Eccentric Quasi-Isometric vs. Isotonic Resistance Exercise of the Elbow Flexors: Acute Neuromuscular, Set, and Sex-Differences in Untrained Individuals When Using a Unilateral Model

Supplementary materials: https://osf.io/sfxun/?view_only=8ae76e6252724a32a1b7dd18472383b0

For correspondence: Trisha.Scribbans@umanitoba.ca

Zachariah J. Henderson[1], Shizhen Wang[1], Trisha D. Scribbans[1]

[1]Faculty of Kinesiology and Recreation Management, University of Manitoba, Winnipeg, Canada

Please cite as: Henderson, Z. J., Wang, S., Scribbans, T. D. (2025). Eccentric Quasi-Isometric vs. Isotonic Resistance Exercise of the Elbow Flexors: Acute Neuromuscular, Set, and Sex-Differences in Untrained Individuals When Using a Unilateral Model. *SportRχiv*.

All authors have approved this version of the manuscript. This article was last modified January, 2025 and has been submitted for peer review.

Abstract

Traditional isotonic resistance exercise (TRD-RE) improves muscle mass, strength, and overall health. However, TRD-RE may be impractical or unfeasible in injury or sport specific situations. Compared to TRD-RE, eccentric quasi-isometric resistance exercise (EQI-RE) is a low-velocity resistance exercise modality suggested to acutely produce similar and/or greater time under tension, motor unit recruitment, and antagonist co-activation. With limited investigations or comparisons to other forms of resistance exercise, however, evidence is lacking. As differences between males and females exist in time under tension and motor unit behaviour in other resistance exercise contexts, the current study explored sex-differences in time under tension and surface electromyography (sEMG) across 2 sets of TRD-RE and EQI-RE. Twenty-seven (n = 13 females) participants performed unilateral TRD-RE and EQI-RE of the elbow flexors while sEMG was collected from the biceps and triceps brachii. Several main and interaction effects of resistance exercise type, set, and sex were present for time under tension, linear envelope peak (LEpeak), absolute (iEMGabs) and relative (iEMG%) integrated sEMG, with set 1 typically having higher sEMG values than set 2, and EQI-RE having greater time under tension than TRD-RE. Notably, females produced significantly more time under tension, iEMGabs, iEMG%, and co-activation than males during EQI-RE, while males experienced a more significant set-to-set reduction in time under tension and LEpeak during TRD-RE. Overall, TRD-RE may result in quicker voluntary excitation and subsequent fatigue of motor units compared to EQI-RE, while females may accrue more resistance exercise volume than males when performing EQI-RE. Theoretically, these effects could lead to long-term sex-differences in strength and hypertrophy outcomes between males and females, TRD-RE and EQI-RE.

Key words: Muscle fatigue, resistance training, weight training, bicep curls

Introduction

Resistance exercise alters muscle physiology and morphology acutely and chronically (McKendry et al., 2021). Acutely, isotonic resistance exercise increases electromyography (EMG) amplitude (e.g., Dankel et al., 2017; Paz et al., 2017), muscle thickness (e.g., Csapo et al., 2011; Yitzchaki et al., 2020) and muscle protein synthesis (Lim et al., 2022). Thus, repeated acute resistance exercise bouts over a period of weeks may lead to muscle morphological adaptations and improvements in performance and health outcomes, such as increased muscle mass, strength, endurance, and control and/or reduction of chronic diseases and musculoskeletal injury (Bennie et al., 2020; Ratamess et al., 2009; Schoenfeld, 2010, 2020; Suchomel et al., 2016). While chronic resistance exercise is considered a potent means of stimulating muscle hypertrophy and/or preventing muscle atrophy (Lim et al., 2022), traditional isotonic resistance exercise involves alternating concentric and eccentric muscle actions at high-velocities with loads > 65% 1-RM (Ratamess et al., 2009). As such, it may be difficult and/or not tolerable to perform with musculoskeletal injury and may not train or reflect the demands of sports that utilise low-velocity movements (Oranchuk et al., 2019). Thus, alternative resistance exercise strategies, such as "eccentric quasi-isometrics", or "EQIs" (Oranchuk et al., 2019), which avoid high-loads and high-velocities have been proposed.

Briefly, an EQI involves initiating and maintaining a holding isometric muscle action (Schaefer & Bittmann, 2017) to positional failure. Rather than ending the exercise at positional failure, the resulting eccentric muscle action is voluntarily resisted through the desired range of motion (ROM; Oranchuk et al., 2019b, 2020). As a novel, low-velocity resistance exercise modality, variations of EQI resistance exercise (EQI-RE) are proposed to acutely increase motor unit recruitment, muscle co-contraction/activation, and time under tension, potentially to a greater degree than traditional isotonic resistance exercise (Morrison, 2016; Oranchuk et al., 2019b; Seedman, n.d.-a, n.d.-b; Sinicki, 2019). Since time under tension and motor unit recruitment are implicated in strength and hypertrophy processes (Lim et al., 2022; Moritani & DeVries, 1979; Nuzzo, 2022; Pearson & Hussain, 2015; Schoenfeld, 2010; Zabaleta-Korta et al., 2020), it has been suggested that the EQI concept could lead to unique musculotendinous morphological and strength adaptations with chronic training (Morrison, 2016; Oranchuk et al., 2019b; Seedman, n.d.-a, n.d.-b; Sinicki, 2019). Despite these suggestions, few studies have investigated EQI-RE acutely or chronically, or compared it to other forms of resistance exercise.

Although it is likely that EQI-RE produces substantial time under tension (Oranchuk et al. 2020), assertations that EQI-RE increases motor unit recruitment or muscle co-activation remain unsubstantiated. Our previous work (Henderson et al., 2023) suggests no unique or substantial increase in surface electromyography (sEMG) amplitude across 4 sets of EQI-RE elbow flexions to volitional fatigue, although females were generally better able to maintain performance and subsequent time under tension across multiple sets compared to males. While females displaying greater muscle fatigue resistance during low-velocity or isometric muscle actions of the elbow flexors is not a surprising outcome (Hunter, 2014, 2016b), previous studies suggest that females could lose this performance advantage when performing higher velocity muscle actions (Gomes et al., 2021; Senefeld et al., 2013; Yoon et al., 2015), such as those performed with traditional isotonic resistance exercise (TRD-RE).

