Elbow Flexor Muscle Thickness and Estimated One-Repetition Maximum in Untrained Individuals is Greater Following 8-weeks of Isotonic vs. Eccentric Quasi-Isometric Resistance Exercise: Exploring the Influence of Sex and Volume

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Abstract

As a novel, low-velocity resistance exercise method, eccentric quasi-isometric resistance exercise (EQI-RE) results in greater time under tension than traditional isotonic resistance exercise (TRD-RE) and is surmised to increase muscle mass and strength. However, females may be more fatigue resistant than males when performing acute EQI-RE, which could lead to long-term differences in time under tension and resistance exercise volume. At present, studies have yet to compare muscle hypertrophy or strength improvements following TRD-RE and EQI-RE training, and whether sex-differences exist in these outcomes. Twenty-two (*n* = 13 females) untrained individuals completed ~8-weeks of effort matched unilateral TRD-RE and EQI-RE of the elbow flexors. Muscle thickness and estimated one-repetition maximum (E-1RM) were evaluated before and after training. TRD-RE produced significantly larger relative increases in muscle thickness (6.7% ± 3.9% vs. 4.0 ± 3.3%, p =.004) and E-1RM (19.6 ± 8.5% vs. 12.8 ± 6.2%, p = .001) than EQI-RE. Although females accrued greater resistance exercise volume than males across the TRD-RE and EQI-RE training, there were no relative sex-differences in muscle thickness or E-1RM improvements (p > .25). Sex-differences in fatiguability may therefore manifest in differences in resistance exercise volume between males and females after 8-weeks of TRD-RE and EQI-RE of the elbow flexors, but this does not lead to relative differences in muscle thickness or E-1RM improvements. Although EQI-RE did produce significant increases, TRD-RE of the elbow flexors appears more effective at increasing muscle thickness and E-1RM.

Keywords: Hypertrophy, b-mode ultrasound, resistance training, strength, bicep curls

Introduction

The exercise prescription principles of specificity and individualisation suggest that exercise selection or programming should address the desired component of fitness or outcomes, and that expected adaptations and/or needs of an individual will vary (Prentice 2017; Klavora and Locke 2018). With respect to resistance exercise, recent attention has been given to the potential influence of sex on strength and hypertrophy adaptations; data suggests that males and females do not substantially differ in relative hypertrophy potential to a given resistance exercise program, although females may experience slightly greater relative strength increases, especially for upper-body musculature (Roberts et al. 2020; Nuzzo 2022). Despite this, there is continued interest and debate regarding the relevance of an individual's sex and/or gender in the context of resistance exercise prescription, especially when it comes to differences in male and female physiology (e.g., Colenso-Semple et al., 2023; Henderson & Scribbans, 2020; Nimphius, 2019; Nolan et al., 2024; Nuzzo, 2022; Parsons et al., 2021). Apart from differences in sex hormones and menstruation, males and females typically differ in muscle fibre type distribution and size (Nuzzo 2024), muscular endurance (Hunter 2014, 2016a, b), and absolute strength (Nuzzo 2022). Many of these differences, however, are specific to the muscle, muscle action (i.e., eccentric vs. isometric), and the intensity of the task (Hunter 2014; Nuzzo 2022), yet collapsing of male and female data for statistical analysis is common, and females remain underrepresented in exercise science studies (Costello et al. 2014; Counts et al. 2016; Sims and Heather 2018; Cowley et al. 2021).

Regardless of sex, improvements in overall health, muscle strength, and muscle mass can be achieved in response to a variety of resistance exercise modalities (Lixandrão et al. 2018; Oranchuk et al. 2019a; Currier et al. 2023) and "muscle strengthening" activities (World Health Organization, 2022). That being said, isotonic (alternating eccentric and concentric muscle actions) resistance exercise is typically studied, recommended, and prescribed to improve strength and stimulate muscle growth (Ratamess et al. 2009; Currier et al. 2023). Recent work, however, suggests that the concentric component of isotonic resistance exercise may contribute little to training-related improvements in muscle hypertrophy and strength relative to the eccentric component (Sato et al. 2022). As such, to optimise improvements in muscle strength and muscle mass (i.e., hypertrophy), there has been increased interest in research on resistance exercise at long muscle lengths and/or that augments the eccentric component of isotonic resistance exercise (Oranchuk et al. 2019a, b; Kassiano et al. 2023; Nuzzo et al. 2023).

Eccentric quasi-isometrics (EQIs) are a low-velocity resistance exercise technique suggested to elicit the hypertrophy benefits of traditional isotonic resistance exercise (TRD-RE), while minimizing muscle fatigue and high levels of torque associated with high-velocity resistance exercise (Oranchuk et al. 2019b). By performing a "holding" isometric muscle action until positional fatigue, and then voluntarily resisting the resulting eccentric muscle action, EQI-RE produces significantly more time under tension than TRD-RE (Henderson et al. 2025). The large quantity of mechanical tension produced during EQI-RE is theorised to result in meaningful muscle hypertrophy (Oranchuk et al. 2019b), while practitioners also purport greater motor unit recruitment and strength development using the EQI concept (e.g., Morrison 2016; Seedman n.d.; Sinicki 2019), despite a paucity of research supporting these claims.

The suggestion that EQI-RE would meaningfully improve isotonic strength would contravene the principle of specificity, in that the velocity of EQI-RE would have little overlap with the velocity and neuromuscular demands of expressing strength during isotonic exercise. For this reason, researchers have cast doubt on the relevance of EQI-RE for improving strength or power during higher velocity movements (Oranchuk et al. 2019b). Furthermore, research in our laboratory suggests unremarkable muscle excitation from acute EQI-RE on its own (Henderson et al. 2023), or when compared to TRD-RE (Henderson et al. 2025). Males and females do, however, appear to have differing neuromuscular and fatigue responses to TRD-RE and EQI-RE (Henderson et al. 2025). Specifically, sex-differences in resistance exercise volume (total repetitions and time under tension) are much greater when performing EQI-RE compared to TRD-RE. Based on the positive relationship of resistance exercise volume with muscle hypertrophy (Schoenfeld et al. 2017), the magnitude of mechanical tension and time under tension are likely the main drivers of morphological adaptations to EQI-RE (Oranchuk et al. 2019b; Henderson et al. 2023). As such, it seems reasonable to suggest that acute sex-differences in resistance exercise volume could manifest in long-term differences in EQI-RE adaptations between males and females. At present, however, no studies have examined long-term hypertrophy or strength improvements to EQI-RE or compared them to TRD-RE.

The purpose of the current study was threefold. Primarily, the current study sought to determine if ~8-weeks of EQI-RE produced comparable changes in muscle mass (muscle thickness) and strength (estimated one-repetition maximum; E-1RM) to TRD-RE in untrained individuals, and whether sex-differences are present in these changes. For both TRD-RE and EQI-RE, the study also explored the relationship between changes in muscle thickness and E-1RM, and the relationship between resistance exercise volume (total repetitions and total time under tension), muscle thickness, and strength changes, and if these relationships were moderated by sex. For the primary objective, it was expected that TRD-RE and EQI-RE would produce significant relative increases in muscle thickness E-1RM after ~8-weeks of training (expressed as a change score relative to pre-testing; % change), with TRD-RE and EQI-RE producing comparable increases in muscle thickness, but TRD-RE resulting in a greater increase in E-1RM. Based on our previous work indicating females produced greater time under tension during EQI-RE as males, it was hypothesised that females would experience greater muscle thickness % change and E-1RM % change than males for EQI-RE, however, we anticipated no meaningful sex-differences for TRD-RE.

Methods

A pre-post, between groups, unilateral design (Macinnis et al. 2017) was used to compare changes in elbow flexor muscle thickness and E-1RM after ~8-weeks of TRD-RE and EQI-RE between males and females. Using a Latin square (Portney et al., 2015) based on hand dominance (as assessed using the Edinburgh Handedness Inventory; Oldfield 1971) and order of completion, each participant's limbs were assigned to either TRD-RE or EQI-RE. B-mode ultrasonography and the Canadian Society for Exercise Physiology 10-RM protocol (Canadian Society for Exercise Physiology 2013) were used to evaluate elbow flexor muscle thickness and supinated dumbbell bicep curl E-1RM of each limb, before and after completion of the TRD-RE and EQI-RE training. All pre-post measures were collected at the same time of day (± 2 hours) when scheduling permitted. The study was approved by the University of Manitoba Research Ethics Board (REB 1; HE2023-0066), and all participants provided informed consent prior to participation.

