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Research article

Effects of Upper Body Eccentric versus Concentric Strength Training and Detraining on Maximal Force, Muscle Activation, Hypertrophy and Serum Hormones in Women

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Abstract

Effects of eccentric (ECC) versus concentric (CON) strength training of the upper body performed twice a week for 10 weeks followed by detraining for five weeks on maximal force, muscle activation, muscle mass and serum hormone concentrations were investigated in young women (n = 11 and n = 12). One-repetition bench press (1RM), maximal isometric force and surface electromyography (EMG) of triceps brachii (TB), anterior deltoid (AD) and pectoralis major (PM), cross-sectional area (CSA) of TB (Long (LoH) and Lateral Head (LaH)) and thickness of PM, as well as serum concentrations of free testosterone, cortisol, follicle-stimulating hormone, estradiol and sex hormone-binding globulin were measured. ECC and CON training led to increases of 17.2 ± 11.3% ($p < 0.001$) and 13.1 ± 5.7% ($p < 0.001$) in 1RM followed by decreases of -6.6 ± 3.6% ($p < 0.01$) and -8.0 ± 4.5% ($p < 0.001$) during detraining, respectively. Isometric force increased in ECC by 11.4 ± 9.6 % ($p < 0.05$) from week 5 to 10, while the change in CON by 3.9±6.8% was not significant and a between group difference was noted ($p < 0.05$). Maximal total integrated EMG of trained muscles increased only in the whole subject group ($p < 0.05$). CSA of TB (LoH) increased in ECC by 8.7 ± 8.0% ($p < 0.001$) and in CON by 3.4 ± 1.6% ($p < 0.01$) and differed between groups ($p < 0.05$), and CSA of TB (LaH) in ECC by 15.7 ± 8.0% ($p < 0.001$) and CON by 9.7 ± 6.6% ($p < 0.001$). PM thickness increased in ECC by 17.7 ± 10.9% ($p < 0.001$) and CON by 14.0 ± 5.9% ($p < 0.001$). Total muscle sum value (LoH + LaH + PM) increased in ECC by 12.4 ± 6.9% ($p < 0.001$) and in CON by 7.1 ± 2.9% ($p < 0.001$) differing between groups ($p < 0.05$) and decreased during detraining in ECC by -6.5 ± 4.3% ($p < 0.001$) and CON by -6.1 ± 2.8% ($p < 0.001$). The post detraining combined sum value of CSA and thickness was in ECC higher ($p < 0.05$) than at pre training. No changes were detected in serum hormone concentrations, but baseline free testosterone levels in the ECC and CON group combined correlated with changes in 1RM ($r = 0.520$, $p < 0.016$) during training. Large neuromuscular adaptations of the upper body occurred in women during ECC, and CON training in 10 weeks. Isometric force increased only in response to ECC, and total muscle sum value increased more during ECC than CON training. However, no changes occurred in serum hormones, but individual serum-free testosterone baseline concentrations correlated with changes in 1RM during strength training in the entire group. Both groups showed significant decreases in neuromuscular performance and muscle mass during detraining, while post detraining muscle sum value was only in ECC significantly higher than at pre training.

Key words: Muscle force, training, EMG, mass, females, testosterone.

Introduction

Several groups of researchers in the 1970's and 1980's have investigated the effects of concentric (CON) and eccentric (ECC) strength training on increases in maximal strength, muscle activation and/or muscle hypertrophy in men (e.g., Komi and Buskirk, 1972; Johnson et al., 1976; Häkkinen and Komi, 1981; Duncan et al., 1989). However, considerable methodological variations between these studies are apparent, e.g., muscle groups (lower or upper body, knee extensors or flexors), individual muscles (biceps or triceps brachii), training protocols, number of sessions per week and durations of the training period, specificity of measurements, and actual mode of training. All these factors may influence the results, but the duration of the training period is particularly important. For example, bench press 1RM in men increased gradually up to 8 weeks of training with CON and ECC training by 12% and 10%, but the gains plateaued thereafter during weeks 9 to 12 of training (Häkkinen and Komi, 1981). Later, Roig et al. (2009) concluded in a meta-analysis that ECC strength training would stimulate a greater increase in maximal eccentric and overall strength when compared to CON only training. Additionally, the review by Douglas et al. (2017) concluded that ECC training stimulates greater increases in muscle cross-sectional area compared to CON training. However, some of the studies may have included ECC training alone or in conjunction with CON contraction compared to CON training only. This may complicate the comparisons between ECC only versus CON only training-induced strength gains and muscle hypertrophy.

Only a few studies have compared the retention of muscle strength following ECC and CONC training interventions. This is important, since it will give valuable information e.g., what is the time duration of the retention, since a prolonged detraining period will lead to more drastic decreases in strength and/or muscle mass (e.g. Coratella and Schena, 2016; Coratella et al., 2021). In addition, there

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may be some differences in the trainability of muscle strength and mass, time duration of retention between the upper and lower body muscles as well as possible differences between men and women. Coratella and Schena, (2016) compared three groups of men who performed volume-matched ECC only, CON only, or traditional (including both phases) bench press training for 6 weeks. They reported that all groups produced similar increases in 1RM strength. However, the interesting finding was that after 6 weeks of detraining, the only group that retained the baseline bench press strength was the ECC intervention. In a recent study, Coratella et al. (2021) compared the effects of 8 weeks of knee extensor CON, ECC and CON-ECC resistance training on strength and mass and the effects of 8 weeks of detraining in women. Concentric and isometric torque increased similarly in all groups, whereas eccentric torque increased more in ECC than in CON. After detraining, isometric torque and thigh lean mass were retained to a greater extent in ECC indicating that an eccentric phase in resistance training may be essential to preserve adaptations during periods of detraining. While the current literature provides evidence about the impact of training using various isolated muscle actions on the adaptations of the lower body, much less research has been completed to examine resistance training adaptations over a somewhat longer period as well as the retention in the upper body, especially in women.

Initial increases in maximal force in previously untrained participants may be accounted for largely by the increased voluntary neural activation at various levels of the neuromuscular system as indicated indirectly by increases in maximal electromyographic activity of trained muscles in both men and women (Moritani and deVries, 1979; Häkkinen and Komi, 1983; Häkkinen et al., 1992). When strength training continues for longer periods, further increases in strength are contributed to a large extent by muscular hypertrophy (e.g., Häkkinen, 1994). Prolonged strength training may not have large chronic effects on serum resting concentrations of endogenous anabolic and catabolic hormones that would be out of normal physiological range in adult men or women (Häkkinen et al., 1985; 1992; Kraemer et al., 1998; Ahtiainen et al., 2003; Kraemer and Ratamess, 2005). However, women have typically large interindividual differences in their serum resting testosterone concentrations (Häkkinen et al., 1992). Whether differences in serum testosterone levels amongst women would be associated with inter-individual differences in their adaptive trainability during maximal ECC or CON strength training of the upper body has not been investigated in women.

There is a paucity of research about the effects of eccentric only versus concentric only strength training of the upper extremities in women. The specific purpose of the present study was to investigate the effects of upper body ECC and CON strength training during a 10-week training and the following 5-week detraining period on maximal isometric force, muscle activation of trained muscles, bench press 1RM and power, muscle cross-sectional area and serum resting hormone concentrations in women.

Methods

Participants

Healthy, non-smoking, physically active 18-35 years old women with some experience in strength training, especially the bench press exercise (0.5 - 1.5 years and 1-2 times a week) for only their own recreational (but not for competitive or athletic purposes) physical fitness purposes (Table 1) were recruited from the Jyväskylä region of Finland by advertisements in newspapers and through social media. Exclusion criteria included any chronic diseases, musculoskeletal or cardiac problems, or medications that would preclude a participant's ability to perform resistance training and testing. In conjunction with the recruitment process, participants completed a Finnish language Physical Activity Readiness Questionnaire (PAR-Q) in addition to questions regarding their physical activity background. Before participating in this study, a resting ECG and health questionnaire from each participant was screened by a medical doctor. Participants were given verbal and written information about the measurement procedures, study design, training protocols, benefits and risks of participation, and invited to sign an informed consent document prior to participation in the study. The University Ethics Committee granted ethical approval.