Potential sex-differences in the temporal manifestation of muscle fatigue with different resistance exercise types are relevant when considering that time under tension is suggested to be the main driver of EQI-RE induced muscle hypertrophy (Oranchuk et al., 2019). If EQI-RE does produce greater time under tension than traditional isotonic resistance exercise (TRD-RE), theoretically, this would lead to greater cumulative resistance exercise volume, and, as total resistance exercise volume is positively associated with muscle hypertrophy (Schoenfeld et al., 2017), greater muscle hypertrophy with EQI-RE compared to TRD-RE. Furthermore, if females are less fatigable to EQI-RE than males, but not TRD-RE, this could result in sex-dependent differences in long-term muscle strength and hypertrophy adaptations to EQI-RE and TRD-RE. As muscle fatigue during EQI-RE and TRD-RE, and between males and females has yet to compared, however, this remains speculative.

Given the purported advantages of EQI-RE to increase time under tension, motor unit recruitment, and agonist-antagonist co-activation relative to more traditional resistance exercise types (Morrison, 2016; Oranchuk et al., 2019b; Seedman, n.d.-a, n.d.-b; Sinicki, 2019), the current study compared the acute muscle fatigue response between EQI-RE and TRD-RE of the elbow flexors. Using a unilateral resistance exercise model (Macinnis et al., 2017), time under tension was quantified during 2 sets of TRD-RE and EQI-RE supinated bicep curls to volitional fatigue, while sEMG of the biceps brachii and triceps brachii were collected to evaluate voluntary peak muscle excitation (linear envelope peak [LEpeak], absolute integrated sEMG [iEMGabs] and relative sEMG [iEMG%] "muscle activity", and normalised triceps brachii-biceps brachii co-activation ratio [CoA]). While LEpeak was expected to be higher during TRD-RE, based on ours (Henderson et al., 2023), and others' (Ličen et al., 2024; Oranchuk et al., 2020, 2021) studies reporting substantial time under tension during EQI-RE, it was hypothesised that EQI-RE would produce greater time under tension, iEMGabs, iEMG%, and CoA than TRD-RE, regardless of sex. Additionally, it was expected that iEMGabs and iEMG% would decrease from set 1 to set 2 with TRD-RE and EQI-RE, as time under tension decreases with fatigue (Henderson et al., 2023; Oranchuk et al., 2021; Ratamess et al., 2012). Due to greater fatigue resistance (Hunter, 2016b), it was also hypothesised that females would accrue greater time under tension and iEMG% than males during EQI-RE but not TRD-RE. Males, however, were expected to produce higher LEpeak and iEMGabs due to having greater muscle mass and less adipose tissue than females (Janssen et al., 2000).

Methods

The investigation was embedded within a longitudinal training project. A unilateral (resistance exercise type), cross-sectional (set), and between-group (sex) design was used to compare time under tension, voluntary biceps brachii excitation, and triceps brachii co-activation between males and females during 2 sets of TRD-RE and EQI-RE of the elbow flexors to volitional fatigue. As a unilateral design, participant's dominant and non-dominant arm (assessed using the Edinburgh Handedness Inventory), as well as order of completion, were assigned to either TRD-RE or EQI-RE types using a Latin square (Portney et al., 2015). Participants completed both sets with the first limb and assigned resistance exercise type (TRD-RE or EQI-RE), before completing the other resistance exercise type for the second limb. All sets were performed using 70% of participant's estimated 1-repetition maximum (E-1RM), while bipolar surface sEMG data were collected over the biceps and triceps brachii. The study was approved by the University of Manitoba Research Ethics Board (REB 1; HE2023-0066), and all participants provided verbal and written consent prior to participation.

Participants

Thirty participants 18-35 years old (15 females, 15 males; sex assigned at birth) were recruited via convenience sampling from the University community. All participants did not regularly partake in structured resistance exercise (defined as ≥ 2x week, ≤ 12-repetitions per exercise), and were cleared for exercise by the Get-Active Questionnaire (Canadian Society for Exercise Physiology, 2017). Furthermore, participants had no history of neurological disorders or recent (< 3 months) injury (e.g., sprain, strain) that would impact their ability to perform unilateral resistance exercise of the upper limb. Participants were instructed to avoid structured and/or strenuous upper-body exercise or physical activity for 72-hrs, caffeine for 3-hrs, and alcohol and cannabis for 24-hrs before the session. All participant's body composition was as assessed by bioelectrical impedance (InBody 270; InBody Co, Seoul, South Korea) prior to the session, and as per manufacturer recommendations.

Estimated 1-RM and Protocol Familiarisation

Participants were familiarised with and completed (at least 3-days apart) 10-RM testing for a unilateral supinated bicep curl as per CSEP (Canadian Society for Exercise Physiology, 2013) to determine their estimated 1-repetition maximum (E-1RM). 10-RM testing was performed for each limb, and E-1RM was calculated for each limb, with the average between limbs used to prescribe relative load (% E-1RM) for both resistance exercise types. Additionally, participants were familiarised with the EQI-RE procedures on two occasions at least 3-days apart, and at least 3-days prior to data collection (Figure 1a.).