Participants

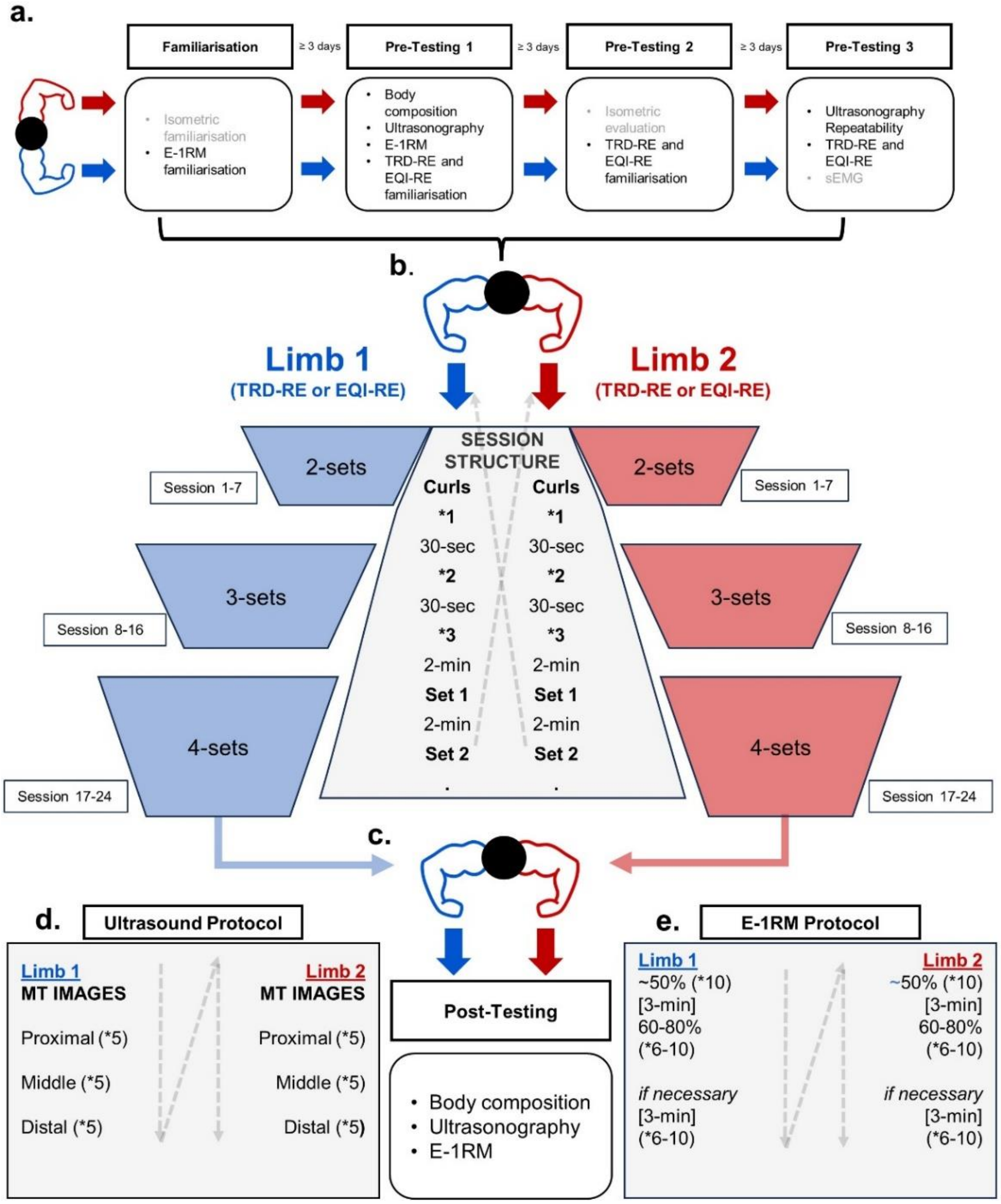
A total of 30 male and female (sex assigned at birth) participants were recruited. Participants were eligible if they 1) were between 18-35 years old, 2) were free of acute and/or chronic musculoskeletal pain or injuries that would affect their ability to participate in unilateral resistance exercise of the elbow flexors with both arms, 3) had no previous diagnoses of cancer or neurological disease/disorders, and 4) were not regularly using prescription anti-inflammatory medications (i.e., weekly use of non-steroidal anti-inflammatory), and 5) were cleared for physical activity by the Get-Active Questionnaire (Canadian Society for Exercise Physiology 2017). Furthermore, participants were to consider themselves untrained (performed structured resistance exercise < 2x per week for at least 6 months) but did not have to be novel to resistance exercise. As current research suggests that the menstrual cycle and oral contraceptive use are likely to have limited and/or trivial effects on adaptations to resistance exercise (Colenso-Semple et al. 2023; Nolan et al. 2024), and with no research examining the effects of intrauterine contraception on resistance exercise adaptations (Henderson and Scribbans 2020), these variables were not controlled for.

Protocol Overview

As part of a larger project, participants came to the lab for 4 in-person sessions (1 familiarisation and 3 pre-testing, ≥ 3 days between sessions), followed by ~8-weeks (23 sessions, ≥ 2 days between sessions) of supervised TRD-RE and EQI-RE, and 1 post-testing session (≥ 3 days after last training session). The current study presents data from the first pre-testing session and the post-testing session. An overview of the study protocol is presented in Figure 1, and relevant reporting items for the resistance exercise intervention are reported in Table 1 as per Lin et al. (2023). All resistance exercise sets were performed with 70% E-1RM.

Figure 1

Protocol Summary



Note. Participants completed a familiarisation for isometric and estimated 1-repetition maximum (E-1RM) strength, followed by 3 pre-testing sessions that included body composition assessment, as well as E-1RM, b-mode ultrasound, traditional isotonic resistance exercise (TRD-RE), and eccentric quasi-isometric resistance exercise (EQI-RE) of the elbow flexors (a.). Following familiarisation and pre-testing, participants completed 23 resistance exercise sessions of 2-4 sets, with one limb performing TRD-RE only, and one limb performing EQI-RE only (b.). After completing all resistance exercise sessions, body composition, ultrasound, and E-1RM, and were repeated (c.). E-1RM protocol (d.). Ultrasound protocol (e.).

Familiarisation

To start the familiarisation session, and as part of a different project, participants were familiarised with a series of unilateral elbow flexion maximal voluntary isometric contractions (MVIC) on an isokinetic dynamometer (Biodex Multi-Joint System Pro; Biodex Medical Systems, Inc.; Shirley, NY) at short, medium, and long muscle lengths. Following MVICs, participants were familiarised with the E-1RM test for a dumbbell unilateral supinated bicep curl.

E-1RM familiarisation was performed sequentially for both limbs, based on assigned order. To perform the E-1RM test, participants were positioned facing parallel to a wall/table with the lateral aspect of the non-involved shoulder 1-2 feet from the wall/table. For balance only, the non-involved limb was allowed to touch the wall and/or table, while the participants held a dumbbell in the limb away from the wall. The researcher and participant first selected a weight that could easily be completed for 10 repetitions (Canadian Society for Exercise Physiology [CSEP] 2013) and corresponded to ~50% of the participants' perceived 1-RM for a unilateral supinated bicep curl. After researcher demonstration, participants performed 10 unilateral repetitions to full elbow flexion while maintaining an upright posture. Participants were instructed to perform as many repetitions as possible, and to try and use a "one second up, two second down" cadence; light verbal correction on cadence was provided if necessary. After 3-minutes of rest, the weight was increased to ~60-80% of participants perceived 1-RM, to allow for volitional fatigue in 6-10 repetitions (CSEP, 2013). Participants were again instructed to perform as many repetitions as possible, and sets were only stopped if there was substantial deviation in form. If participants were able to complete 10 repetitions, the set was stopped, and participants were given another 3-minutes of rest. Weight was then increased again to allow for volitional fatigue in 6-10 repetitions (CSEP, 2013). Procedures were then repeated for the contralateral arm. A visual reference of the set-up is presented in Figure 2.

Figure 2

Default Set-up for 10-RM, TRD-RE, and EQI-RE.

Note.. Position of body and involved arm relative to the wall when performing 10-RM, TRD-RE, or EQI-RE.

Pre-Testing 1

Descriptive data (height, weight, age, sex) were recorded, and participants' body composition was assessed by bioelectrical impedance (InBody 270; InBody Co, Seoul, South Korea) as per manufacturer recommendations. Participants then laid supine on a treatment table for ~15 minutes, with their knees and elbows fully extended, forearms supinated, head, neck, and legs supported by a pillow. During this time, the ultrasound operator palpated and marked the acromion process and antecubital crease using a permanent marker (Perkisas et al. 2018). The distance of a line from the acromion process to the antecubital crease was then measured, and 50% (proximal), 65% (middle), and 80% (distal) of the distance from the acromion process was marked on this line. Elbow flexor muscle thickness was evaluated at these points of interest using b-mode ultrasound.