Table 1. Characteristics of women participants at the beginning of the training period. Data are Means ± SD.

	All (n=23)	ECC (n=11)	CON (n=12)
Age (yrs)	27.2 ± 4.5	25.2 ± 4.6	29.0 ± 3.6
Height (m)	1.67 ± 0.06	1.67 ± 0.04	1.67 ± 0.08
Body mass (kg)	66.8 ± 8.0	68.6 ± 8.0	65.2 ± 7.9
BMI (kg/m2)	24.0 ± 3.0	24.7 ± 3.5	23.4 ± 2.4

All= all training subjects, ECC= eccentric training group, CON= concentric training group.

Familiarization

Each participant was thoroughly familiarized with all experimental testing protocols and individual settings were recorded for each device to be used in the study. In addition, a preliminary 1RM bench press test was performed to reduce measurement variability during the control period (Figure 1).

Study design

Participants acted as their own controls over a one-week period including the measurements before (week -1) and after the control period (week 0) where no strength training was performed. The strength training intervention lasted 10 weeks, including measurements at mid- (week 5) and post-training at week 10. This was followed by a 5-week detraining period with all measurements repeated at week 15 (Figure 1). Participants were randomly (pair-matched) divided into two training groups (CON and ECC) based on their maximal isometric force and 1RM results in the bench press recorded at the week -1 measurement.

Twenty-four women were selected for the investigation and one woman dropped out (personal reasons) during the study period. Twenty-three women successfully completed the study: 12 women in the ECC training group and 11 women in the CON training group. In all, ten women reported using hormonal contraceptives (four of them in the CON group and six in the ECC group).

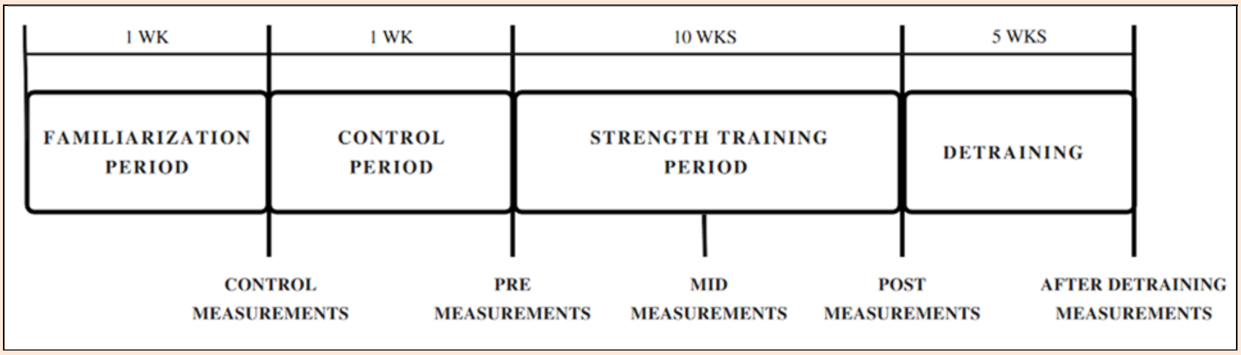

Figure 1. Experimental design of the study.

Measurements

Maximal one repetition bench press (1RM).

Dynamic concentric 1RM of the upper body was measured in a supine position at the Smith machine. After performing general exercises for the upper body participants completed a bench press specific warm-up: 5x~70%1RM, 3x~80%1RM and 2x~90%1RM, with 1-minute rests between the sets. The load was then increased incrementally by 1.25-2.5kg until the individual 1RM was found with a 2-minute recovery between the sets. No more than 5 attempts were permitted. The highest weight that a participant could successfully lift (from the stopped position on the chest to full extension keeping the back and buttocks in contact with the bench) was recorded with accuracy of 1.25kg. Participants were verbally encouraged by the research assistant to achieve their best performance during this and all performance measurements. In addition, two assistants were always present to secure the participants safety by catching the barbell in case of a missed performance.

Maximal isometric bench press force ($ISOM_{max}$).

Maximal isometric force production of the upper body was measured at an elbow angle of 90 degrees (measured with a goniometer) using an isometric bench press device (Neuromuscular Research Center, Faculty of Sport and Health Sciences, University of Jyväskylä, Finland). Participants were instructed to produce as much force as possible and as fast as they could for about 3 seconds. During each isometric test, participants were verbally encouraged to achieve their best performance.

Force data were collected at a sampling frequency of 2000 Hz, and then filtered (20 Hz low-pass filter) and analyzed using customized scripts (Signal 4.10, CED, U.K.). Participants performed a minimum of three maximum voluntary contractions. If the maximum force during the last trial was greater than 5% more than the previous trial, an additional trial was performed up to a maximum of five trials. In terms of maximal force, the best performance trial was used for statistical analysis. The coefficient of variation (CV) for $ISOM_{max}$ in the bench press action across the Control period was 6.8%.

Power measurements

Power production in the concentric phase of the bench press (starting from the stopped position on the chest) was measured in the Smith machine. Three different loads of 30, 45 and 60% of the concentric 1RM of the upper extremities were used. Three separate single throwing attempts were performed at each load with a recovery of 2 minutes between the loads. Power was recorded using a linear encoder attached to the barbell (Musclelab^{TM}, Ergotest Innovation AS, Norway). Two assistants were present to secure the safety of the participant by catching the barbell at the top of the throw and lowering the barbell back to the starting position.

Surface electromyography

EMG was recorded from the triceps brachii (TB), anterior deltoid (AD) and pectoralis (PM) muscles of the right upper limb during the maximal isometric bench press test. Bipolar silver-silver chloride surface electrodes (Ambu Blue-Sensor N, Copenhagen, Denmark) with an inter-electrode distance of 20 mm were attached to muscle-specific locations following SENIAM guidelines (Hermens et al., 1999). Small indelible ink tattoos (diameter 0.1 - 1.0mm) were placed on the skin at the beginning of the study (during the familiarization visit before the start of the control measurements) to ensure that the electrodes were replaced exactly onto the same location in each measurement (Häkkinen and Komi, 1983). A telemetric recording system (Noraxon Inc. Scottsdale, Arizona, USA) with a sampling frequency of 2000 Hz was used for data collection. The EMG signals were transmitted to a receiver box and then converted from analog to digital (Cambridge Electronic Design Ltd., Cambridge, United Kingdom) to a computer where Signal 4.14 software (Cambridge Electronic Design Ltd., Cambridge, United Kingdom) was used for data recording and further offline analysis. The data was band-pass filtered over 20 - 350 Hz and a symmetric root-mean square (RMS) filter applied for each muscle separately before the average of the three muscles was computed over the 500 - 1500 ms period during the force plateau phase. The coefficient of variation (CV) for EMG (average of the three agonist muscles) across the Control period was 10.7%.