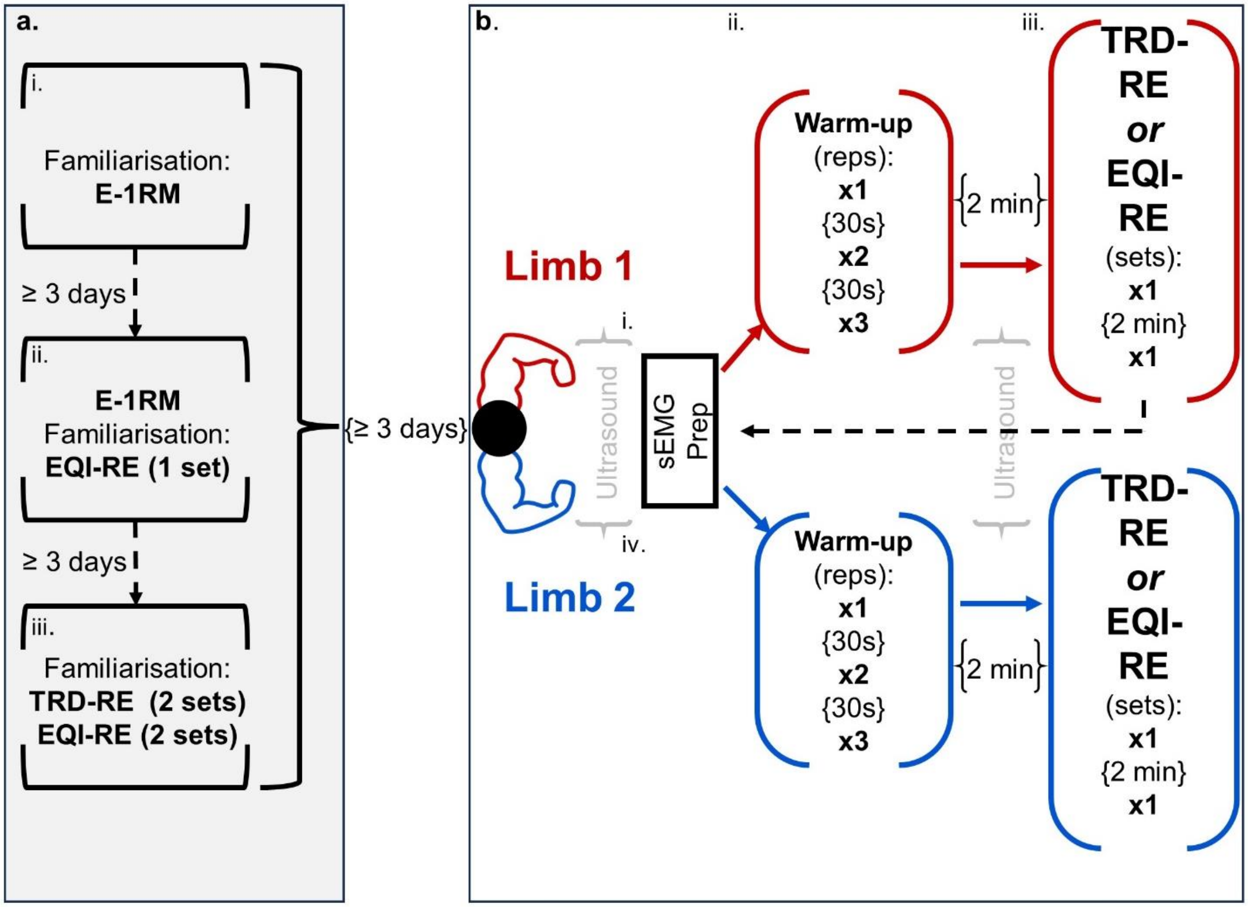
Protocol

Data were collected during one, 1.5-hr session in an exercise laboratory set at 20 °C (Figure 1b.). To quantify the typical error of ultrasound measures for the larger project, participants began the session by lying in a supine position for ~45 minutes. The skin over the biceps and triceps brachii were then prepped for sEMG using standard procedures, including abrading the skin surface and wiping with water (Henderson et al., 2023; Lulic-Kuryllo et al., 2021; Piervirgili et al., 2014). Disposable dual sEMG electrodes (Ag/AgCl, 20mm interelectrode distance; Noraxon U.S.A. Inc, Scottsdale, AZ) were then positioned approximately parallel with the muscle fibres, based on procedures and recommendations by Barbero et al. (2012) and SENIAM (www.seniam.org). For the biceps brachii, the distal portion of the electrode bordered a line at 62% of the distance from the acromion to the cubital crease, while the electrode for the lateral head of the triceps brachii was positioned just lateral to 40% of the distance from the acromion to the lateral epicondyle. Electrodes were connected to an Ultium™ EMG system (24-bit sampling resolution, >100 dB common mode rejection ratio, baseline noise < 1 μV; Noraxon U.S.A. Inc.) via wireless Ultium™ EMG/inertial measurement unit (IMU) sensors (10-500 Hz bandpass filter, ± 16 g tri-axial accelerometer, 2048 LSB/g sensitivity, 16-bit sampling resolution), which were affixed to participants' skin using double-sided EMG sensor tape (Noraxon U.S.A. Inc.). For the purposes of identifying repetition start and end-time via acceleration, an additional EMG/IMU sensor was placed at the radial styloid process (Figure 2).

Baseline data was then recorded with participants standing in a relaxed, upright position, with arms and hands held naturally at their sides. For both the TRD-RE and EQI-RE limbs, participants began with a 3-set warm-up consisting of 1, 2, and 3 repetitions of unilateral supinated bicep curls using 70% of their E-1RM, with 30-seconds of rest between sets. During the warm-up, the researchers and onboard software monitored the sEMG for signal quality; in cases of excessive baseline noise or impedance, the electrode area was re-prepped, and a new electrode was applied before continuing. After 2-minutes of rest, participants performed their first set of TRD-RE or EQI-RE followed by 2-minutes of rest and a second set. Participants then spent ~10-minutes lying in supine rest, after which all sEMG preparation and warm-up procedures were repeated for the remaining limb, and followed by 2 sets of the remaining resistance exercise type (Figure 1).