Muscle Thickness. A LOGIQ™ E10s (GE Healthcare, Chicago, U.S.) multi-purpose ultrasound and linear transducer array (ML6-15D, 50mm field of view, 80 mm depth, 4.5-15MHz bandwidth, GE Healthcare, Chicago, U.S) were used to obtain 2-dimensional b-mode ultrasound images. First, water-soluble transmission gel (Wavelength ® MP; National Therapy Products Inc, Brampton, On, Canada) was applied liberally and as needed over the marked points of interest and to the linear transducer. Starting at the most proximal point of interest, the linear transducer was oriented parallel to the biceps brachii muscle fibres. Minimal and consistent pressure was applied to the transducer to achieve maximum transducer-skin contact and limit compression of subcutaneous tissues (Chen et al. 2017; Kojić et al. 2021). With the transducer in contact with the skin, "LOGIQView" was used visualise an initial sagittal view of the elbow flexors. With the signal frequency set at 15 MHz, gain and depth were then adjusted for each participant to obtain optimal image resolution and depth (Adkins and Murray 2020), such that the superficial fascia and humeral surfaces were easily visible. Once image resolution and depth were optimised, a minimum of three still images were captured. Images were then obtained at the middle and distal points of interest using the same processes and then repeated on the contralateral limb. Participants were asked to remain as still and relaxed as possible for all ultrasound measurements. Following completion of muscle thickness imaging, participants performed the E-1RM testing.

Estimated One-Repetition Maximum Testing. To increase core body temperature, participants completed a 5-minute cardiovascular warm-up on a stationary bike at a 5-6 RPE (modified BORG scale; CSEP, 2013). The E-1RM testing was then completed as per the familiarisation session, with participants performing an initial warm-up set of 10 repetitions, followed by one or two more sets with a weight that participants could perform no more than 6-10 repetitions. After the final set for the first limb and 3-5 minutes of rest, procedures were repeated for the remaining limb. Based on the weight and number of repetitions completed, participants 1-RM was then estimated for each limb (Canadian Society for Exercise Physiology, 2013) and averaged. The average between limb E-1RM was then used to prescribe intensity for TRD-RE and EQI-RE (70% E-1RM).

Eccentric Quasi-Isometric Familiarisation. Following the E-1RM testing, participants were introduced to a dumbbell unilateral supinated EQI elbow flexion using visual and auditory instruction. Participants assumed the same position relative to the wall or table as the E-1RM testing and were again allowed to support themselves with the opposite limb. While holding a dumbbell at their side in a supinated grip, participants flexed their elbow to approximately -

130° of elbow flexion. In this position, participants were asked to maintain this position as long as possible by bracing their arm and elbow in position. When eccentric changes in joint angle occurred due to fatigue, participants were told to resist the resulting eccentric (lengthening) muscle action and attempt to maintain joint position until the dumbbell eventually reached full elbow extension, without compensating for the loss in position with a concentric (shortening) muscle action (Oranchuk et al. 2020). When participants felt comfortable with the instructions, they performed a single EQI elbow flexion repetition for the assigned limb, and any additional instructions during the repetition were given on an individual bases depending on participant's proficiency.

Pre-Testing 3 and 4

As part of additional investigations, participants completed two more pre-testing sessions, spaced at least 3-days apart. Participants performed the unilateral elbow flexion MVICs in a similar fashion as pre-testing 1. Following completion of the MVIC protocol, participants were introduced and instructed on performing a dumbbell unilateral supinated bicep curl (TRD-RE) in a similar fashion as the E-1RM test, with the addition of a 60 beat per minute metronome to guide repetition tempo. Participants were told to try and perform each repetition using a 1-second up (concentric), 2-second down (eccentric) tempo, but to do as many repetitions as possible regardless of their ability to maintain tempo; sets were only stopped if there was substantial deviation in form (e.g., excessive back arching. Depending on assigned order of completion, participants then performed two practice sets of the TRD-RE and EQI-RE using the corresponding limbs, with 2-minutes rest between sets and limbs.

Data and procedures from the final pre-testing session (pre-testing 4) are presented in Henderson et al. (2025). For the purposes of calculating muscle thickness reliability for other investigations, ultrasound procedures from pre-testing 2 were repeated. This was followed by performance of the TRD-RE and EQI-RE as they would be conducted for the duration of the training program, while surface electromyography was recorded from each limb.

Resistance Exercise Sessions

After completing the final pre-testing session, participants performed the supervised TRD-RE and EQI-RE training protocol for a total of 23 sessions. Participants were given a dumbbell corresponding to their 70% E-1RM to complete the training protocol in the lab or virtually over Zoom (Zoom Communications, Inc.; San Jose, USA). Alternating the starting limb every session, participants began each session with 3 warm-up sets of 1, 2, and 3 repetitions of dumbbell unilateral supinated bicep curls, with 30-seconds of rest between sets. After ~2 minutes of rest, participants performed set 1 of either TRD-RE or EQI-RE, followed by 2-minutes of rest and then set 2. After another 2-minutes of rest, the warm-up procedures and sets were repeated using the remaining limb/resistance exercise type. For sessions 1-7 (phase 1), 8-15 (phase 2), and 16-23 (phase 3), participants performed 2, 3, and 4 sets of TRD-RE and EQI-RE, respectively. For all sets, the supervising researcher counted and recorded the number of repetitions for TRD-RE and manually timed time under tension for EQI-RE using a stopwatch.

For virtual resistance exercise sessions, participants were requested to position their device (i.e., personal computer, mobile phone, etc.) on a table or chair, such that the camera angle was perpendicular to the sagittal plane when participants were positioned parallel against a wall or table. At minimum, the participants' mid-thigh was visible in the camera frame. Participants then performed the TRD-RE and EQI-RE as described, utilising a wall or table to support the contralateral limb, and a 60 beats per-minute digital metronome (google.com) to guide repetition cadence. The supervising researcher recorded and counted the number of repetitions for TRD-RE, and time under tension for EQI-RE. In case of technical difficulties, participants were instructed to continue with the session as described. No adverse events occurred during training and deviations from the intended protocol are noted in Table 1.

Table 1

Relevant Reporting Items for TRD-RE and EQI-RE

Items	TRD-RE	EQI-RE	Notes/Deviations
Exercise Description	Dumbbell unilateral supinated BC Full elbow ext. to ~full flex.	Dumbbell unilateral supinated EQI elbow flexion ~130° flex to full elbow ext.	
Frequency and Duration	23-sessions, 3-session/week, minimum 2-days between sessions	23-sessions, 3-session/week, minimum 2-days b/w	*Mean time to complete: 60.3 ± 4.3 days (8.5 weeks). 6 participants completed 22 sessions.*
Warm-up	Sets of 1, 2, and 3 BC repetitions 30-seconds b/w sets, 2-min before TRD-RE set 1	Sets of 1, 2, and 3 BC repetitions 30-seconds b/w sets, 2-min before EQI-RE set 1	
Intensity	70% E-1RM BC	70% E-1RM BC	
Repetitions and Sets	Participant determined maximum repetitions/volitional fatigue	Participant determined volitional fatigue/contact with hip, 1 EQI elbow flexion = 1 set	*For TRD-RE, participants were to complete max repetitions regardless of tempo.*
Tempo	60 BPM metronome; 2-sec ECC, 1-sec CON	N/A, variable	*Metronome for guide/assistance only, set not ended based on tempo.*
Rest Interval	2-min b/w sets	2-min b/w sets	
Focus	External + internal	External + internal	
Muscle Action	ECC + CON	Isometric + ECC	
Progression and Periodisation	Linear; + 1 set every 7-8 sessions (session 1: 2 sets)	Linear; + 1 set every 7-8 sessions (session 1: 2 sets)	
Equipment	Adjustable dumbbell, 1-inch plates, 1-1/4, 2.5, 5, 10 lbs	Adjustable dumbbell, 1-inch plates, 1-1/4 lb to 10 lbs	*70% E-1RM rounded to multiples of 2.5 lb. 0.5 lbs plates were used when participants 70% E-1RM was <10 lbs*
Location	University lab or virtually	University lab or virtually	*Virtual sessions completed through zoom.*
Supervision	In-person and/or virtually, 1:1 ratio	In-person and/or virtually, 1:1 ratio	*If necessary for scheduling and researchers were satisfied with form, participants were able to perform sessions unsupervised. Occasional 1:2 researcher to participant ratio.*
Time of Day	Variable	Variable	*Flexible based on participant schedule.*

Note. BC= Bicep curl, TRD = traditional isotonic, EQI = eccentric quasi-isometric, RE= resistance exercise, CON = concentric, ECC = eccentric, BPM = beats per minute, flex. = flexion, ext. = extension.

Post-Testing

A minimum of 2-days after the last TRD-RE and EQI-RE session, participants returned to the lab, and procedures from pre-testing session 2 for muscle thickness and E-1RM were repeated.

Data Processing

Muscle thickness (cm) was defined as the distance between the superficial and deep aponeurosis (Perkisas et al. 2018). Ultrasound images were first exported as JPEG files for analysis in ImageJ open software (https://imagej.net/, V 1.54g), after which the same researcher performed all measurements. For each participant's images, pixels were converted to cm so that all distance measurements were relative to image depth. The straight-line tool was used to draw a line perpendicular to the muscle fibres at the centre of each field of view, joining the superficial and deep aponeurosis. The distance between these points was recorded for each image at the proximal, middle, and distal points of interest for both TRD-RE and EQI-RE limbs. The largest and smallest distances were removed for each region of interest, and a trimmed mean of 3 measurements was calculated for proximal, middle, and distal muscle thickness. These trimmed means were then averaged to generate a single value for each limb. E-1RM was calculated from participant's last set (2 or 3) based on the following formula and values presented by the Canadian Society for Exercise Physiology (2013).