Muscle cross-sectional area (CSA) and thickness

Muscle cross-sectional area of TB (Long and Lateral head: LoH and LaH) was measured as anatomical cross-sectional area (CSA) in the axial plane of the right arm, whilst pectoralis major (PM) thickness was measured using a B-mode ultrasound device (SSD-a10; Aloka, Tokyo, Japan). The sum value of these three variables (LoH+LaH+PM) was also calculated. Small indelible ink tattoos (as in the protocol of EMG electrodes) for TB muscle and a reference tattoo on the right side of the body for PM (with additional measures) were placed at the beginning of the study to ensure as best as possible the same locations for each measurement. A 10-MHz linear-array probe (60-mm length) coated with water-soluble transmission gel and housed in a custom-made convex support was used. CSA measurements were performed using the extended-field-of-view function as previously described (Walker et al., 2020), which is a valid method of assessing muscle CSA changes over time (Ahtiainen et al., 2010). TB measurements were taken at the mid-point between the medial epicondyle and the acromion. The probe was oriented perpendicular to the skin and positioned with minimal contact to avoid tissue deformation. Three images were taken during each measurement and the average of the three values was taken for further analyses. All measurements were recorded and analyzed (ImageJ software version 1.44, National Institutes of Health, Bethesda, Maryland, USA) by the same experienced researcher, who was blinded to participant allocation. The coefficient of variation (CV) for tests across the Control period was 2.0% for TB CSA and 2.4% for PM thickness.

Subjective muscle soreness

The resting morning value of perceived muscle soreness (chest, shoulder, and arm extensor muscles) was collected throughout the 10-week strength-training period using the Visual Analogical Scale (0-100). The participants were asked to mark the level of their muscle pain during the first and second morning after each training session each week (i.e. twice in weeks 2, 4, 6, 7, 8 and 9 and once in weeks 1, 5, and 10).

Blood samples

Blood samples were collected in the mornings (between 7.00 - 9.30) after 12 hours of fasting. Participants were asked to refrain from strenuous physical activity for 48 hours prior to the measurements. A qualified lab technician collected blood samples into serum tubes (Venosafe, Terumo Medical Co., Belgium). The samples were centrifuged for 10 min at 2000g at a temperature of +4°C (Heraeus Megafuge 1.0 R, Thermo Scientific, Karsruhe, Germany) and serum separated. Serum was kept at -80°C until analyzed for serum free-testosterone (TES), cortisol (COR), sex hormone-binding globulin (SHBG), follicle-stimulating hormone (FSH) and estradiol. COR, SHBG, FSH, and estradiol were analyzed using immunoassay (Immulite 2000 device, Siemens, USA). TES was analyzed using ELISA (Dynex, USA). Analytical sensitivity-free TES was 0.06 pmol/l, COR 5.5 nmol/l, SHBG 0.02 nmol/l, FSH 0.10 U/l and estradiol 55.0 pmol/l. Intra assay CVs were for TES 6.7%, SHBG 6.5%, COR 6.0%, FSH and estradiol 6.7%.

Strength training

Participants in both groups were trained twice a week over the 10-week experimental training period with at least two recovery days in between sessions. An isokinetic bench press device specially constructed for our research was used for training in the laboratory. Each training session for each subject was fully supervised. The velocity used in the bench press action was 0.2 m/s for the ECC phase in the ECC group (and subjects did not produce any force during the CON phase). The same velocity of 0.2 m/s was used for the CON phase in the CON group (and participants produced no force during the ECC phase). At the start of each bench press contraction, subjects first produced their maximal isometric force. Depending on their group, they continued to produce their maximal force throughout the following ECC or CON action depending on their group. The total duration of each repetition in the ECC and CON action was always two seconds. The resting time between each repetition of each set was two seconds. For safety reasons the angle of the elbows at the start for the ECC group was set such that the subject could not accidentally lock their elbows at the fully extended position. In addition, in both groups, there was always approximately a 3-cm space between the chest and the barbell of the machine. These device settings, hand positions, and head were all marked for each subject individually to standardize their position throughout the study.

Each repetition (in all 3-4 single reps per set with two seconds in between each rep) of each set was required to be performed with maximal effort in every training session. The volume of the strength training program increased progressively across the 10-week training period. The mean number of sets increased gradually from 2 to 4, and the number of single reps increased from 3 to 4 during the training period in the first week's training session. In the second training session, the number of sets increased gradually from 3 to 4, and the number of singles remained 4. Each subject was verbally encouraged to perform her maximum in each repetition of each set. The participation rate for the bench press training sessions was 100% in both ECC and CON groups.

In addition, after each bench press training session, all participants also performed some strength training exercises under supervision in the gym of our laboratory. This included only moderate load and low volume training for the legs and trunk muscles to maintain strength and mass of these muscle groups. No measurements were performed for these muscle groups. Participation for these training sessions was 99.5% and 95.9% in the ECC and CON group, respectively.

Detraining

After the 10-week strength-training period, all subjects in both groups started the 5-week detraining period. During this time, no strength training was allowed but subjects could do some low-intensity physical activities (jogging, some ball games etc.) 2-3 times per week for 30-45 minutes, as they had been accustomed to before the start of this study. The type, duration, and frequency of physical activity were captured using questionnaires during the last measurement at the end of the detraining period.

Statistical analysis

Standard statistical methods were used for the calculation of mean and standard deviation (S.D.) using Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) and IBM SPSS Statistics 26 (SPSS Inc., Chicago, Illinois, USA) programs. The results are expressed as absolute values and relative changes during the control and training periods and during the detraining period. The Shapiro-Wilk test was applied to determine the normality of distribution. The normally distributed variables were analyzed for statistical significance over the intervention period (control, pre-training, mid-training, post-training, and post detraining) using repeated measures ANOVA (5 × 2) for within and between ECC and CON groups comparisons and not normally distributed variables using the Friedman test. In both cases, the Bonferroni correction was used. In addition, relative changes (%) in the variables between ECC and CON groups were analyzed over the different time points (control and pre-training, pre- and mid-training, mid and post-training, pre- and post-training, post-training and post detraining, pretraining and post detraining) and their statistical significance was determined using either independent sample t-test or a Mann-Whitney U test, respectively. Correlations between the two variables were analyzed using Spearman correlation coefficient analysis. The statistically significant levels used were represented as follows $p \leq 0.05$*, $p \leq 0.01$**, and $p \leq 0.001$***.

Results

Dynamic bench press 1RM

During the control period no significant change occurred in 1RM from 40.5 ± 9.5 kg to 41.8 ± 9.6 kg in the ECC group and a minor but significant change ($p < 0.01$) from 40.3 ± 9.9 kg to 42.7 ± 10.9 kg in the CON group (Table 2.). However, there was no significant between group difference during the control period. During the 10-week training period increases of 17.2 ± 11.3% and 13.1 ± 5.7% took place in 1RM in ECC ($p < 0.001$) and CON ($p < 0.001$) respectively, but no significant between group difference occurred. During 5 weeks of detraining the ECC and CON groups showed decreases of -6.6 ± 3.6% ($p < 0.01$) and -8.0 ± 4.5% ($p < 0.001$) with no significant between-group difference. The post-detraining 1RM values both in ECC and CON groups were not significantly higher compared to those recorded at pre-training.

Maximal isometric force

No significant changes occurred in isometric force during the control period in the two groups (Table 2). During the 10-week strength training period increases of 11.1 ± 11.6% in ECC (ns.) and 5.6 ± 9.8% (ns.) in CON occurred in maximal force. The value of 540 ± 90N at week 10 in ECC was larger ($p < 0.05$) than that of 491 ± 108N at week 5. During detraining the ECC and CON groups showed decreases of -10.9 ± 6.3% ($p < 0.01$) and -6.9 ± 5.5% ($p < 0.05$) in maximal isometric force with no significant between group difference. The post-detraining maximal isometric force values in both ECC and CON were not significantly different compared those recorded at pre-training.

Concentric power

Average concentric power at loads of 30, 45 and 60% (of 1RM) did not change during the control period either in ECC or CON (Figure 2). During the 10-week training period the only significant increase of 11.8 ±12.0 % ($p < 0.05$) occurred at the load of 45% in CON with no significant changes in ECC. No significant changes occurred in both ECC and CON in average power during detraining and these values did not differ significantly from those recorded at pre-training.

