than changes in fascicle length. Nevertheless, the fact that fascicle length was only measured at one site on each muscle is a limitation of the current study as it is recognised that muscular
adaptation to training may be heterogeneous along the length of a muscle and may differ between vastii. With regards to muscle thickness, the fact that EB brought about an increase in VL thickness while thickness in CONV did not change and thickness in the control group decreased over time is consistent with numerous previous studies which suggest that eccentric resistance training is more effective at increasing muscle hypertrophy than concentric training. The lack of change in GM thickness with both training modalities is consistent with the finding that soleus muscle protein synthesis responds relatively poorly to an acute bout of resistance training when compared to VL protein synthesis.

Paragraph Number 45 The lower RPE in upper body exercises in EB compared to CONV concurs with the findings of Reeves and colleagues, who compared conventional training to eccentric-only training in older adults. Lower ratings of exertion may be important for resistance training program compliance. The lack of change in RPE over time in both training groups for most exercises is expected due to the adjustment of training weights with every 1RM test conducted throughout the training program, so that participants exercised at the same intensity throughout the programs. The decrease in RPE over time in EB for toe press is most likely due to participants becoming more familiar with performing the exercise, rather than an actual decrease in exertion, due to the unusual nature of the exercise.

Paragraph Number 46 The finding that neither training modality had a significant impact on central and peripheral arterial pulse wave velocity supports the findings of Maeda et al., who found that 12 weeks of isokinetic (concentric and eccentric) leg resistance training had no effect on carotid and femoral artery pulse wave velocities in healthy young females. On the other hand, Okamoto and colleagues reported higher brachial-ankle pulse wave velocity after 8 weeks of concentric-only resistance training, but no change after eccentric-only resistance
training in older men. Other studies have found evidence of decreased central arterial compliance as a result of conventional resistance training in men. One reason for this discrepancy could be that previous studies that observed increases in arterial stiffness following weight training measured central arterial stiffness, while the method used in the current study takes into account central as well as peripheral arteries. Heffernan et al. found that peripheral arterial stiffness decreased in the exercised limb following weight training. Therefore, the differential changes in central and peripheral arterial stiffness may have masked overall changes in arterial stiffness in the current study. The index of arterial stiffness employed in the current study is one of a number of methods to describe arterial stiffness and there are limitations to this method. For example, the method of measuring the distance travelled by the pulse wave does not take into account differences in body shape and assumes that the aorta is straight. Even though this method has been validated by Tsai and colleagues, more research may be needed before the effects of EB and CONV on arterial stiffness are more clearly understood.

CONCLUSION

Paragraph Number 47 This study suggests that eccentrically-biased resistance training is a viable alternative to conventional resistance training for older adults. Whilst improvements in one repetition maximum and functional capacity were similar for both training modalities, quadriceps thickness and torque at higher isokinetic velocities increased only after EB. While longer term studies are required, these findings suggest that EB may be particularly valuable for a population that is prone to sarcopenia and falls. Generally lower ratings of perceived exertion in eccentrically-biased training may also have implications for program compliance. Furthermore, whilst eccentric-only training is impractical in a real-world gym setting due to the
consistent need for assistance from a spotter to aid with the lifting of the weights, this study has demonstrated that eccentrically-biased training can be successfully performed without assistance, using resistance training machines that are widely available.

ACKNOWLEDGEMENTS
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REFERENCES


<table>
<thead>
<tr>
<th>Training method</th>
<th>Contraction mode</th>
<th>Sets</th>
<th>Reps</th>
<th>Relative Intensity</th>
<th>Volume-load&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONV Concentric</td>
<td>2</td>
<td>10</td>
<td></td>
<td>75%</td>
<td>1500</td>
</tr>
<tr>
<td>Eccentric (bilateral)</td>
<td>2</td>
<td>10</td>
<td></td>
<td>75%</td>
<td>1500</td>
</tr>
<tr>
<td>EB Concentric</td>
<td>3</td>
<td>10</td>
<td></td>
<td>50%</td>
<td>1500</td>
</tr>
<tr>
<td>Eccentric (unilateral)</td>
<td>3</td>
<td>5</td>
<td></td>
<td>100%</td>
<td>1500</td>
</tr>
</tbody>
</table>

CONV = conventional resistance training; EB = eccentrically-biased training

1 Relative intensity = % of 1RM

2 Volume-load = sets × repetitions × relative intensity
Table 2

*Estimates of total work for each limb*

<table>
<thead>
<tr>
<th>Group</th>
<th>Total work (A.U.)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg press CONV</td>
<td>76320 ± 6147</td>
<td>0.17</td>
</tr>
<tr>
<td>EB</td>
<td>79507 ± 4876</td>
<td></td>
</tr>
<tr>
<td>Toe press CONV</td>
<td>74623 ± 8296</td>
<td>0.18</td>
</tr>
<tr>
<td>EB</td>
<td>78463 ± 5396</td>
<td></td>
</tr>
<tr>
<td>Bench press CONV</td>
<td>75244 ± 6098</td>
<td>0.77</td>
</tr>
<tr>
<td>EB</td>
<td>73866 ± 15012</td>
<td></td>
</tr>
<tr>
<td>Lat pulldown CONV</td>
<td>75673 ± 5199</td>
<td>0.34</td>
</tr>
<tr>
<td>EB</td>
<td>77685 ± 5122</td>
<td></td>
</tr>
</tbody>
</table>