E-1RM = weight used / (corresponding %1-RM of repetitions completed/100)

Statistical Analysis

Data analyses were performed using Excel (Microsoft 365; Microsoft Corporation, Redmond, USA), Jamovi (V 2.4.11), and SPSS 28 (IBM, Inc.; Armonk, USA). To establish that the protocol increased muscle thickness and E-1RM, absolute changes in muscle thickness and E-1RM were evaluated using paired samples t-tests within male and female groups. For the purposes of inferential statistical analysis and to examine relative effects, the difference in absolute muscle thickness and E-1RM between pre-testing and post-testing was converted to a change score (% change) relative to baseline. Two-way mixed ANOVAs were used to assess the effect of resistance exercise type (TRD-RE vs. EQI-RE) and sex (male vs. female) on muscle thickness % change and E-1RM % change. Further exploratory analysis was done to assess the influence of sex and resistance exercise volume (total repetitions and time under tension) during the TRD-RE and EQI-RE protocol with muscle thickness % change and E-1RM % change; differences between males and females were evaluated using Mann-Whitney U-tests, while

Pearson correlations analyses evaluated the relationship between resistance exercise volume with muscle thickness % change and E-1RM % change. Simple moderator analysis assessed if sex affected these relationships, with total repetitions and total time under tension as predictor variables.

Assumptions of normality and homogeneity of variance were assessed via Shapiro-Wilks and Levene's tests, respectively, with significance set at $p \leq .05$ (Levene 1960; Field 2009). Assumptions of linearity and co-linearity were evaluated by Pearson's correlations; variables were considered highly correlated if $r \geq .8$. Outliers were defined as data points outside 1.5x the interquartile range. Small, medium, and large effect sizes (η_p^2) were generalised as .01, .06, and .14 (Richardson 2011). For the moderator analysis, predictor and moderator variables were mean centred.

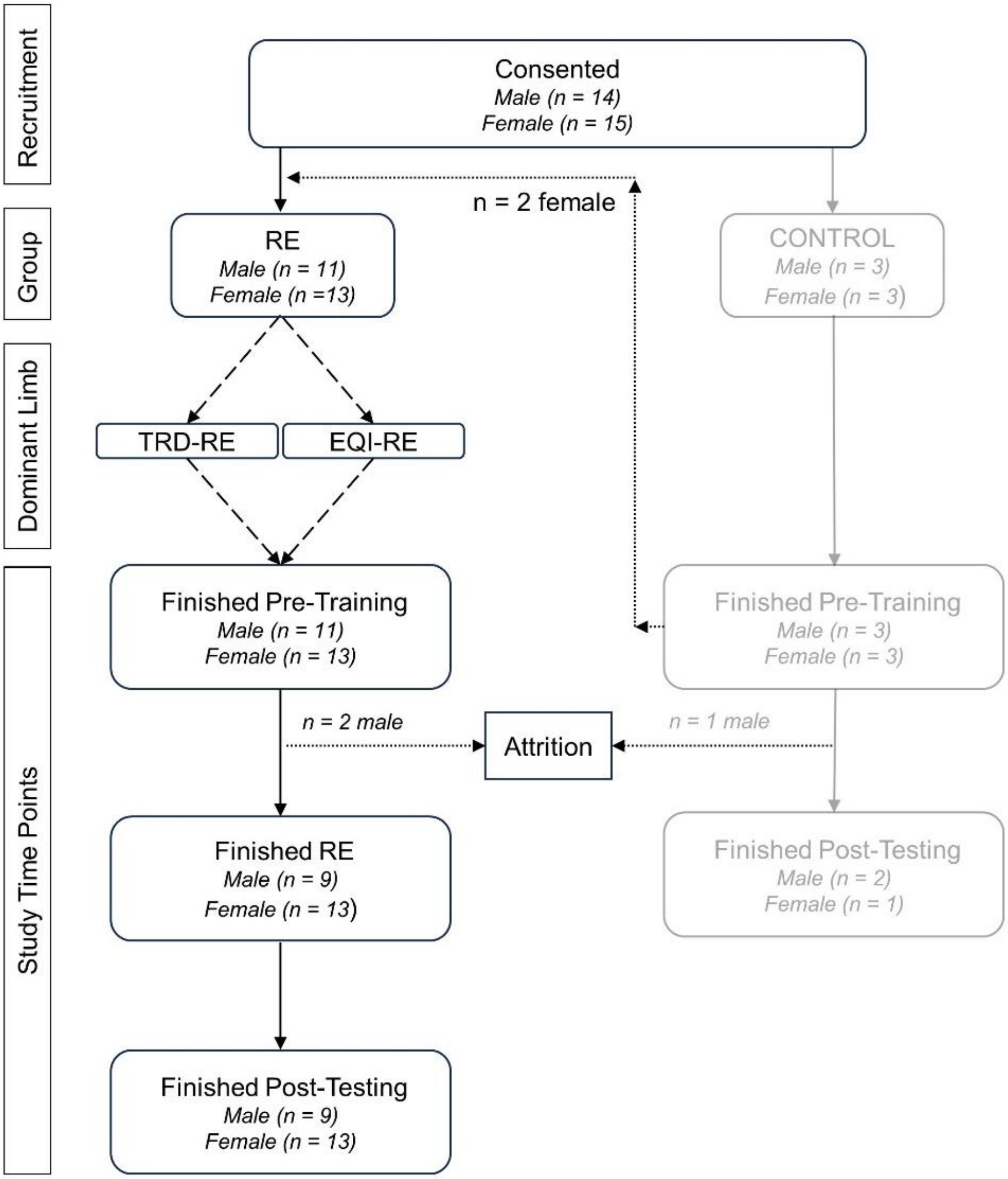
To reflect participant drop-out and sample size feasibility, a compromise power analysis was used to determine α. Based on a compromise power analysis for a large effect size (η_p^2 = .14) where β/α probability ratio was assumed to = 1, the sample size achieved a power (1-β err prob) of 0.75 when α = .25 (G*Power V. 3.1.9.2; Faul et al., 2007). As such, $p \leq .25$ was considered significant for ANOVAs. Significant main and/or interaction effects were followed up with pairwise simple contrasts. To maintain power, α was not corrected for post-hoc comparisons. For exploratory analysis, a conventional $p \leq .05$ was considered significant. Confidence intervals are presented as in SPSS, with 75% confidence intervals (CI) reported for α = .25, and 95% CI for α = .05. For moderator analysis, all CIs are standardised. Variability is presented as ± standard deviation (SD) unless otherwise specified.

Results

A total of 25 (12 males, 13 females) participants completed pre-testing and started the TRD-RE and EQI-RE training protocol. Further, a subset of *n* = 6 elected to serve as reference controls and did not initially perform resistance exercise between pre- and post-testing (~8-weeks); two female participants chose to complete the resistance exercise after initially serving as controls, and one male participant served as a control after initially completing two resistance exercise sessions. Three male participants were lost to attrition after completing pre-testing, and for reasons unrelated to the study (e.g., illness, vacation). As such, a total of 9 males, and 13 females were included in the final analysis (*n* = 22; Figure 3). Demographics and baseline descriptive statistics of the sample, TRD-RE, and EQI-RE limbs are presented in Table 2.

Figure 3

Study Flow Chart



Note. Twenty-nine participants were eligible and consented to the study, of which 24 participants elected to complete the resistance exercise protocol, while 6 participants elected to serve as control participants. Two participants from the control group elected to perform the resistance exercise after serving as controls. TRD-RE = traditional isotonic resistance exercise, EQI-RE = eccentric quasi-isometric resistance exercise.

Protocol Characteristics

On average, males completed the TRD-RE and EQI-RE protocol with an absolute load of 18.5 ± 4.5 lbs, resulting in an actual relative intensity of 69% E-1RM. Females completed the TRD-RE and EQI-RE protocol with an absolute load of 12.5 ± 2.6 lbs, resulting in an actual relative intensity of 70% E-1RM. Average time to complete the TRD-RE and EQI-RE was 60.3 ± 4.3 days (8.5 weeks).

Table 2

Demographic and Descriptive Statistics for Study Sample and Assigned Limbs

	Male (n = 9)		Female (n = 13)	
Descriptives	M (SD)	Range	M (SD)	Range
Age (years)	21.0 (2.7)	18.0-27.0	25.9 (3.4)	19.0-32.0
Height (cm)	181.1 (11)	167.7-199.5	166 (5.5)	157.0-176.0
Weight (kg)	80.4 (16.8)	64.1-111.3	69.7 (18.2)	51.0-118.3
Lean Mass (kg)	35.8 (6.1)	27.7-49.8	26.2 (3.8)	20.7-34.2
Body Fat %	20.4 (10.5)	8.8-34.3	29.8 (11.1)	12.2-49.2

	Male		Female	
Lean Mass[a] (kg)	M (SD)	Range	M (SD)	Range
TRD-RE Limb	3.5 (0.6)	2.3-5.0	2.4 (0.6)	1.6-3.8
EQI-RE Limb	3.5 (0.6)	2.5-4.8	2.4 (0.6)	1.6-3.8

Note. M = mean, SD = standard deviation.