Maximal EMG

No significant changes occurred in maximal EMG activity of individual muscles of PM, TB or AD recorded in maximal isometric bench press during the control, training, or detraining periods (Table 3). The relative increases during the 10-week training period in PM of 20.9 ± 44.6% and 9.5 ± 26.3%, TB 22.3 ± 43.2% and 21.7 ± 32.5% and AD 28.1 ± 46.6% and 26.7 ± 47.5% in ECC and CON were not statistically significant. The relative increases in mean maximal sum EMG activity of PM, TB and AD muscles during the 10-week training period of 16.6 ± 19.0% and 20.7 ± 31.2% in ECC and CON were not statistically significant (Table 3). However, in the total group of participants, an increase of 15.6% ($p < 0.05$) occurred in the mean maximal sum EMG activity (Table 3). Individual changes in maximal sum EMG activity of PM+AD muscles correlated ($r = 0.596$, $p = 0.003$) with individual changes in maximal isometric bench press force during the 10-week training period in the total group of ECC and CON participants (Figure 3).

During detraining, decreases of -23.3 ± 10.6% ($p < 0.001$) and -15.1 ± 11.9% ($p < 0.05$) occurred in maximal sum EMG activation of PM and AD in ECC and CON, respectively. Individual changes in maximal sum EMG activation of PM and TB muscles correlated with changes in maximal isometric bench press force ($r = 0.490$, $p = 0.021$) during the 5-week detraining period in the total group ECC and CON participants (Figure 3). The values in maximal sum EMG activation of the muscles after detraining did not differ significantly from those recorded pre-training in both ECC or CON.

Muscle CSA and thickness

No significant changes occurred in CSA or thickness of individual muscles of TB or PM during the control period (Table 4). CSA of TB (LoH) increased during the 10-week training period in ECC by 8.7 ± 8.0% ($p < 0.001$) and CON by 3.4 ± 1.6% ($p < 0.01$) and there was a between-group difference ($p < 0.05$). CSA of TB (LaH) increased during training in ECC by 15.7 ± 8.0% ($p < 0.001$) and CON by 9.7 ± 6.6% ($p < 0.001$) but the between-group difference did not reach the significant level ($p = 0.051$). The thickness of PM increased during the training period both in ECC by 17.7 ± 10.9% ($p < 0.001$) and CON by 14.0 ± 5.9% ($p < 0.001$). The combined sum value of CSA and thickness of TB and PM (LoH+LaH+PM) increased during training in ECC by 12.4 ± 6.9% ($p < 0.001$) and CON by 7.1 ± 2.9% ($p < 0.001$) (Table 4) and there was a significant between group difference ($p < 0.05$). Individual changes in the combined sum value of CSA and thickness correlated ($r = 0.707$, $p = 0.001$) with changes in dynamic bench press 1RM during the training period in the total group of ECC and CON participants (Figure 4).

Table 2. Dynamic bench press 1RM (Dyn BP) and maximal isometric bench press (Isom BP) force at Control, Pre-, Mid-, Post-Strength Training and After Detraining in the ECC and CON groups of women participants. Data are Means ± SD.

		Control (-1 wk)	Pre (0 wk)	Mid (5 wk)	Post (10 wk)	After Detraining (+5 wk)
Dyn BP 1RM	ECC (n=11)	40.5 ± 9.5	41.8 ± 9.6	45.7 ± 8.8*	48.2 ± 7.0*/¤¤¤	44.9 ± 6.5**
(kg)	CON (n=12)	40.3 ± 9.9	42.7 ± 10.9**	45.7 ± 11.4**	48.0 ± 11.6**/¤¤¤	44.3 ± 11.8***
Isom BP force	ECC (n=11)	470 ± 107	492 ± 105	491 ± 108	540 ± 90*	482 ± 93**
(N)	CON (n=12)	472 ± 140	472 ± 136	478 ± 135	496 ± 146	463 ± 134*

ECC = eccentric training group, CON = concentric training group, Significant difference from previous measurement within the group. * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001 Significant change between pre-, and post-training measurements. ¤ p ≤ 0.05, ¤¤ p ≤ 0.01, ¤¤¤ p ≤ 0.001

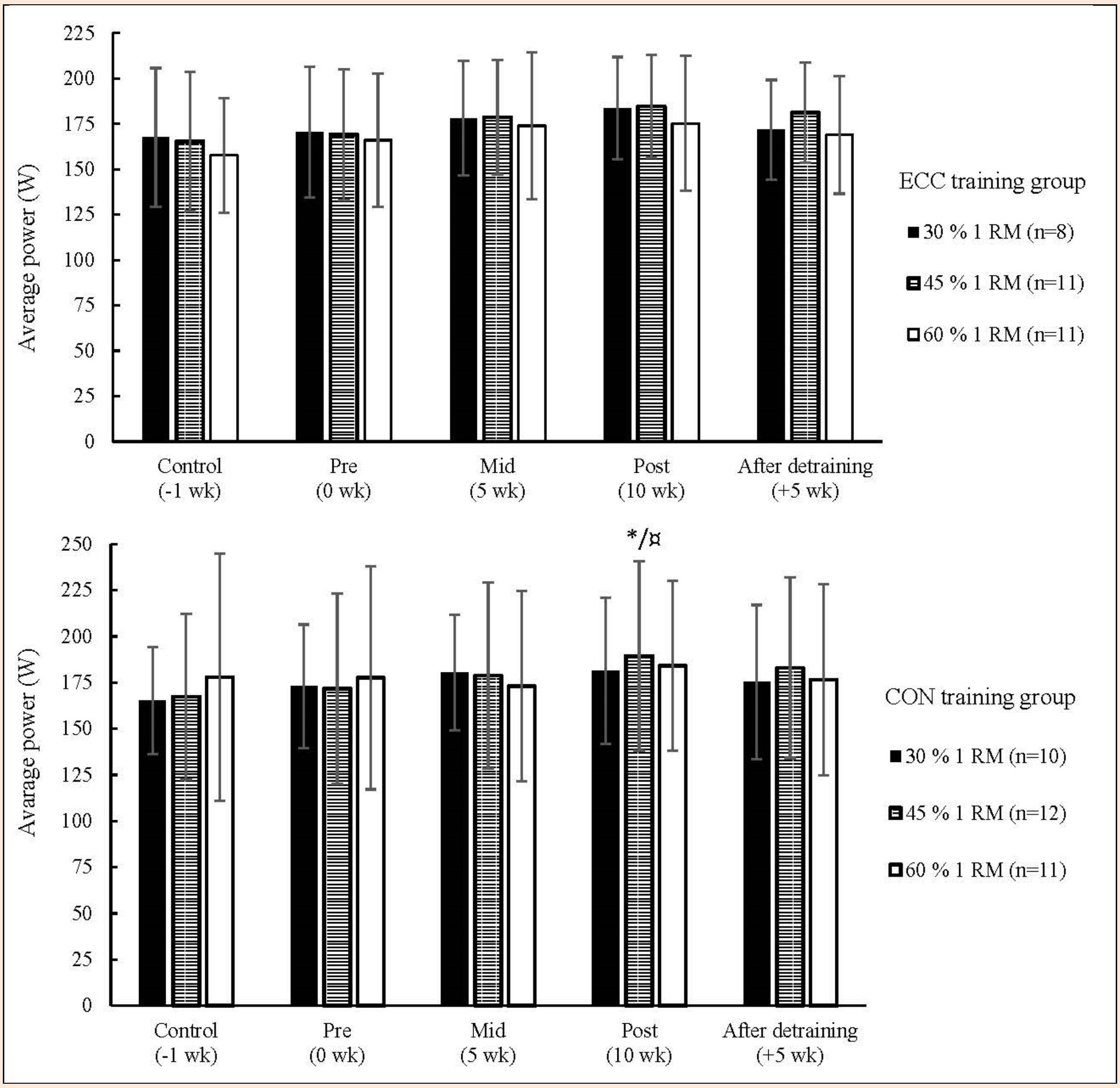

Figure 2. Average power of the eccentric (ECC) (upper) and concentric (CON) (lower) groups for all three measured loads of 30, 45 and 60 % of 1RM bench press. Significant difference from previous measurement within the group, * p ≤ 0.05. ¤ Significant change between pre and post measurement, ¤ p ≤ 0.05.