Data presented as mean ± SD. CONV = conventional resistance training; EB = eccentrically-biased training; A.U. = arbitrary units. P-values are for two-tailed independent *t*-tests performed to compare total work performed both groups.
### Table 3

*Changes in 1RM as a result of training*

<table>
<thead>
<tr>
<th></th>
<th>Group</th>
<th>Pre-training</th>
<th>Post-training</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg press 1RM (kg)</td>
<td>CONV</td>
<td>159 ± 38</td>
<td>195 ± 45</td>
<td>23**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>171 ± 51</td>
<td>211 ± 61</td>
<td>23**</td>
</tr>
<tr>
<td>Toe press 1RM (kg)</td>
<td>CONV</td>
<td>200 ± 50</td>
<td>263 ± 64</td>
<td>31**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>196 ± 37</td>
<td>265 ± 54</td>
<td>35**</td>
</tr>
<tr>
<td>Bench press 1RM (kg)</td>
<td>CONV</td>
<td>36 ± 13</td>
<td>46 ± 15</td>
<td>30**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>37 ± 14</td>
<td>47 ± 14</td>
<td>24**</td>
</tr>
<tr>
<td>Lat pulldown 1RM (kg)</td>
<td>CONV</td>
<td>48 ± 17</td>
<td>58 ± 18</td>
<td>23**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>50 ± 14</td>
<td>61 ± 15</td>
<td>24**</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD; 1RM = one repetition maximum; % Difference = percentage difference between pre- and post-training data. Asterisks indicate significant difference between pre- and post-training (**P < 0.01).
### Table 4

*Changes in pulse wave velocity and functional capacity*

<table>
<thead>
<tr>
<th></th>
<th>Group</th>
<th>Pre-training</th>
<th>Post-training</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse wave velocity (m·s⁻¹)</strong></td>
<td>CONV</td>
<td>14.5 ± 10.3</td>
<td>16.0 ± 10.8</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>10.8 ± 3.7</td>
<td>12.1 ± 7.4</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>11.7 ± 4.2</td>
<td>13.3 ± 5.5</td>
<td>14</td>
</tr>
<tr>
<td>6MFWT (s)</td>
<td>CONV</td>
<td>2.79 ± 0.57</td>
<td>2.66 ± 0.61</td>
<td>-5**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>2.79 ± 0.32</td>
<td>2.60 ± 0.29</td>
<td>-7**</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.74 ± 0.40</td>
<td>2.86 ± 0.38</td>
<td>4*</td>
</tr>
<tr>
<td>TUG (s)</td>
<td>CONV</td>
<td>4.55 ± 0.81</td>
<td>4.34 ± 0.64</td>
<td>-5**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>4.51 ± 0.43</td>
<td>4.39 ± 0.38</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>4.58 ± 0.54</td>
<td>4.50 ± 0.48</td>
<td>-2</td>
</tr>
<tr>
<td>Stair climb power (W)</td>
<td>CONV</td>
<td>400 ± 117</td>
<td>412 ± 121</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>433 ± 138</td>
<td>456 ± 141</td>
<td>5**</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>404 ± 101</td>
<td>410 ± 99</td>
<td>1</td>
</tr>
<tr>
<td>Stair descent power (W)</td>
<td>CONV</td>
<td>376 ± 83</td>
<td>392 ± 81</td>
<td>4*</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>366 ± 105</td>
<td>380 ± 111</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>362 ± 62</td>
<td>360 ± 60</td>
<td>-1</td>
</tr>
<tr>
<td>Vertical jump height (cm)</td>
<td>CONV</td>
<td>25.4 ± 9.1</td>
<td>27.3 ± 8.6</td>
<td>7**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>28.1 ± 5.7</td>
<td>28.9 ± 5.3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>25.9 ± 4.9</td>
<td>25.2 ± 6.0</td>
<td>-2</td>
</tr>
<tr>
<td>Peak jumping power (W)</td>
<td>CONV</td>
<td>985 ± 466</td>
<td>1055 ± 499</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>1085 ± 453</td>
<td>1085 ± 458</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>1083 ± 344</td>
<td>1040 ± 422</td>
<td>-4</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD; 6MFWT = six metre fast walk test; TUG = Timed up and Go test; % Difference = percentage difference between pre- and post-training or post-control data. Asterisks indicate significant difference between pre- and post-training or post-control (*P < 0.05; **P < 0.01).
Table 5