[a] TRD-RE and EQI-RE limbs were not statistically different based on paired sample t-test ($p > .05$)

Mean and standard deviation, as well as violin plots for absolute muscle thickness and E-1RM are presented for reference in Table 3 and Figure 4. Data for absolute muscle thickness and E-1RM was normally distributed ($p > .05$). Based on paired samples t-tests, TRD-RE and EQI-RE limbs were not statistically different at pre-testing for muscle thickness and E-1RM ($p > .05$). As expected, both TRD-RE and EQI-RE produced significant absolute increases in muscle thickness and E-1RM in males and females ($p = .007$ to $p < .001$) with very large effect sizes (d > 1.195; Table 3). Based on a subset of control limbs that did not complete the TRD-RE and EQI-RE protocol, there were limited differences in muscle thickness (coefficient of variation = 1.1%) or E-1RM (coefficient of variation = 6.9%) after ≥ 8-weeks (supplementary Table) (n = 10 limbs).

Table 3

Absolute Muscle Thickness, Estimated One-Repetition Maximum, and Volume

	Male			Female		
Muscle Thickness (cm)	*Pre*	*Post*	*Cohen's d*	*Pre*	*Post*	*Cohen's d*
TRD-RE Limb	3.18 ± 0.34	3.39 ± 0 .29[a]	2.533	2.53 ± 0.39	2.68 ± 0.36[a]	1.406
EQI-RE Limb	3.21 ± 0.37	3.35 ± 0.36[b]	1.195	2.52 ± 0.33	2.61 ± 0.33[a]	1.396
	Male			Female		
Estimated-1RM (lbs)	*Pre*	*Post*	*Cohen's d*	*Pre*	*Post*	*Cohen's d*
TRD-RE Limb	26.98 ± 6.42	32.73 ± 6.00[a]	2.190	18.01 ± 3.90	22.98 ± 5.25[a]	1.654
EQI-RE Limb	26.49 ± 5.79	30.11 ± 5.73[a]	2.704	17.99 ± 4.00	20.91 ± 5.32[a]	1.471
	Male			Female		
Volume	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
TRD-RE Limb (reps)	168.1 ± 32.5	285 ± 60.2	423 ± 127.6	205.2 ± 41.4	356.7 ± 86.3	553.3 ± 186.2
EQI-RE Limb (TUT)	19.1 ± 8.2	34.2 ± 10.7	44.1 ± 8.8	22.3 ± 5.7	49.7 ± 18.3	72.4 ± 31.4

Note. Values are presented as mean ± standard deviation. TRD-RE = traditional isotonic resistance exercise, EQI-RE = eccentric quasi-isometric resistance exercise. 1-RM = one repetition maximum. TUT = time under tension. reps = repetitions.

[a] Significantly greater than pre ($p < .001$)

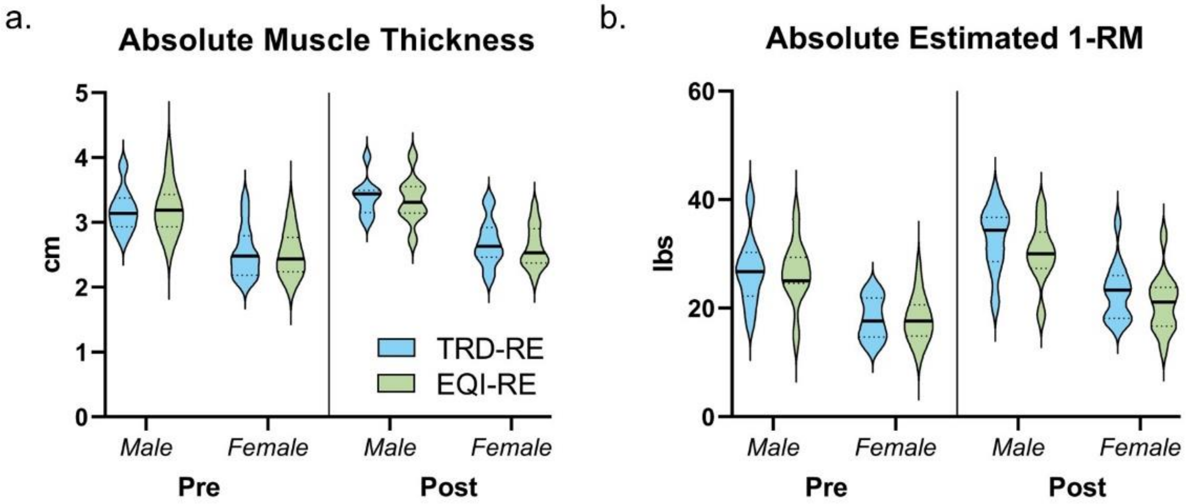
[b] Significantly greater than pre ($p = .007$)

Muscle Thickness and E-1RM

All muscle thickness % change and E-1RM % change data were normally distributed with homogeneous error variance ($p > .05$). On average, male and female participants experienced a 6.8 ± 3.0% and 6.6 ± 4.5% increase in muscle thickness from TRD-RE, respectively. After EQI-RE, males experienced a 4.5 ± 3.9% increase in muscle thickness, while females experienced a 3.6 ± 2.9% increase in muscle thickness. Collectively, these muscle thickness % change data represent a significant main effect of RE type with a large effect size, F (1, 20) = 10.544, $p = .004$, $\eta_p^2 = .345$. Specifically, TRD-RE produced a significantly greater increase in muscle thickness than EQI-RE (6.7% ± 3.9% vs. 4.0 ± 3.3%; standard error of the difference = 0.825, 75% CI: 1.701 to 3.655). There was, however, no significant effect of sex, or type*sex interaction for muscle thickness % change ($p > .25$; Figure 5a).

Figure 4

Violin Plots of Observed Data for Traditional Isotonic Resistance Exercise (TRD-RE) and Eccentric Quasi-Isometric Resistance Exercise (EQI-RE)

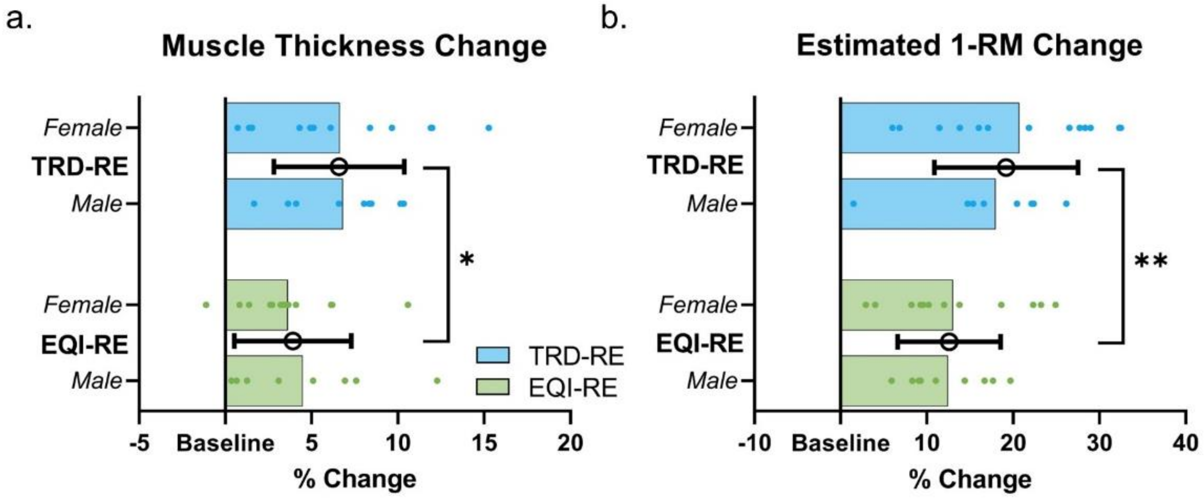


Note. Violin plot for absolute muscle thickness (a.). Violin plot for estimated 1-repetition maximum (E-1RM; b.). Solid horizontal line denotes median. Horizontal dotted lines denote 25th and 75th percentiles. Blue = TRD-RE, Green = EQI-RE.

On average, male and female participants experienced an 18.0 ± 7.3% and 20.7 ± 9.4% increase in E-1RM, respectively, after TRD-RE. After EQI-RE, males experienced a 12.4 ± 4.8% increase in E-1RM, while females experienced a 13.0 ± 7.2% increase in E-1RM. Collectively, these E-1RM % change data represent a significant main effect of RE type with a large effect size, $F\ (1, 20) = 14.834$, $p = .001$, $\eta_p^2 = .426$. Specifically, TRD-RE produced a significantly larger increase in E-1RM than EQI-RE (19.6 ± 8.5% vs. 12.8 ± 6.2%; standard error of the difference = 1.71, 75% CI: 4.57 to 8.64). There was, however, no significant effect of sex, or type*sex interaction for E-1RM % change ($p > .25$; Figure 5b).