During the 5-week detraining period, CSA of TB (LoH) decreased both in ECC by -4.2 ± 3.7% (p < 0.01) and -4.7 ± 3.1% (p < 0.001) in CON and that of TB (LaH) by -7.9 ± 5.6% (p < 0.05) and -6.8 ± 4.6% (p < 0.01), respectively. The decrease of -10.7 ± 10% in the thickness of PM during detraining in ECC was not significant (p = 0.16), while in CON the decrease of -11.1 ± 8.1 % was significant (p < 0.05). The combined sum value of CSA and thickness decreased during detraining similarly in both ECC by -6.5 ± 4.3% (p < 0.001) and CON by -6.1 ± 2.8% (p < 0.001). Individual changes in the combined sum value of CSA and thickness during detraining correlated (r = 0.635, p = 0.001) with changes in dynamic bench press 1RM in the total group of ECC and CON participants (Figure 4). The post-detraining combined sum muscle mass value was in ECC higher (p < 0.05) than at pre-training. No significant difference occurred in CON and no between-group difference was observed.

Table 3. Maximal EMG (mV) of PM (pectoralis major), TB (triceps brachii), AD (anterior deltoid) and the SUM of PM+TB+D.A. during the maximal isometric bench press action in the ECC, CON and total group (ALL) of women participants at Control, Pre-, Mid-, Post- Strength Training and After Detraining. Data are Means ± SD.

		Control (-1 wk)	Pre (0 wk)	Mid (5 wk)	Post (10 wk)	After Detraining (+5 wk)
PM (mV)	ECC (n=11)	0.135 ± 0.090	0.156 ± 0.112	0.162 ± 0.105	0.161 ± 0.084	0.118 ± 0.050
	CON (n=11)	0.133 ± 0.068	0.153 ± 0.099	0.149 ± 0.079	0.165 ± 0.100	0.154 ± 0.100
	ALL (n=22)	0.134 ± 0.078	0.155 ± 0.103	0.155 ± 0.091	0.163 ± 0.090	0.136 ± 0.079
TB (mV)	ECC (n=11)	0.259 ± 0.085	0.262 ± 0.104	0.272 ± 0.111	0.308 ± 0.117	0.269 ± 0.147
	CON (n=11)	0.264 ± 0.107	0.239 ± 0.099	0.221 ± 0.079	0.268 ± 0.070	0.223 ± 0.094
	ALL (n=22)	0.261 ± 0.094	0.250 ± 0.100	0.246 ± 0.097	0.288 ± 0.096	0.246 ± 0.123
AD (mV)	ECC (n=10)	0.348 ± 0.172	0.302 ± 0.155	0.310 ± 0.147	0.362 ± 0.147	0.268 ± 0.100
	CON (n=11)	0.369 ± 0.158	0.354 ± 0.146	0.340 ± 0.148	0.429 ± 0.196	0.355 ± 0.152
	ALL (n=21)	0.359 ± 0.161	0.329 ± 0.149	0.325 ± 0.145	0.397 ± 0.173	0.314 ± 0.134***
SUM (mV)	ECC (n=10)	0.730 ± 0.214	0.711 ± 0.207	0.730 ± 0.220	0.823 ± 0.243	0.630 ± 0.197###
	CON (n=11)	0.764 ± 0.279	0.746 ± 0.245	0.709 ± 0.244	0.861 ± 0.248	0.732 ± 0.232#
	ALL (n=21)	0.748 ± 0.245	0.729 ± 0.222	0.719 ± 0.227	0.843±0.240#¤	0.684 ±0.217###

ECC = eccentric training group, CON = concentric training group, ALL = all female participants. Significant difference between post and detraining measurements within the group. *** p ≤ 0.001. Significant difference from previous measurement within the group. # p ≤ 0.05, ### p ≤ 0.001. Significant change between pre, and post-training measurements. ¤ p ≤ 0.05.

Table 4. Relative changes in thickness of PM (pectoralis major), cross-sectional area of TB (triceps brachii, LoH: long head) and TB (LaH: lateral head) and Sum of all three muscles in the ECC and CON groups of women during the Control period (week -1 and 0) and during training Pre-Mid (week 0 and 5), Mid-Post (week 5 and 10), Pre-Post (Week 0 and 10) and during Detraining (Week 10 and 15). Data are Means ± SD.

		Control Period Change %	Pre-Mid Training Change %	Mid-Post Training Change %	Pre-PostTraining Change %	PostTraining PostDetraining Change %
PM	ECC (n=11)	2.6 ± 3.3 %	10.2 ± 8.0 %	6.7 % ± 5.8 %	17.7 % ± 10.9 %	-10.7 % ± 10.0 %
	CON (n=12)	1.5 ± 3.6 %	8.1 ± 5.5 %	5.7 % ± 6.4 %	14.0 % ± 5.9 %	-11.1 % ± 8.1 %
TB LoH	ECC (n=11)	0.4 % ± 2.7 %	5.3 % ± 4.9 %	3.1 % ± 3.7 %	8.7 % ± 8.0 %	-4.2 % ± 3.7 %
	CON (n=12)	1.1 % ± 1.7 %	2.5 % ± 2.4 %	0.9 % ± 2.1 %	3.4 % ± 1.6 %	-4.7 % ± 3.1 %
TB LaH	ECC (n=11)	0.3 % ± 2.3 %	9.4 % ± 4.6 %	5.7 % ± 5.6 %	15.7 % ± 8.0 %	-7.9 % ± 5.6 %
	CON (n=12)	1.8 % ± 3.4 %	4.7 % ± 3.9 %	4.8 % ± 3.6 %	9.7 % ± 6.6 %	-6.8 % ± 4.6 %
Sum of all	ECC (n=11)	0.5 % ± 1.8 %	7.5 % ± 3.7 %	4.5 % ± 3.4 %	12.4 % ± 6.9 %	-6.5 % ± 4.3 %
	CON (n=12)	1.5 % ± 2.2 %	3.8 % ± 2.5 %	3.2 % ± 2.1 %	7.1 % ± 2.9 %	-6.1 % ± 2.8 %

ECC = eccentric training group, CON = concentric training group.

Serum hormone concentrations

No significant changes were detected in mean serum hormone and SHBG concentrations in either ECC or CON groups during the control, training, or detraining periods (Table 5). However, individual serum-free testosterone concentrations at the pre-measurement correlated (r = 0.520, p = 0.016) with changes in dynamic bench press **1**RM during the 10-week training period in the total group of ECC and CON participants (Figure 5).

Subjective muscle soreness

No statistically significant changes were observed in resting morning values of perceived muscle soreness recorded 1 and 2 days after the training sessions in the ECC and CON groups of participants during the 10-week strength training period (Figure 6).

Discussion

Ten weeks of maximal eccentric and concentric strength training of the upper extremities only twice a week in women led to significant gains in dynamic strength (1RM) in both groups. At the same time, isometric force increased only in ECC. Total muscle mass sum value of trained TB and PM muscles increased more during ECC than CON training. No changes occurred in serum hormone concentrations, but individual baseline serum-free testosterone concentrations correlated with changes in 1RM during strength training in the whole group of women. During detraining, both groups showed significant decreases in dynamic 1RM, maximal isometric force, maximal EMG activation, muscle mass of the upper extremities, while after detraining the muscle mass value remained only in ECC significantly higher than at pre-training.