Figure 1

Study Overview and Resistance Exercise Protocol



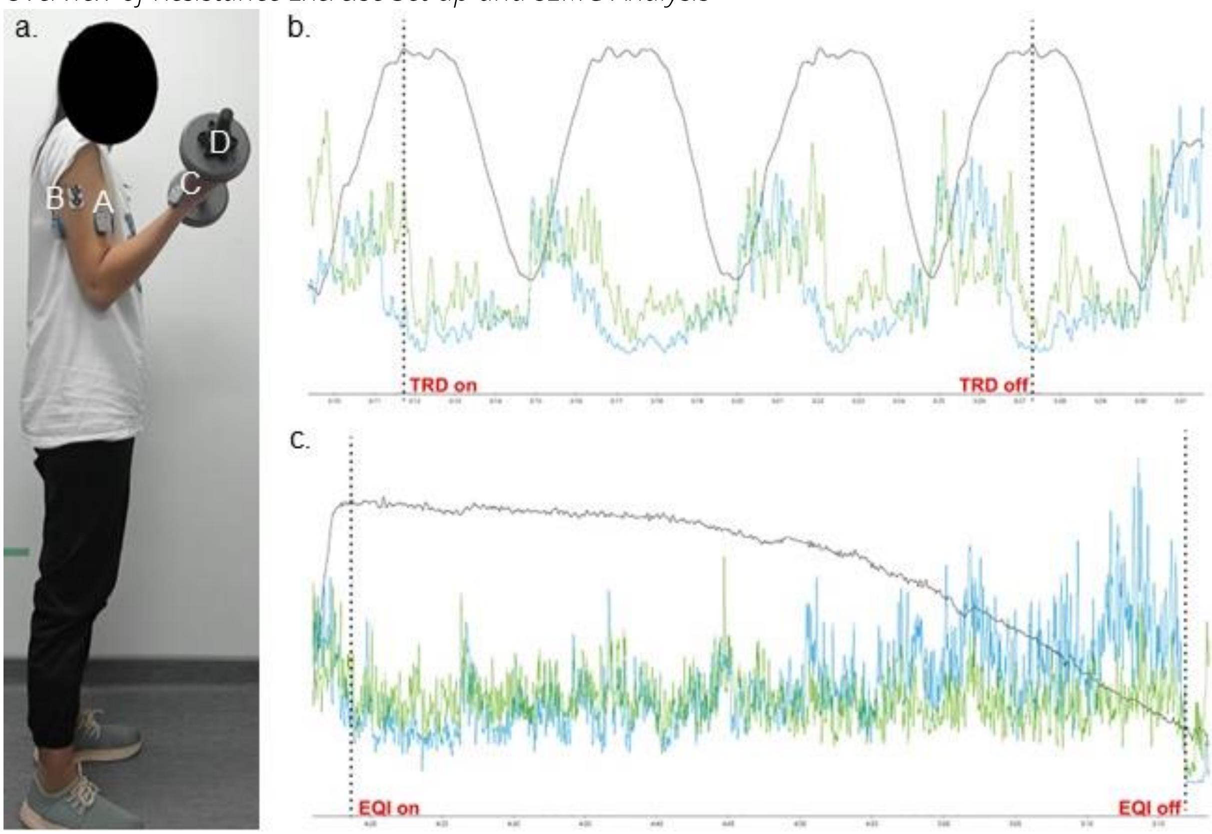
Note. Prior to the data collection session, participants completed 3 sessions in the lab (a.), where they were familiarised with the unilateral supinated bicep curl estimated 1-repetition maximum test (E-1RM; Canadian Society for Exercise Physiology) on both limbs (i), performed true baseline E-1RM tests, were familiarised with EQI resistance exercise (ii.), and practiced the TRD-RE and EQI-RE protocol (iii.). A minimum of 3 days later, participants completed the full resistance exercise protocol (b.). The first limb was prepped for surface electromyography (sEMG), then participants performed a standardised warm-up of 1, 2, and 3 unilateral bicep curl repetitions, followed by 2 sets of TRD-RE or EQI-RE to volitional fatigue. After 10-minutes of lying rest, the remaining limb was prepped for sEMG and then performed the standardised warm-up, followed by 2 sets of the remaining resistance exercise type (iv.). Shaded areas represent parts of additional investigations.

TRD-RE and EQI-RE. For both the TRD-RE and EQI-RE, participants were positioned 1-2 feet from a wall, with their feet shoulder-width apart and parallel to the wall. The involved limb was positioned away from the wall, while the uninvolved limb was allowed to be abducted against the wall for support (Figure 2a.). After picking the dumbbell up off the floor, participants held the dumbbell at their side in a supinated grip, before initiating either resistance exercise type.

For the TRD-RE limb, participants performed continuous supinated dumbbell bicep curls using a metronome guided 1-second concentric and 2-second eccentric muscle action. Participants were instructed to perform repetitions from full elbow extension through at least ~130° of elbow flexion and were immediately and verbally corrected if they did not complete a repetition to full ROM. For each set, participants performed as many continuous repetitions as possible until they could no longer complete a single repetition, regardless of repetition velocity, and the set was ended if participants required excessive momentum to perform repetitions. For EQI-RE, participants were instructed to flex their elbow to ~130°, and then brace and maintain joint position for as long as possible without causing concentric or eccentric muscle actions (Oranchuk et al., 2020, 2021). Participants were told to then voluntarily resist the eccentric (lengthening) muscle action that would occur as they fatigued, for as long as possible, until the dumbbell returned to the starting position at their sides and/or contacted their thigh. If participants under or overshot the initial 130° position, their elbow angle was immediately and verbally corrected. Verbal encouragement was provided during the TRD-RE and EQI-RE.

Figure 2

Overview of Resistance Exercise Set-up and sEMG Analysis



Note. Set-up at starting position (a.) and example data trace overlay for TRD-RE (b.) and EQI-RE (c.). A= biceps brachii electrode placement, B = triceps brachii electrode placement, C = IMU placement, D = dumbbell corresponding to 70% of E-1RM. Onset and offsets are identified by dotted lines; EQI = Eccentric quasi-isometric set, TRD = Traditional isotonic set. Black line = vertical acceleration, blue line = biceps brachii linear envelope, green line = triceps brachii linear envelope. X-axis are not to scale.

Data Processing

sEMG and IMU data were sampled at 2000 Hz and 200 Hz, respectively, and recorded in MR3 Software (v. 3.18, Noraxon U.S.A). Data were then exported as .csv files and imported into LabChart 8 (ADInstruments Inc., Colorado Springs, USA), where custom macros were used to further bandpass filter (20-500 Hz; zero-phase lag Finite Impulse Response (FIR)), full-wave rectify, and subsequently lowpass filter (8Hz; FIR) the sEMG data to create a linear envelope. Acceleration data were smoothed using a lowpass filter (5 Hz; FIR) and vertical acceleration was used to define the start and end of each TRD-RE and EQI-RE set. For TRD-RE, peak-to-peak analysis was used to define each repetition, with the first acceleration peak (i.e., peak elbow flexion) representing the start of the first repetition/set, and the last peak representing the end of the last repetition/set (Figure 2b). The start of each EQI-RE set was manually defined as the point after the initial elbow flexion where acceleration visually stabilized, while the end of each set was considered the lowest acceleration value where sEMG excitation was visibly present (Figure 2c; Kamen & Gabriel, 2010).

For each TRD-RE and EQI-RE set, the largest sEMG linear envelope value within a set was "LEpeak." The sEMG linear envelope of the biceps and triceps brachii was then integrated using the rectangular rule (iEMG), and the resulting iEMG value was considered to be absolute "muscle activity" (iEMGabs). To calculate relative iEMG (iEMG%), the linear envelope was normalised to the peak value during set 1, and again integrated using the rectangular rule. To calculate antagonist co-activation ratio (CoA), the iEMG% of the triceps brachii was divided by the iEMG% of the biceps brachii. The time to perform each EQI-RE and TRD-RE set (i.e., onset to offset) was time under tension. Custom LabChart 8 macros were used to extract the variables which were then exported to Excel (Microsoft 365; Microsoft Corporation, Redmond, USA).

Statistical Analysis

Statistical analyses were performed in open-source Jamovi software (v 2.3.21) and SPSS 28 (IBM, Inc.; Armonk, USA). To compare the effects of TRD-RE vs. EQI-RE (type) on time under tension, biceps brachii excitation (LEpeak, iEMGabs, iEMG%), and triceps brachii-biceps brachii co-activation ratio (CoA) between males and females (sex) and across 2 sets (sets), 5 three-way mixed-factorial ANOVAs (2[type]*2[set]*2[sex]) with repeated measures on set and type were conducted. For main and interaction effects, α was based on a compromise power analysis.