Figure 5

Male and Female % Change for Traditional Isotonic Resistance Exercise (TRD-RE) and Eccentric Quasi-isometric Resistance Exercise (EQI-RE)



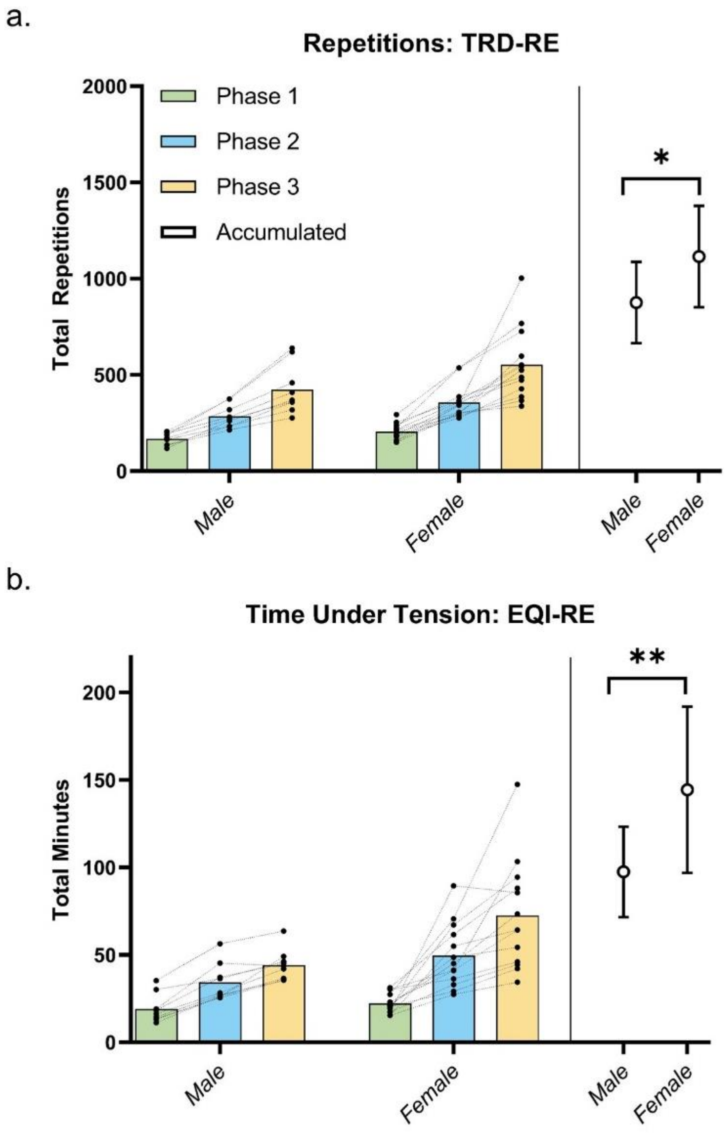
Note. Muscle thickness % change (a.). Estimated 1-repetition maximum % change (b.). Bars represent mean within sex, coloured dots represent observed data points. Symbol and error bars represent collapsed mean and standard deviation of male and female data. Blue = TRD-RE, Green = EQI-RE.
* = *p* ≤ .005 between RE type, ** = *p* ≤ .001 between RE type.

Volume

Repetition data for TRD-RE and time under tension data for EQI-RE for each phase of training are presented in Figure 6. Total repetitions across the resistance exercise protocol were not normally distributed (*p* = .028). As such, given the unequal male and female group sizes, Mann-Whitney U tests were used to compare total repetitions and time under tension between males and females. Across the TRD-RE protocol, females completed significantly more repetitions than males (1115 ± 263 vs. 876 ± 212 repetitions), *U* = 28.00, *p* = .043 (Figure 6a). Females also accrued significantly more time under tension than males across the EQI-RE training (144 ± 47 min vs. 97 ± 26 min), *U* = 20.00, *p* = .009 (Figure 6b).

Figure 6

Summary Male and Female Training Data of Traditional Isotonic Resistance Exercise (TRD-RE) and Eccentric Quasi-isometric Resistance Exercise (EQI-RE)



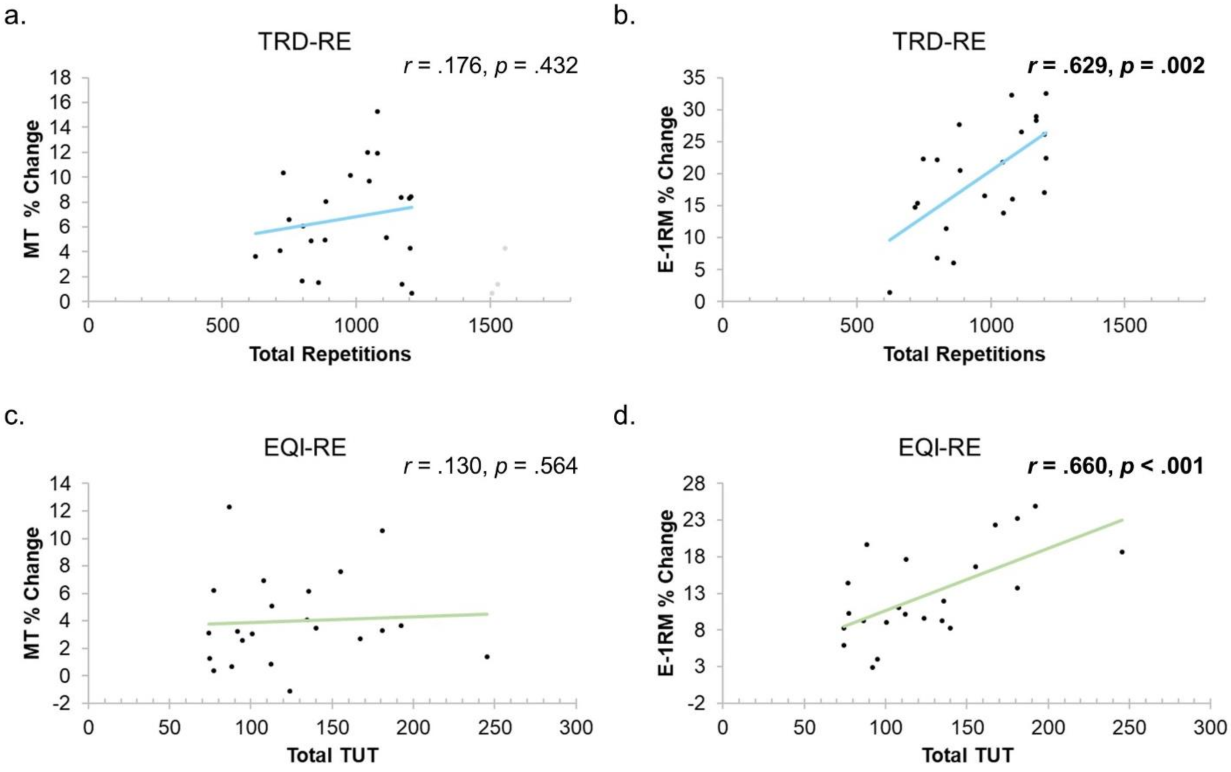
Note. Total repetitions during each phase, and accumulated repetitions across the entire protocol for TRD-RE (a.). Total time under tension (TUT) during each phase, and accumulated TUT across the entire protocol for EQI-RE (b.) Green bar = phase 1 (session 1-7), blue bar = phase 2 (session 8-15), yellow bar = phase 3 (session 16-23). Black dots represent observed data points, dotted lines link individuals' data points. White symbols and error bars = mean accumulated total and standard deviation for all phases of the TRD-RE and EQI-RE protocol.
* = $p < .05$, ** = $p < .02$.

Exploratory Analysis

For exploratory analysis, statistical outliers and spurious outliers were removed and replaced with the next lowest score + 1(Field 2009); total repetition data were replaced for the three highest female participants. One female participant was replaced for total time under tension, and one male participant was replaced for EQI-RE muscle thickness % change. When male and female data were collapsed ($n = 22$), E-1RM % change was not associated with muscle thickness % change for TRD-RE or EQI-RE ($r < .1$, $p > .05$). For TRD-RE, there was a slight positive, but non-significant association of total repetitions with muscle thickness % change, $r(20) = .176$, $p = .432$ (Figure 7a); however, there was a significant and modest positive association of total repetitions with E-1RM % change, $r(20) = .629$, 95% CI: .282 to .830, $p = .002$ (Figure 7b). Similarly, for EQI-RE, there was slight positive, but non-significant association of total time under tension with muscle thickness % change, $r(20) = .130$, $p = .564$ (Figure 7c), and a significant and modest association of total time under tension with E-1RM % change, $r(20) = .660$, 95% CI: .288 to .832, $p < .001$ (Figure 7d).