Our results showed that strength training of the upper extremities only twice a week by performing only 2-4 sets comprised of only 3-4 single maximal ECC or CON repetitions per set per training session led to large increases of 17% and 13% in dynamic bench press 1RM in the present ECC and CON groups of women. This finding from maximal single repetitions and rather a low overall volume of the present strength training is unique. It also may give some interesting perspective to consider, since a recent review (Hagstrom et al., 2020) where it was concluded that strength training for the upper body in women should be performed with 3-4 sets per exercise on 2-4 training days per week to stimulate maximal strength gains. Nevertheless, the present increases in maximal dynamic strength are somewhat similar to both earlier and recent studies obtained during 6-12 weeks of CON and/or ECC strength training in the lower extremities in women and men (Coratella et al., 2018; 2021; Roig et al., 2009; Coratella and Schena, 2016) and in the upper extremities in men (Häkkinen and Komi 1981). Coratella et al., (2021) showed recently that 8 weeks of CON, ECC and CON-ECC resistance training for knee extensor muscles in women increased both concentric and isometric torque similarly in all groups, whereas eccentric torque increased more in ECC than in CON. In the case of the upper body, we found that dynamic bench press 1RM in both ECC and CON groups increased significantly during both the first five as well as the latter five weeks of strength training. This may, in part, be due to the progressive increases in the numbers of sets and maximal singles per set in both groups over the training period. Since muscle EMG activation was not recorded during the dynamic bench press 1RM actions, it remains to be determined to what extent specific training mode adaptations in maximal muscle activation might have occurred during the training period. It is also important to note that our participants performed either ECC or CON training actions with the same rather slow velocity (0.2 m/s) in the training sessions. However, the bench press 1RM included the lowering phase followed by a short duration pause at the chest before completing the propulsive phase of the lift. This specificity may have contributed to some extent to the gains in 1RM in both groups. After 5 weeks of detraining, both ECC and CON groups showed significant decreases of -7% and -8% in bench press 1RM. In general, both the magnitudes of the reductions in maximal dynamic 1RM during the present detraining period are somewhat similar to those reported over 4 - 8 weeks of detraining for the knee extensors in women (Coratella et al., 2018) and in men (Häkkinen et al., 1985; Roig et al., 2009; Coratella and Schena, 2016). However, a shorter detraining period of only 2-3 weeks has been reported to lead to no significant decreases in 1 RM of the knee extensors in men and women (Häkkinen et al., 2000).

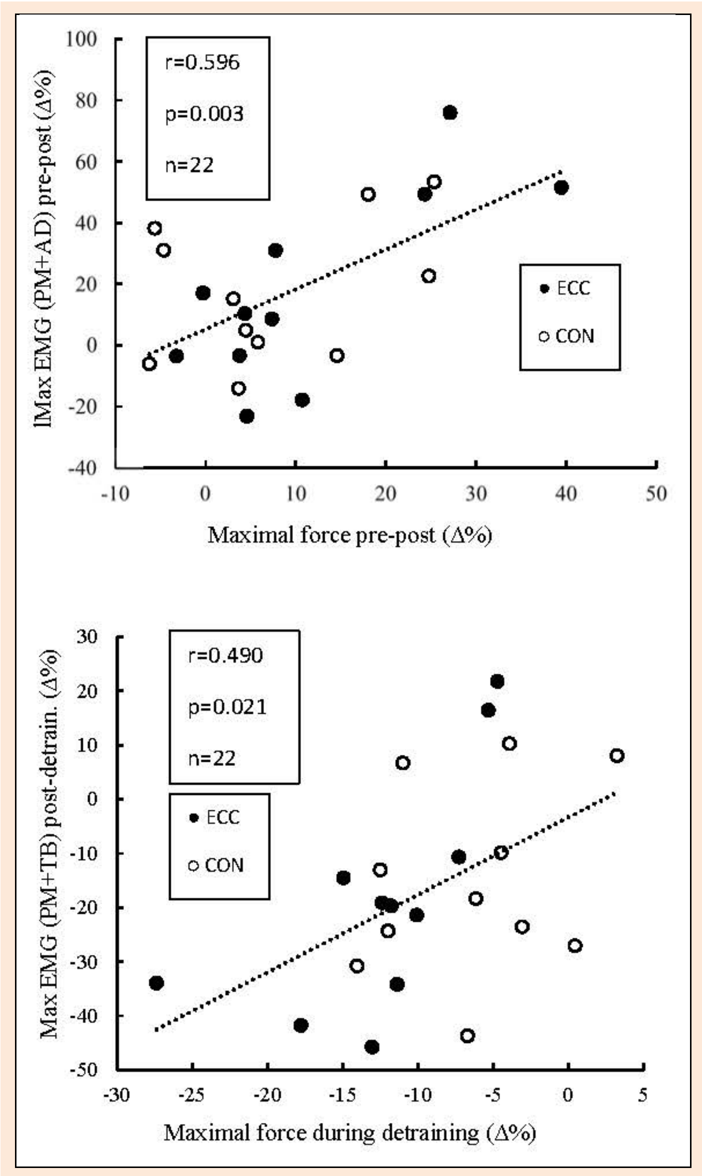

Figure 3. **The relationship between individual changes in maximal total EMG activation of pectoralis major and anterior deltoid (PM+AD) muscles and changes in maximal isometric bench press force during the 10-week strength training period (upper figure) as well as between individual changes in maximal total EMG activation of pectoralis major and triceps brachii (PM+TB) muscles during the 5-week detraining period (lower figure) in the total group of eccentric (ECC) and concentric (CON) women participants.**

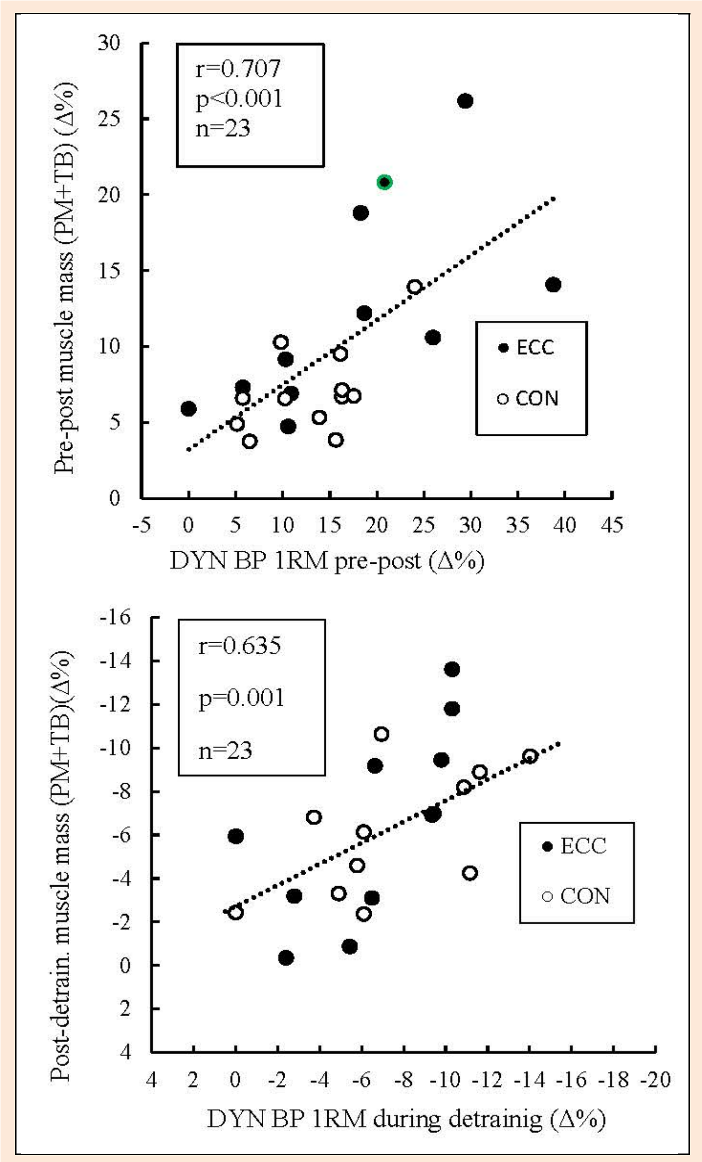

Figure 4. The relationship between individual changes in the total muscle mass value of pectoralis major and triceps brachii and individual changes in dynamic bench press (DYN BP) 1RM during the 10-week strength training period (upper figure) and during the 5-week detraining period (lower figure) in the total group of eccentric (ECC) and concentric (CON) groups of women participants.