Muscle architecture data

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-training</th>
<th>Post-training</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM θ (º)</td>
<td>CONV 19.9 ± 3.6</td>
<td>20.6 ± 2.7</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EB 19.6 ± 1.4</td>
<td>18.9 ± 3.2</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>Control 19.9 ± 3.5</td>
<td>18.0 ± 2.7</td>
<td>-10*</td>
</tr>
<tr>
<td>GM L_f (cm)</td>
<td>CONV 5.56 ± 0.97</td>
<td>5.38 ± 0.81</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>EB 5.67 ± 0.76</td>
<td>5.92 ± 0.83</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Control 5.85 ± 1.07</td>
<td>6.17 ± 1.25</td>
<td>5</td>
</tr>
<tr>
<td>GM Thickness (cm)</td>
<td>CONV 1.87 ± 0.28</td>
<td>1.87 ± 0.21</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>EB 1.89 ± 0.24</td>
<td>1.89 ± 0.25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Control 1.94 ± 0.25</td>
<td>1.87 ± 0.29</td>
<td>-3</td>
</tr>
<tr>
<td>VL Site 1 Thickness (cm)</td>
<td>CONV 3.88 ± 0.46</td>
<td>3.96 ± 0.47</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>EB 4.03 ± 0.62</td>
<td>4.22 ± 0.68</td>
<td>5*</td>
</tr>
<tr>
<td></td>
<td>Control 4.18 ± 0.74</td>
<td>3.95 ± 0.55</td>
<td>-6*</td>
</tr>
<tr>
<td>VL Site 2 Thickness (cm)</td>
<td>CONV 4.71 ± 0.50</td>
<td>4.71 ± 0.62</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>EB 4.49 ± 0.53</td>
<td>4.64 ± 0.52</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Control 4.50 ± 0.49</td>
<td>4.47 ± 0.46</td>
<td>-1</td>
</tr>
<tr>
<td>VL θ (º)</td>
<td>CONV 12.9 ± 2.8</td>
<td>11.9 ± 3.6</td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>EB 11.5 ± 4.4</td>
<td>11.9 ± 3.1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Control 11.9 ± 3.2</td>
<td>11.1 ± 3.5</td>
<td>-7</td>
</tr>
<tr>
<td>VL L_f (cm)</td>
<td>CONV 11.1 ± 2.6</td>
<td>11.5 ± 3.6</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EB 12.3 ± 3.8</td>
<td>12.9 ± 5.1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Control 12.3 ± 4.3</td>
<td>12.1 ± 4.5</td>
<td>-2</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD; GM = medial gastrocnemius; VL = vastus lateralis; θ = pennation angle; L_f = fascicle length; % Difference = percentage difference between pre- and post-training or post-control data. Asterisks indicate significant difference between pre- and post-training or post-control (*P < 0.05).
Table 6

*Knee extensor isometric and isokinetic torque data*

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Group</th>
<th>Pre-training (Nm)</th>
<th>Post-training (Nm)</th>
<th>% Difference</th>
</tr>
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<tbody>
<tr>
<td>Isometric</td>
<td>CONV</td>
<td>160 ± 40</td>
<td>166 ± 46</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>175 ± 38</td>
<td>187 ± 44</td>
<td>7*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>162 ± 40</td>
<td>162 ± 41</td>
<td>0</td>
</tr>
<tr>
<td>60°s⁻¹</td>
<td>CONV</td>
<td>126 ± 36</td>
<td>135 ± 39</td>
<td>7*</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>129 ± 30</td>
<td>137 ± 32</td>
<td>6*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>125 ± 25</td>
<td>128 ± 29</td>
<td>2</td>
</tr>
<tr>
<td>120°s⁻¹</td>
<td>CONV</td>
<td>101 ± 31</td>
<td>109 ± 32</td>
<td>8**</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>101 ± 24</td>
<td>108 ± 26</td>
<td>7**</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>98 ± 19</td>
<td>101 ± 20</td>
<td>3</td>
</tr>
<tr>
<td>240°s⁻¹</td>
<td>CONV</td>
<td>75 ± 26</td>
<td>77 ± 26</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>74 ± 21</td>
<td>78 ± 22</td>
<td>5*</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>70 ± 16</td>
<td>72 ± 18</td>
<td>3</td>
</tr>
<tr>
<td>360°s⁻¹</td>
<td>CONV</td>
<td>59 ± 21</td>
<td>60 ± 24</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>EB</td>
<td>56 ± 16</td>
<td>62 ± 19</td>
<td>11**</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>56 ± 12</td>
<td>56 ± 11</td>
<td>0</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD; % Difference = percentage difference between pre- and post-training or post-control data. Asterisks indicate significant difference between pre- and post-training or post-control (*$P < 0.05$; **$P < 0.01$).
Figure SDC 1. Change (Δ) in torque for knee extensors for conventional training (CONV), eccentrically-biased training (EB) and the control group. Values are means and SD. Asterisks indicate significant difference between pre- and post-training or post-control (*P < 0.05; **P < 0.01).