Figure 7

Relationship of Resistance Exercise Volume With Estimated One-repetition Maximum (E-1RM) and Muscle Thickness (MT)



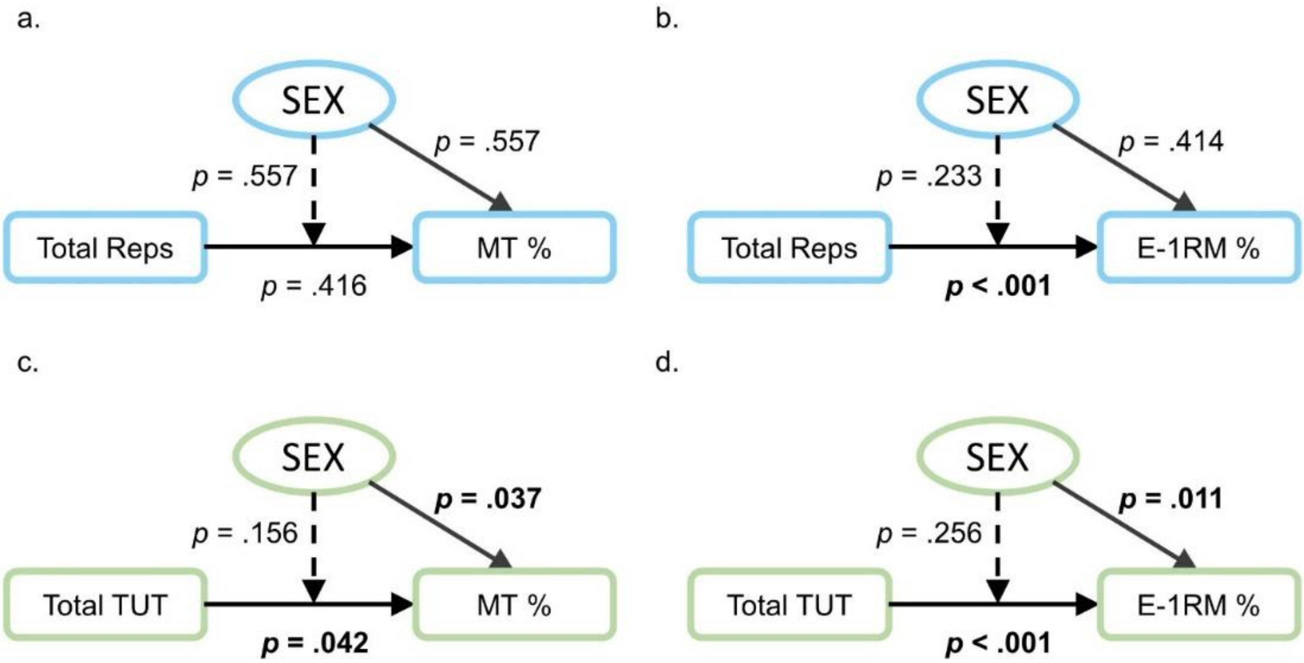
Note. Pearson's correlation of total repetitions with muscle thickness % change (MT % change) for traditional isotonic resistance exercise (TRD-RE; a.) Pearson's correlation of total repetitions with E-1RM % change for TRD-RE (b.). Pearson's correlation of total time under tension (TUT) with MT % change for eccentric quasi-isometric resistance exercise (EQI-RE; c.). Pearson's correlation of total time under tension (TUT) with E-1RM % change for EQI-RE (d.). Lines of best fit for TRD-RE are displayed by blue lines, lines of best fit for EQI-RE are displayed by green lines. For figure a.), grey dots represent spurious outliers that were removed and replaced with the next highest score +1. *r* = Pearson's r. Significant correlations ($p < .05$) are bolded.

Sex did not moderate any effect of total repetition or time under tension on muscle thickness % change or E-1RM % change ($p < .05$), although there were direct effects of total repetitions, total time under tension, and sex. For TRD-RE, there was no significant effect ($p > .05$) of total repetitions or sex on muscle thickness % change (Figure 8a). There was, however, a significant effect of total repetitions, but not sex, on E-1RM % change, $b = 0.034$ (standard error: 0.008), 95% CI: 0.019 to 0.049, $Z = 4.448$, $p < .001$ (Figure 8b), suggesting that greater total repetitions during TRD-RE was a predictor of greater E-1RM % change. For EQI-RE, there was a significant effect of total time under tension, $b = 0.033$ (standard error: 0.016), 95% CI:

0.001 to 0.064, *Z* = 2.032, *p* = .042, and sex, *b* = -2.636 (standard error 1.216), 95% CI: -5.108 to -0.165, Z = -2.090, *p* = .037 on muscle thickness % change (Figure 8c). Similarly, there was a significant effect of total time under tension, *b* = 0.124 (standard error: 0.021), 95% CI: 0.082 to 0.166, *Z* = 5.806, *p* < .001, and sex, *b* = -4.277 (standard error: 1.680), 95% CI: -7.569 to -0.984, Z = -2.546, *p* = .011 on E-1RM % change (Figure 8d). As such, these models would suggest that greater time under tension was a significant predictor of greater muscle thickness % change and E-1RM % change, while being male was predictive of greater muscle thickness % change and E-1RM % change in response to EQI-RE.

Figure 8

Moderation Models of the Relationship of Resistance Exercise Volume with Muscle Thickness (MT) % Change, Estimated One-Repetition Maximum (E-1RM) % Change, and Sex



Note. Model of total repetitions and MT % change moderated by sex for traditional isotonic resistance exercise (TRD-RE; a.). Model of total repetitions and E-1RM % change moderated by sex for TRD-RE (b.). Model of total time under tension (TUT) and MT % change moderated by sex for eccentric quasi-isometric resistance exercise (EQI-RE, c.). Model of total time under tensions (TUT) and E-1RM % change moderated by sex for EQI-RE (d.). TUT = time under tension, MT % = muscle thickness % change, E-1RM % = estimated 1-repetition maximum % change. Solid arrows denote direct effects, dashed arrows denote moderator effect.
Significant beta estimates (*p* < .05) are bolded.

Discussion

The current study examined the effects of traditional isotonic (TRD-RE) and eccentric quasi-isometric resistance exercise (EQI-RE) between untrained males and females on relative muscle thickness change (MT % change) and E-1RM change (E-1RM % change) of the elbow flexors following ~8.5 weeks of resistance exercise training. Additionally, the current study explored the relationship of resistance exercise volume (total repetitions or total time under tension) during the TRD-RE and EQI-RE protocol with muscle thickness % change and E-1RM % change, and whether sex influenced any relationship. When relative changes in elbow flexor muscle thickness and E-1RM were compared, TRD-RE increased muscle thickness and E-1RM significantly more than EQI-RE, however, there were no significant differences between males and females, and changes in relative muscle thickness were not related to changes in E-1RM. With respect to resistance exercise volume during TRD-RE and EQI-RE, females performed significantly more repetitions and produced significantly greater time under tension than males. Exploratory analysis revealed that, for TRD-RE, total repetitions and sex *were not* predictive of muscle thickness % change, whereas total repetitions, but not sex, *were* predictive of E-1RM% change. Conversely, for EQI-RE, total time under tension and sex were predictive of muscle thickness % change and E-1RM % change. Sex did not moderate the relationship of total repetitions or total time under tension with muscle thickness % change or E-1RM % change.

There are innate differences between males and females that can contribute to differences in muscle hypertrophy and strength. From recent meta-analyses (Roberts et al. 2020; Nuzzo 2022, 2024) it can be presumed that males have greater muscle mass, strength, and proportion of type II muscle fibres than females, while females have a greater proportion of type 1 muscle fibres than males. Unsurprisingly, this is reflected in baseline data; baseline muscle thickness for females was ~80% of males, while baseline E-1RM for females was ~68% of males. Although females' muscle thickness and E-1RM were slightly higher than what has been reported previously(Nuzzo 2022), it was expected that absolute values of muscle thickness and E-1RM would be higher in males regardless of resistance exercise type or time (pre to post-testing). It was also expected that given the untrained nature of participants, resistance exercise would produce significant increases in muscle thickness and E-1RM, regardless of resistance exercise type. As such, to remove baseline differences and appropriately evaluate sex-differences we elected to examine relative changes in muscle thickness and E-1RM as our primary outcomes.

Indeed, our assumptions regarding absolute muscle thickness and E-1RM were correct, in that both TRD-RE and EQI-RE produced significant increases in muscle thickness and E-1RM, while males had greater muscle thickness and E-1RM than females at both time points. Our hypothesis for relative changes, however, were only partially correct; although TRD-RE produced significantly greater increases in muscle thickness and E-1RM than EQI-RE after ~8-weeks, there were no sex-differences in relative muscle thickness or E-1RM improvements following TRD-RE or EQI-RE. This, despite females accruing more repetitions *and* time under tension over the course of the protocol. Using an almost identical resistance exercise protocol for the elbow flexors, our previous work (Henderson et al. 2025) suggests that males and females completed a similar number of repetitions during an acute bout of unilateral TRD-RE, while females produced significantly greater time under tension than males during an acute bout of unilateral EQI-RE. Therefore, we hypothesised that this difference in time under tension would accumulate across several training sessions, and, assuming that resistance exercise volume and time under tension are predictive of muscle hypertrophy(Schoenfeld et al. 2017), we hypothesised that females would experience a greater relative increase in muscle thickness than males from EQI-RE. Conversely, given the similar number of TRD-RE repetitions in the aforementioned study (Henderson et al. 2025) we hypothesised that males and females would experience similar relative increases in muscle thickness from TRD-RE. Although our exploratory analysis would seem to lend support to our hypothesis, in that total time under tension and sex were both significant and independent predictors of muscle thickness % change, it was males, and not females, who experienced a slightly greater relative increase in muscle thickness, despite performing less time under tension.