The increases in maximal isometric forces were minor in both ECC and CON groups compared to the gains in dynamic 1RM performance during the present 10-week strength training period. The statistically significant improvement of 10% in isometric force occurred only in ECC during the latter 5-week training period. On the other hand, the 5-week detraining period led to significant decreases of -11% in ECC and -7% in CON in maximal isometric force. No previous studies are available related to CON and ECC strength training or detraining effects on the isometric force of the upper body in women. However, in a meta-analysis, Roig et al. (2009) reported that gains in maximal isometric force of the knee extensor might not differ much between ECC or CON training.

Although mean maximal sum EMG activation of PM, TB and AD muscles during the maximal isometric action increased during the 10-week training period by 17 ± 19 % and 21 ± 31 % in ECC and CON respectively, large inter-individual variation occurred in both groups and these changes were not statistically significant. However, in the total combined group of ECC and CON women a significant increase of 16% during training occurred in maximal sum EMG activation of these muscles. It is important to note that large interindividual differences occurred during training in the gains of both isometric force and maximal EMG and thus no between group differences were observed. However, individual changes in the maximal EMG activation of trained muscles of the upper extremities and changes in isometric force were correlated significantly during the training and detraining in the total group of women (Figure 3). Significant increases during strength training and decreases during detraining in maximal electromyographic activity of the knee extensors have been observed in several previous studies in both men and women, especially in previously untrained participants (Moritani and DeVries, 1979; Häkkinen and Komi, 1983; Häkkinen et al., 1992). Although it is important to be cautious with interpretations of surface EMG data, regular and perhaps more individualized strength training is vital in increasing and maintaining maximal voluntary neural activation of the trained muscles. However, the methods used in the present study do not reveal possible mechanisms of decreased muscle activation during detraining.

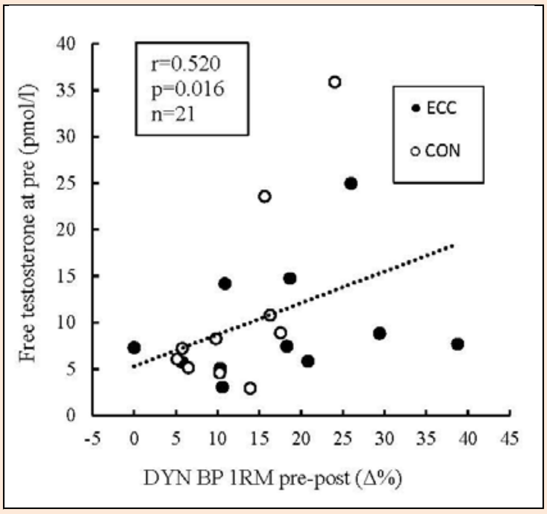

Figure 5. The relationship between individual free testosterone concentrations at the pre training measurement and individual changes in dynamic bench press (DYN BP) 1RM during the 10-week strength training period in the total group eccentric (ECC) and concentric (CON) women participants.

A significant increase in average power occurred only in the CON group and at the load of 45% of 1RM with no significant changes in ECC. Since power was measured during the concentric action, this finding demonstrates the specificity of measurement and training mode. Furthermore, the present training program included no power-type training at submaximal loads with higher velocity needed to drive larger gains in power and explosive strength as observed in women both in the upper (Kyröläinen et al., 1998) and lower body (Häkkinen et al., 1990). Although eccentric strength training effectively promotes strength gains, whether the neural specificity of eccentric exercises may compromise the transferability of strength gains to more functional movements require further investigation (Roig et al., 2009). Since only minor increases in average power occurred in both groups, it could be expected that the 5-week detraining period did not lead to significant decreases in concentric power.

Interestingly, CSA of the long head of TB increased during the training period more in ECC than CON and differed significantly between the groups. In addition, the total sum value of all three muscles increased during strength training more in ECC than CON, differing also between the groups. The PM thickness increased significantly during the training period in both groups. The overall magnitude (12.4%) of muscle hypertrophy in the ECC group can be considered large, since the training protocol was focused on maximal strength and included only 2-4 sets of 3-4 single maximal ECC repetitions per set per training session performed only twice a week. Bench press exercise is known to activate PM, TB and AD muscles (e.g., Stastny et al., 2017). Previous studies in men have observed greater strength training-induced muscle hypertrophy in PM than in TB muscles (Brandão et al., 2020) as also observed in the present female ECC and CON groups. The current findings regarding larger hypertrophy of the upper extremities in women using ECC vs. CON strength training are unique. Larger increases in muscle hypertrophy of knee extensor muscles by eccentric training compared to concentric training have been reported earlier by Higbie et al. (1996) in women and Seger et al. (1998) in men as well as Vikne et al. (2006) regarding elbow flexors in men during 2-3 months of strength training. A typical training protocol for muscle hypertrophy could employ a repetition range of 6-12 reps per set (with loads performed near or until failure) with short rest intervals between sets and it is also important to consider how training is optimally periodized over time (Schoenfeld et al., 2021; Lopez et al., 2021). Nevertheless, Schoenfeld et al. (2017) also concluded that eccentric muscle actions resulted to somewhat greater muscle hypertrophy than concentric actions. It is also important to note that some studies have included eccentric training performed alone or in conjunction with concentric contractions in comparison to concentric training only. This may complicate the accurate comparisons between eccentric only versus concentric only training-induced muscle hypertrophy and strength gains (Douglas et al 2017). The present study also showed that individual changes in the combined sum value of CSA and thickness of PM and TB correlated significantly with changes in bench press 1RM during the training period in the total group of ECC and CON (Figure 4). Those women with greater hypertrophy also demonstrated greater gains in dynamic 1RM and mostly belonged to the ECC group.

Table 5. Serum hormone and SHBG concentrations in the ECC and CON groups of women participants at Control, Pre-, Mid-, Post- Strength Training and After Detraining. Data are Means ± SD.