As the current study was part of a larger project, and therefore not specifically powered to the outcomes, a compromise power analysis based on 27 participants for a 2(type) *2(set) interaction and within-subject main effects was performed to determine significance cut-offs (G*Power V. 3.1.9.2; Faul et al., 2007). Assuming a β/α probability ratio of 1, a power (1- β error probability) of 0.91 was achieved for a large effect size ($\eta_p^2 = 0.14$) when $\alpha = .21$-$.22$. As such, 2 (type) *2(set) interactions were considered significant at $p \leq .22$, and Bonferroni corrected for post-hoc comparisons. Due to software limitations, sex was not included in compromise power calculations, and therefore three-way interactions should be interpreted cautiously. Assumptions of normality and homogeneity of variances were assessed with Shapiro-Wilk's and Levene's tests ($p < .05$; Field, 2009; Levene, 1960), respectively. Outliers and extreme outliers were defined as data points outside 1.5x and 3x the interquartile range, respectively. Due to expected variability in the data and modest sample size, outliers were left in the analysis; however, extreme outliers were replaced with the next lowest score + 1, as per (Field, 2009). Significant main and interaction effects were followed by simple main effects and pairwise contrasts. Small, medium, and large effect sizes (η_p^2) were generalised as .01, .06, and .14. Variability is presented as ± standard deviation (SD) unless otherwise specified.

Results

Of the 30 participants recruited, two participants were lost to attrition and did not complete the protocol, while one participant was excluded due to missing accelerometer data. As such, 27 participants (14 male, 13 female), or 54 limbs were included in the final analysis. Demographics and body composition for each participant and limb are presented in Table 1. Both E-1RM and lean mass for TRD-RE and EQI-RE limbs were not statistically different. The resistance exercise protocol was performed with an actual relative load of 69.1 ± 2.3% and 69.5 ± 2.1% of E-1RM in males and females, respectively. Biceps Brachii signal-to-noise ratio ranged from 1.63 – 2.57, while triceps brachii ranged from 0.98 – 2.26; triceps brachii signal-to-noise ratio was < 1.2 in two instances during EQI-RE.

Table 1

Demographic and Descriptive Statistics for Study Sample and Assigned Limbs

	Male (*n* = 14)		Female (*n* = 13)	
Descriptives	M (SD)	Range	M (SD)	Range
Age (years)	21.9 (3.9)	18-30	25.1 (3.3)	19-32
Height (cm)	179.6 (9.9)	167.7-199.5	166 (5.7)	157-176
Weight (kg)	76.7 (16.9)	52.7-111.3	70.5 (17.7)	51.0-118.3
Lean Mass (kg)	34.9 (6.8)	26.3-49.8	26 (3.8)	20.7-34.2
Body Fat%	18.9 (8.9)	8.7-34.3	31.3 (9.7)	14.0-49.2
	Male		Female	
E-1RM[a] (lbs)	M (SD)	Range	M (SD)	Range
TRD-RE Limb (*n* = 27)	27.4 (5.8)	17.6-40.0	17.7 (4.0)	12.5-24.1
EQI-RE Limb (*n* = 27)	26.6 (5.2)	15.1-36.7	17.6 (4.0)	12.0-27.1
	Male		Female	
Lean Mass[a] (kg)	M (SD)	Range	M (SD)	Range
TRD-RE Limb (*n* = 27)	3.4 (0.8)	2.3-5	2.4 (0.6)	1.6-3.8
EQI-RE Limb (*n* = 27)	3.4 (0.7)	2.4-4.8	2.4 (0.6)	1.6-3.8

	Male		Female	
TRD-RE Repetitions	M (SD)	Range	M (SD)	Range
Set 1 (*n* = 27)	13.6 (2.6)	10-20	13.3 (2.3)	9-18
Set 2 (*n* = 27)	6.4 (2.2)	3-11	6.9 (1.7)	4-9

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).

As expected, data were not normally distributed, although no more than one extreme outlier was present for any variable; a total of 7 data points were replaced across all dependent and independent variables. Traditional transformation methods (Log10, square root) did not meet the assumption of homogeneity of variance; thus, ANOVAs and interpretation were based on observed scores. Estimated marginal means, data normality, and homogeneity of variance after replacement are presented in Table 2. ANOVA tables for main effects, interaction effects, and pairwise comparisons can be found in Appendix A.

Table 2

Means for Dependent Variables Split by Type, Set, and Sex

		TRD-RE	EQI
DV	Sex	Mean (SD)	Mean (SD)
LEpeak Set 1 [d]	M	1430.2 (529.4)	488.4 (368.7) [b]
μV	F	646.4 (263.2)	360.7 (178.3)
LEpeak Set 2 [c, d]	M	1222.79 (434.7)	542.6 (370.7)
μV	F	586.7 (180.7)	337.4 (147.4)
iEMGabs Set 1	M	18686.3 (7853.5)	17036.6 (13454.8)
μV /s	F	9571.8 (5518.3) [b]	17207.0 (11531.3)
iEMGabs Set 2 [c]	M	9544.9 (4906.2)	12776.6 (9481.3)
μV /s	F	5070.1 (2715.2) [b]	10909.7 (5793.8)
iEMG% Set 1	M	1303.3 (288.8)	3372.3 (1257.0)
%/s	F	1441.6 (402.9)	4487.5 (1752.3)
iEMG% Set 2	M	679.8 (324.1)	2620.9 (1273)
%/s	F	823.4 (272)	3085.8 (1215.8) [b]
CoA Set 1	M	1.3 (0.2)	1.2 (0.3) [b]
iEMG%/iEMG%	F	1.1 (0.2)	1.3 (0.2)
CoA Set 2 [c]	M	1.2 (0.3)	1.1 (0.4)
iEMG%/iEMG%	F	1.1 (0.1)	1.3 (0.4)
TUT Set 1	M	55.4 (12.7)	101.6 (35.7)
seconds	F	47.9 (8.3)	149.6 (67.7)
TUT Set 2	M	28.0 (10.8)	64.7 (22.1) [b]
seconds	F	28.4 (7.6)	92.0 (28.2)

Note. M = male, F = female, SD = standard deviation, DV = dependent variable, LEpeak = peak biceps brachii excitation, iEMGabs = absolute biceps brachii integrated surface electromyography, iEMG% = relative biceps brachii integrated surface electromyography, CoA = triceps brachii-biceps brachii co-activation ratio, TUT = time under tension.