It is regularly demonstrated that females have equivalent relative hypertrophic and strength responses to males across a variety of isotonic resistance exercise protocols, at least in the short term, and females may even have a slight advantage when it comes to improving upper-body strength (Roberts et al. 2020). As such, the current study is in line with these observations, and supports similar results for EQI-RE; males and females had similar relative improvements in elbow flexor muscle mass and strength when beginning a resistance exercise program, and females had a slightly greater, although non-significant improvement in E-1RM than males following TRD-RE. Along with the sex-differences in resistance exercise volume, the current study highlights the complexities of muscle hypertrophy and strength mechanisms, and may suggest different contributing mechanisms for males and females.

As previously discussed, measurable physiological differences between males and females exist (e.g., sex hormones, muscle fibre type/strength), which can lead to conclusions that ascribe observed sex-differences to physiological factors that are innate to males or females. Indeed, in the current study, male participants were substantially stronger and had more absolute muscle mass than females. Although our primary analysis suggests there are no sex-differences in muscle thickness % change or E-1RM % change in response to TRD-RE and EQI-RE, there is increasing discussion regarding the impact of confounding and modifiable factors, such as strength, skill, or experience on observed sex-differences (Nimphius 2019; Parsons et al. 2021). In the context of the current study, fatiguability and/or time under tension could be considered a relevant and modifiable factor, as, despite females generally being more fatigue-resistant in the current study, it is a trainable characteristic that differs between trained and untrained individuals (Hunter 2016a; Gentil et al. 2017). Indeed, this was our rationale for exploring whether sex moderated the assumed relationship of resistance exercise volume and muscle thickness % change. As time under tension was associated with E-1RM % change for EQI-RE and given that EQI-RE volume within sets is limited by an individual's fatiguability (Henderson et al. 2023), it is conceivable that if sex did moderate this relationship, that males and females may need to perform a differing number of EQI-RE sets to achieve similar relative resistance exercise volume. Based on the lack of sex-differences in muscle thickness % change and E-1RM % change for both TRD-RE and EQI-RE, however, it may also be inferred that males require less resistance exercise volume than females to achieve the same relative increases in muscle mass and strength.

As recent work has challenged the idea that muscle mass heavily contributes to muscle strength (Buckner et al. 2021; Spitz et al. 2023), we also examined the relationship of muscle thickness % change with E-1RM % change to determine if greater increases in muscle mass were related to changes in E-1RM. Although both TRD-RE and EQI-RE increased absolute muscle thickness and E-1RM after ~8.5 weeks, relative increases in muscle thickness and E-1RM were not associated for either resistance exercise type, suggesting that E-1RM improvements were largely due to neurological or metabolic factors and not changes in muscle mass (Buckner et al. 2021; Nuzzo 2022; Spitz et al. 2023). As alluded to by Oranchuk et al. (2019b), the fact that TRD-RE increased E-1RM significantly more than EQI-RE would indicate that EQI-RE may not be an efficient means of improving power or strength characteristics, especially at high movement velocities. While the greater efficacy of TRD-RE for increasing E-1RM strength could be easily explained by its greater specificity to the E-1RM test, the significantly greater increase in relative muscle thickness and E-1RM from TRD-RE compared to EQI-RE challenges some of the theorised advantages of EQI-RE. For example, practitioners have espoused EQI style training as an effective, or more effective means of producing muscle hypertrophy and strength than TRD-RE (e.g., Morrison 2016; Seedman n.d.; Sinicki 2019), while Oranchuk et al. (2019b) theorised that EQI-RE would be a time and energy-efficient way of increasing muscle size and creating beneficial musculotendinous adaptations. Assuming 3-seconds per TRD-RE repetition, the current study suggests that EQI-RE took longer to complete, and, contrary to previous claims, produced inferior muscle thickness and E-1RM improvement compared to TRD-RE.

Limitations are present for the resistance exercise protocol, measurement techniques, and design of the current study. In an effort to maintain adherence and reduce barriers to participation, participants were given the option of completing the TRD-RE and EQI-RE protocol virtually. As such, we elected to progress participants by adding a set (volume) rather than increasing load, removing the need for participants to return to the lab during ~8 weeks to test their strength or to pick up additional weight. The downside to this, however, was that some participants' repetition and time under tension performance drastically increased, potentially due to their novelty to resistance exercise and E-1RM testing. Therefore, initial E-1RM may have been underestimated in some participants, leading to a lower relative training intensity across the 8-weeks. Regarding ultrasound measurements, while inter-rater reliability was very good for muscle thickness, there is a risk of bias in that the same researcher collected data and measured muscle thickness of ultrasound images and not blinded to limb assignment. Relevant to the unilateral, between-limb nature of the design, systemic responses (i.e., fatigue, endocrine) to the first limb/resistance exercise type during a resistance exercise session or testing would have influenced the second limb/resistance exercise type (Macinnis et al. 2017). To mitigate this, participants alternated starting with TRD-RE or EQI-RE each session, while limb assignment to resistance exercise type, as well as starting limb for pre- and post-testing were counterbalanced. With respect to confounding factors, participants' dietary, sleep, and alcohol habits were not monitored over the course of the ~8-weeks. As protein intake, sleep quality/quantity, and alcohol consumption can impact adaptations to exercise (Mann et al. 2014), participants' lifestyles may have been suboptimal for muscle hypertrophy and strength development. Additionally, it is important to note the study was conducted with young, healthy, untrained individuals, where training effects are more robust (Lopez et al. 2021). As such, results cannot be extrapolated to a trained population.

With its limitations, the current study provides direction for EQI-RE and sex-differences research. It is important to note that while muscle thickness and strength increases from EQI-RE were not as large as TRD-RE, they were still significant and meaningful compared to pre-testing. As suggested by Oranchuk et al. (2019), EQI-RE may therefore be useful in rehabilitation settings to stimulate strength and hypertrophy improvements where isotonic resistance exercise may not be appropriate. Although the study was not conducted in a rehabilitation setting or an injured population, resistance exercise participation among the general population is low. Twenty percent of Americans (Kruger et al., 2006), and 13.2% of Australians (Dalbo et al., 2015) perform resistance training twice per week, with significantly less participation among certain sociodemographic, including women (Kruger et al., 2006; Dalbo et al., 2015). As such, most patients in a general rehabilitation setting would be "untrained." Thus, the results of the current study may have relevance in general population musculoskeletal rehabilitation, however, future work may consider examining EQI-RE in specific populations. Relevant to intensity and progressing exercise, future work may also consider potential implications of performing EQI-RE with higher intensities (i.e., > 80% 1-RM), different ROM (short vs. long muscle lengths), and different muscles/exercises (bench press vs. leg press) on sex-differences in strength, power, muscle morphology, architecture, or tendon stiffness.

Conclusion

In untrained males and females, the current study revealed significant increases in muscle thickness and E-1RM from 8-weeks of TRD-RE or EQI-RE; however, there were no relative sex-differences in muscle thickness and E-1RM improvements. Females accrued greater relative resistance exercise volume than males for both TRD-RE and EQI-RE, but sex did not moderate the relationship of resistance exercise volume with improvements in E-1RM for TRD-RE or EQI-RE. As such, the current study does not support equivalent strength and hypertrophy outcomes from EQI-RE when compared to TRD-RE, but suggests similar strength and hypertrophy adaptations between males and females regardless of resistance exercise type. Future work should consider evaluating EQI-RE in situations where TRD-RE would not be appropriate or feasible.

Contributions

Contributed to conception and design: ZJH, SMC, TDS
Contributed to acquisition of data: ZJH, SW
Contributed to analysis and interpretation of data: ZH, TDS
Drafted and/or revised the article: ZJH, TDS
Final approval of the version to be published: ZJH, SW, SMC, TDS,

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Data and Supplementary Material Accessibility

Data sets can be found at https://osf.io/3qf49/?view_only=a1b4e201a9b444fa935da43f418c7385

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World Health Organization (2022) Physical Activity Fact Sheet

Supplementary Materials

Supplementary Table 1

Control Limbs – Absolute Muscle Thickness and E-1RM

Muscle Thickness (cm)	*Pre*	*Post*
TRD-RE Limb (*n* = 4)	2.93 ± 0.39	2.90 ± 0.40
EQI-RE Limb (*n* = 4)	2.91 ± 0.41	2.92 ± 0.42
	Male	
Estimated-1RM (lbs)	*Pre*	*Post*
TRD-RE Limb (*n* = 5)	20.44 ± 4.86	20.36 ± 6.03
EQI-RE Limb (*n* = 5)	20.42 ± 4.97	20.18 ± 5.76