		Control (-1 wk)	Pre (0 wk)	Mid (5 wk)	Post (10 wk)	After Detraining (+5 wk)
Free testosterone	ECC (n=11)	9.64 ± 8.87	9.53 ± 6.24	11.09 ± 5.93	9.61 ± 3.70	12.57 ± 6.58
(pmol/l)	CON (n=10)	12.67 ± 8.65	11.33 ± 10.36	12.70 ± 9.69	12.44 ± 8.71	13.69 ± 11.64
Cortisol	ECC (n=11)	546.2 ± 165.4	486.0 ± 177.9	491.7 ± 121.2	459.8 ± 142.6	427.5 ± 144.7
(nmol/l)	CON (n=11)	434.3 ± 129.0	388.7 ± 119.3	404.1 ± 125.0	393.0 ± 99.0	422.5 ± 81.8
SHBG	ECC (n=9)	110.5 ± 102.7	111.2 ± 99.1	110.2 ± 91.3	107.9 ± 94.7	92.2 ± 97.0
(nmol/l)	CON (n=11)	60.1 ± 27.0	57.1 ± 29.2	62.0 ± 26.2	66.5 ± 23.7	60.8 ± 28.4
Estradiol	ECC (n=11)	361.7 ± 368.9	398.4 ± 395.7	474.2 ± 535.9	475.4 ± 825.6	399.4 ± 473.6
(pmol/l)	CON (n=11)	501.7 ± 391.1	404.2 ± 245.5	284.8 ± 160.4	521.8 ± 524.1	418.6 ± 506.8
FSH	ECC (n=10)	4.87 ± 2.94	3.62 ± 2.01	5.04 ± 3.07	6.40 ± 3.18	6.32 ± 2.78
(U/l)	CON (n=11)	6.25 ± 2.67	5.12 ± 2.33	6.97 ± 2.46	6.44 ± 2.59	7.17 ± 2.62

ECC = eccentric training group, CON = concentric training group

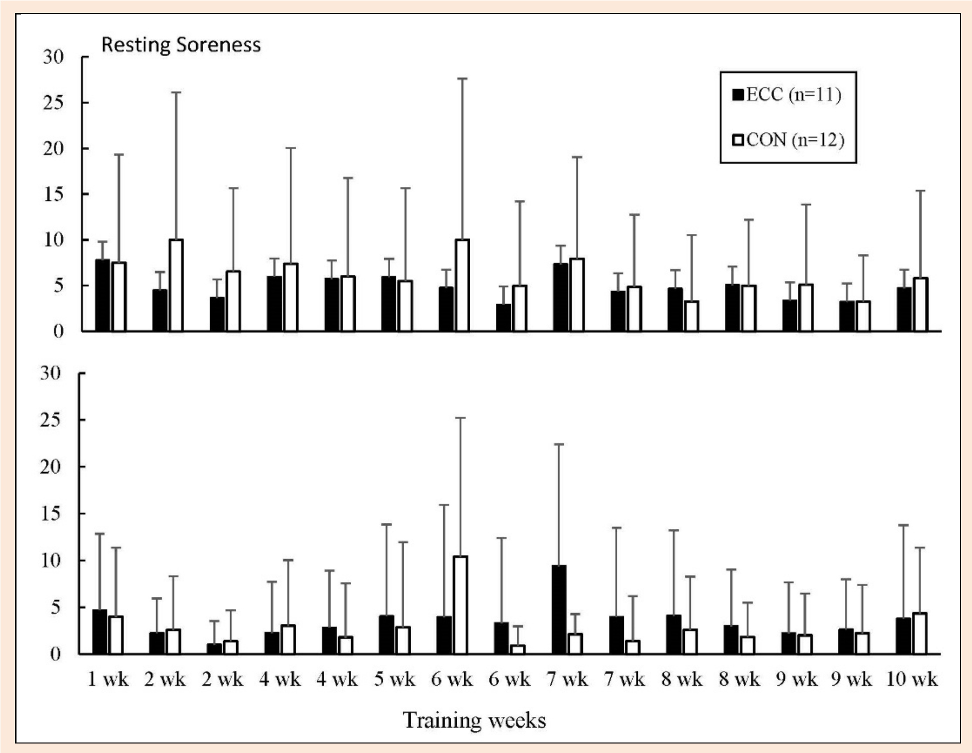

Figure 6. Resting morning values of perceived muscle soreness (mean of chest, shoulder and arm extensor muscles) one day (upper figure) and two days (lower figure) after the training sessions in the ECC and CON groups of female participants during the strength training period of 10 weeks (recorded once or twice per each week; except week 3). Data are Means ± SD.

Our study showed that the 5-week detraining period in women led to similar decreases in the combined size of PM and TB muscles by -6% in both the ECC and CON groups. Individual changes in muscle mass during detraining correlated significantly with changes in bench press 1RM in the total group of ECC and CON participants. However, the decrease in thickness of PM during detraining was not significant for ECC, only in CON and after detraining the muscle combined sum value of CSA and thickness remained only in ECC significantly higher than that recorded at pre-training. This finding is interesting and well in line with the results of Coratella et al. (2021) who reported that lean mass of the knee extensors was retained over an 8-week detraining period only in eccentric trained women. The authors suggested that including the eccentric phase in resistance training may be essential to preserve adaptations during detraining. However, mechanisms related to this phenomenon need further investigation.

The present study showed no statistically significant changes in the serum hormone or SHBG concentrations during the 10-week upper body strength training or detraining periods in ECC or CON groups. In general, we interpret this finding to suggest that our ECC and CON upper body strength training programs with progressive increases in the overall volume of training and a recovery of at least two days between training sessions might have been well within reasonable physiological limits. In part, the finding may be supported by low resting morning perceived muscle soreness values reported by the participants in both the CON and ECC groups throughout the training intervention. Interestingly, individual baseline serum-free testosterone concentrations correlated significantly with individual changes in bench press 1RM during the training period in the entire group of female participants. Although this finding should be treated with caution, it is unique. It may be used to infer that in women the basal concentration of free testosterone is of importance for strength development during strength training of the upper body. Further, adaptations to strength training in women seem to be highly individual. In addition, when the overall volume of strength training is higher and a training period longer than in the present study, strength training especially in women may need proper and individualized periodization (Häkkinen 1994). Nevertheless, the present findings regarding serum hormones, especially testosterone concentrations, correspond well with several other strength training studies that have focused on strength training of the lower body 2-3 times a week both in women and men (Häkkinen et al., 1985; 1992; Ahtiainen et al., 2003; Kraemer and Ratamess, 2005).

There are some limitations in the present study. It needs to be acknowledged that a separate control group was not included, but the participants acted as their own controls over the one-week control period with no strength training. Ten women reported using hormonal contraceptives, but these participants were distributed across both groups. The training period could have been somewhat longer than 10 weeks, because actual differences between the training protocols may occur after 8 to 10 or after 10 to 12 weeks of training (Häkkinen and Komi, 1981; Häkkinen 1994; Schoenfeld et al., 2017). On the other hand, the strengths of the present study were that the participation rate for the training sessions was 100% in both ECC and CON groups and each training sessions was fully supervised. The volume (number of sets and single reps per set) of strength training increased progressively both in ECC and CON groups. Small indelible ink tattoos were placed onto the skin of the muscles trying to ensure that the EMG electrodes would be placed exactly onto the exact locations for each measurement (Häkkinen and Komi 1983). However, the EMG measurements can include errors e.g., due to possible changes in muscle fat during the prolonged intervention, which cannot necessarily be totally avoided. Muscle hypertrophy was measured by ultrasound to record either CSA or thickness of the trained muscles using small indelible ink tattoos and/or reference marks to minimize errors in the consistency of locations.

Conclusion

To conclude, 10 weeks of eccentric or concentric strength training of the upper body only twice a week using a maximal single repetition protocol in women led to relatively large increases in dynamic bench press 1RM. In contrast, eccentric training produced larger muscle hypertrophy of trained muscles than concentric training. Large individual differences occurred in the trainability of the neuromuscular performance in both eccentric and concentric training in women. For practical purposes the concentric only mode could be used for an initial phase (e.g., 6-8 weeks), since it is as effective as eccentric for dynamic strength gains, while thereafter, ECC only (or a combination of both ECC and CON; not investigated in the present study) training could be used for an additional training phase (e.g., 4-6 weeks) to continue to enhance muscle hypertrophy.

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Key points

- Maximal eccentric and concentric strength training in women for 10 weeks (only twice a week) led to great gains in dynamic strength of upper body.
- Upper body muscle mass increased more after eccentric than concentric strength training.
- During detraining for 5 weeks both groups showed decreases in strength and muscle mass.
- However, post-detraining combined sum muscle mass value was only in ECC higher than at pre-training.

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