[b] Significant Shapiro-Wilks Test ($p < .05$)

[c] Significant Levene's Test, TRD-RE ($p < .05$)

[d] Significant Levene's Test, EQI-RE ($p < .05$)

Effect of Resistance Exercise Type and Set

Time Under Tension. There were significant and large main effects of type (p < .001, η_p^2= 0.77) and set (p < .001, η_p^2= .76), with TRD-RE producing significantly less time under tension than EQI-RE (39.9 ± 1.75 vs. 101.97 ± 7.19 s) and set 1 producing significantly more time under tension than set 2 (88.6 ± 5.6 vs. 53.3 ± 2.8 s). There was also a significant and large type*set interaction (p = .002, η_p^2 = 0.324), with simple effects and pairwise contrasts indicating that TRD-RE produced significantly less time under tension than EQI-RE during set 1 (p < .001, η_p^2= 0.7) and set 2 (p < .001, η_p^2 = 0.82), while set 1 produced more time under tension than set 2 when performing TRD-RE (p < .001, η_p^2 = 0.88) or EQI-RE (p < .001, η_p^2 = 0.63).

LEpeak. There were significant and large main effects for type (p < .001, η_p^2 = 0.83) and set (p = .01, η_p^2 = 0.24), with TRD-RE resulting in higher LEpeak values than EQI-RE (971.5 ± 71.0 vs. 432.3 ± 55.1 μV) and set 1 resulting in higher LEpeak values than set 2 (731.5 ± 64.3 vs. 672.4 ± 54.2 μV). There was also a significant type*set interaction, (p = .002, η_p^2 = 0.32); simple effects and pairwise contrasts indicated TRD-RE produced significantly greater LEpeak compared to EQI-RE during set 1 (p <.001, η_p^2 = 0.83) and set 2 (p < .001, η_p^2 = 0.76). However, set 1 only produced significantly higher LEpeak than set 2 when performing TRD-RE (p = .002, η_p^2 = 0.317), and there were no significant differences between sets when performing EQI-RE (p = .398).

iEMGabs. There were significant and large main effects for type (p = .025, η_p^2 = 0.19) and set (p < .001, η_p^2 = 0.67), with TRD-RE producing significantly less iEMGabs than EQI-RE (10718.3 ± 999.3 vs. 14482.5 ± 1921.3 μV /s), and set 1 producing significantly more iEMGabs than set 2 (15625.4 ± 1652.6 vs. 9575.3 ± 1041.5 μV /s).

CoA. There were no main or interaction effects of type and/or set for CoA.

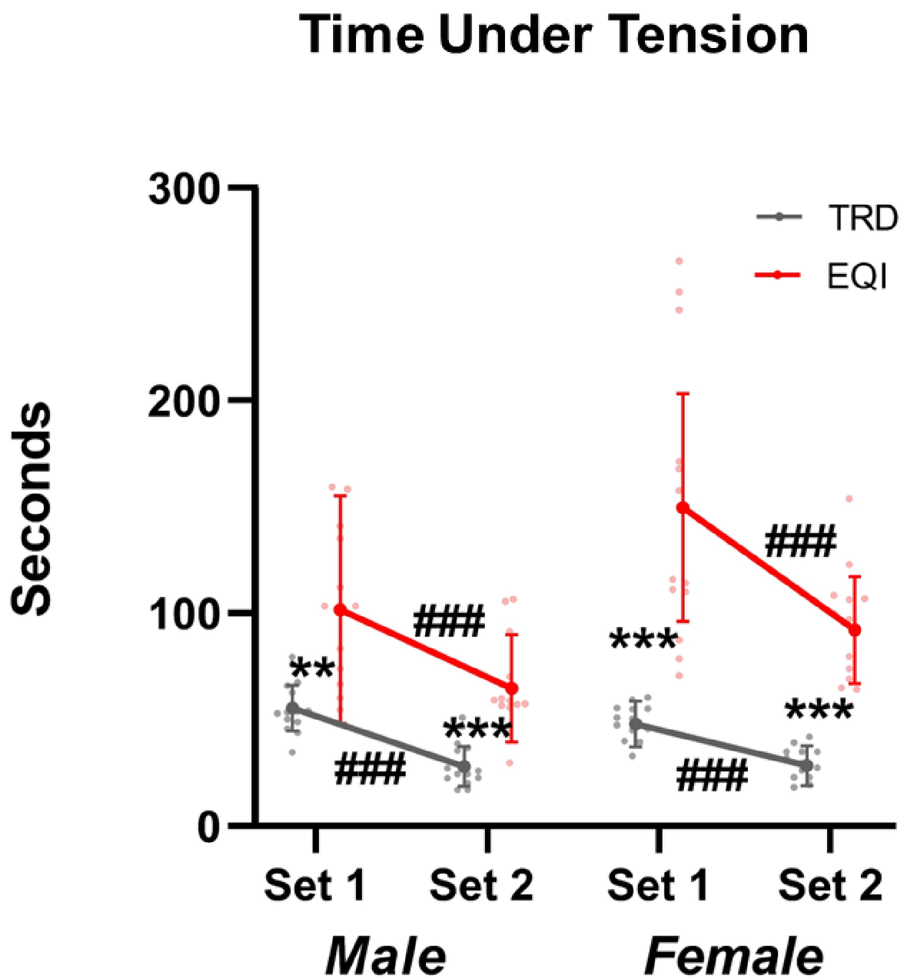
iEMG%. There were significant and large main effects for type (p < .001, ηp^2 = 0.79) and set (p < .001, η_p^2 = 0.73), with TRD-RE producing significantly less iEMG% than EQI-RE (1062 ± 57 vs. 3391.7 ± 252.3 %/s), and set 1 producing significantly more iEMG% than set 2 (2651.2 ± 163.4 vs. 1802.5 ± 130.1 %/s). There was also a significant and large type*set interaction, (p < .008, η_p^2 = 0.25), with simple effects and pairwise contrasts indicating that TRD-RE produced significantly less iEMG% than EQI-RE during set 1 (p < .001 η_p^2 = 0.85) and set 2 (p < .001, η_p^2 = 0.6), while set 1 produced significantly more iEMG% than set 2 when performing TRD-RE (p < .001, η_p^2 = 0.78) or EQI-RE (p < .001, η_p^2 = 0.77).

Effect of Sex

Time Under Tension. There was a significant and large main effect of sex (p = .041, η_p^2 = .157), with males producing significantly less time under tension than females (62.4 ± 5.5 vs. 79.5 ± 5.7 s). Furthermore, there was a large and significant type*sex (p = .006, η_p^2 = .265), and sex*type*set interaction (p = .049, η_p^2 = 0.15). Simple effects and pairwise contrasts indicated there were no sex-differences in time under tension with TRD-RE (p = .321). However, males produced significantly less time under tension than females when performing EQI-RE (p = .015, η_p^2 = 0.22). For the sex*type*set interaction, when performing TRD-RE, males produced significantly more time under tension than females during set 1 (p =.085, η_p^2 = 0.12), but there were no sex-differences during set 2 (p =.915). When performing EQI-RE, however, females produced significantly greater time under tension than males during set 1 (p = .028, η_p^2 = 0.18), and set 2 (p = .009, η_p^2 =.24, Figure 3, Table 2).

Figure 3

Interaction of Resistance Exercise Type and Set Split by Sex for Time Under Tension

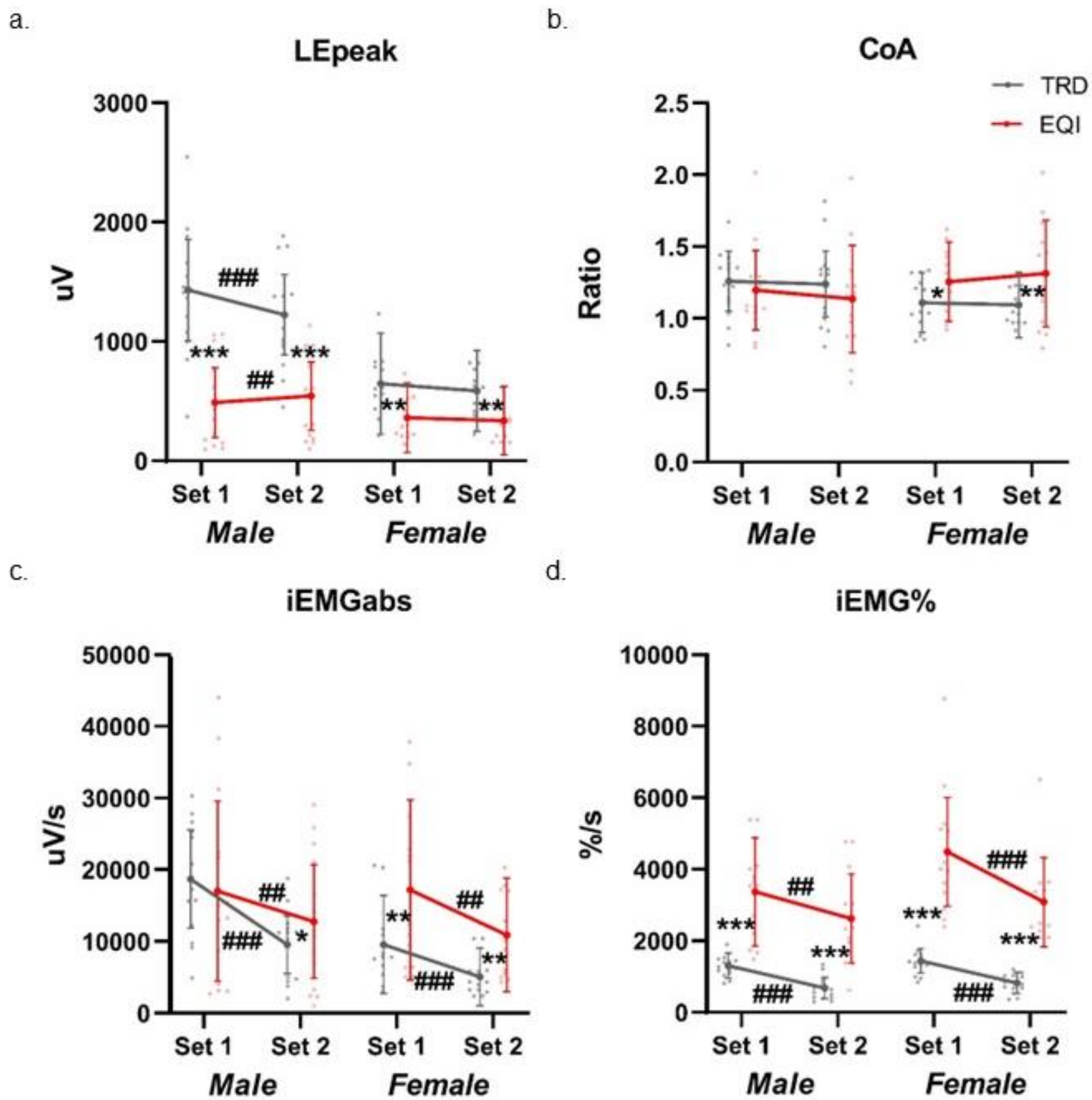


Note. ** $p \leq .05$, *** $p \leq .01$ between type. ### $p \leq .01$ between sets. Symbols represent estimated marginal means. Error bars denote standard deviation. Individual dots represent observed data points. Red = EQI-RE, grey = TRD-RE. For simplicity, significant sex-differences are not indicated on figures; *p*-values are Bonferroni corrected as in SPSS 28.

LEpeak. There was a significant and large main effect of sex (p = .001, η_p^2 = 0.36), with males producing higher LEpeak values than females (482.8 ± 84.3 vs. 921.0 ± 81.2 μV). Furthermore, there were significant and large type*sex (p < .001, η_p^2 = 0.55), and type*set*sex interactions (p = .017, η_p^2 = 0.21). Simple effects and pairwise contrasts indicated that males produced significantly higher LEpeak than females when performing TRD-RE (p < .001, η_p^2 = 0.5) or EQI-RE (p = .143, η_p^2 = 0.08), while TRD-RE produced higher LEpeak than EQI-RE for both males (p < .001, η_p^2 = 0.848) and females (p = .001, η_p^2 = 0.36). When this interaction was broken down by set, TRD-RE produced higher LEpeak than EQI-RE during set 1 and set 2, regardless of sex (p = .002 to p < .001, η_p^2 = 0.30 to η_p^2 = 0.86). However, when performing EQI-RE, there was no significant difference in LEpeak between males and females during set 1 (p = 0.27), although males produced significantly greater LEpeak than females during set 2 (p = .074, η_p^2 = .12). Additionally, while set 1 produced higher LEpeak than set 2 when males performed TRD-RE (p = .001, η_p^2 = .37) or EQI-RE (p = .039, η_p^2 = .16), in females, there was no significant difference between set 1 and set 2 when performing TRD-RE (p = .30) or EQI-RE (p = .376; Figure 4a, Table 2).

Figure 4

Interaction of Resistance Exercise Type and Set Split by Sex for Biceps Brachii



Note. LEpeak (linear envelope peak; a.), CoA (triceps brachii-biceps brachii co-activation ratio; b.) iEMGabs (absolute biceps brachii integrated surface electromyography; c.), and iEMG% (relative (normalised) biceps brachii integrated surface electromyography; d.). * $p \leq .22$, ** $p \leq .05$, *** $p \leq .01$ between type. ## $p \leq .05$, ### $p \leq .01$ between sets. Symbols represent estimated marginal means. Error bars denote standard deviation. Individual dots represent observed data points. For simplicity, significant sex-differences are not indicated on figures; *p*-values are Bonferroni corrected as in SPSS 28.

CoA. There was no main effect of sex, however, there were significant and modest-large type*sex (p = .039, η_p^2 = .16) and type*set*sex interactions (p = .172, η_p^2 = .07). Simple effects and pairwise contrasts indicated that, when performing TRD-RE, males had greater CoA than females (p = .075, η_p^2 = 0.12), however, there were no sex-differences when performing EQI-RE (p = .338). In females, EQI-RE produced significantly larger CoA than TRD-RE (p = .048, η_p^2 = 0.15), while in males, CoA was not significantly different between TRD-RE and EQI-RE (p = .332). Broken down by set, when performing TRD-RE, females produced greater CoA than males during set 1 (p = .076, η_p^2 = 0.12) and set 2 (p = .114, η_p^2 = 0.10). When performing EQI-RE, however, there were no sex-differences during set 1 (p = .594) or set 2 (p = .230). Furthermore, in females, TRD-RE produced less triceps brachii CoA than EQI-RE during set 1 (p = .108 η_p^2 = 0.10) and set 2 (p = .034, η_p^2 = 0.17), however, in males, there were no significant differences between TRD-RE and EQI-RE during set 1 (p = .463) or set 2 (p = .277; Figure 4b, Table 2).

iEMGabs. There was a significant and large main effect of sex (p = .001, η_p^2 = 0.36), with males producing significantly more iEMGabs than females (14511.1 ± 1823.4 vs. 10689.7 ± 1892.2 μV/s). Furthermore, there was a significant and modest type*sex (p = .07, η_p^2 = .13) and type*set*sex interactions (p = .015, η_p^2 = 0.21). Simple effects and pairwise contrasts indicated that males produced significantly greater iEMGabs than females during TRD-RE (p = .002 η_p^2 = 0.67), however, there was no significant sex-difference in iEMGabs during EQI-RE (p = .827). Furthermore, TRD-RE produced significantly less iEMGabs than EQI-RE in females (p = .006, η_p^2 = 0.26), but in males there was no significant difference between TRD-RE and EQI-RE (p = .72). Broken down by set, when performing TRD-RE, males produced greater iEMGabs than females during set 1 (p =.002, η_p^2 = 0.32) and set 2 (p = .008, η_p^2 = 0.25), however, when performing EQI-RE, there were no significant differences between males and females during set 1 (p = .972) or set 2 (p = .546). Additionally, in females, TRD-RE produced less iEMGabs than EQI-RE during set 1 (p = .017 η_p^2 = 0.2) and set 2 (p = .003, η_p^2 = 0.3). In males, iEMGabs during set 1 was not statistically different when performing TRD-RE or EQI-RE (p = .570), although TRD-RE produced significantly less iEMGabs than EQI-RE during set 2 (p = .07, η_p^2 = 0.13; Figure 4c, Table 2).

iEMG%. There was a significant and modest main effect of sex, (p = .105, η_p^2 = 0.11), with males producing significantly less iEMG% than females (1994.1 ± 192.2 vs. 2459.6 ± 199.4 %/s). Furthermore, there were small-modest type*sex (p = .186, η_p^2 = .07), set*sex (p = .13, η_p^2 =.09), and type*set*sex interactions (p = .048, η_p^2 = 0.15). Simple effects and pairwise contrasts indicated there were no sex-differences in iEMG% when performing TRD-RE (p = .228), however, females produced more iEMG% than males when performing EQI-RE (p = .13, η_p^2 = 0.09). Regardless of resistance exercise type, females produced significantly greater iEMG%

than males during set 1 (p = .067, η_p^2 = 0.13), but there were no sex-differences during set 2 (p = .253). When considering type, set, and sex, performing TRD-RE did not result in significant sex-differences in iEMG% during set 1 (p = .312) or set 2 (p = .226). When performing EQI-RE, however, females produced significantly greater iEMG% than males during set 1 (p = .068, η_p^2 = 0.13), although there were no sex-differences during set 2 (p = .342; Figure 4d, Table 2).

Discussion

The current study compared the acute muscle fatigue response across 2 sets of traditional isotonic (TRD-RE) and eccentric quasi-isometric resistance exercise (EQI-RE) of the elbow flexors, and between the sexes. In line with our hypothesis, EQI-RE produced significantly and substantially more time under tension, iEMGabs, and iEMG% than TRD-RE, while TRD-RE led to higher LEpeak than EQI-RE. Furthermore, LEpeak, iEMGabs, iEMG%, and time under tension significantly decreased from set 1 to set 2, while males produced significantly higher LEpeak and iEMGabs, but significantly lower iEMG% and time under tension than females. Unlike our hypothesis, resistance exercise type, set, or sex did not individually affect CoA. Surprisingly, follow-up comparisons revealed several type*set*sex interactions that were not considered by our initial hypothesis, which will be addressed in the subsequent discussion.

The current study corroborates that when intensity is matched, EQI-RE produces more time under tension than TRD-RE. While this was assumed prior to the current study (Oranchuk et al., 2019), only one study had directly compared EQI-RE time under tension to another form of resistance exercise (eccentric knee extension); when resistance exercise volume was equated by angular impulse, average time under tension for eccentric resistance exercise of was 135 ± 72 s, whereas average time under tension for EQI-RE was 242 ± 132 s (Oranchuk et al., 2020). Although inferential comparison was not reported, this represents a 79% and significant (paired t-test; $p < .05$) increase in time under tension when performing EQI-RE. Comparatively, there was also a significant and substantial time under tension difference between resistance exercise type in the current study, with EQI-RE producing 256% more time under tension than TRD-RE. In line with our hypothesis, when this difference was broken down by sex, females produced 45% more time under tension than males across both sets (241.6 vs. 166.3 s; Table 2). Based on our previous work (Henderson et al., 2023) and the broader muscle fatigue literature, this result is not unexpected, as females are typically more fatigue-resistant than males during sustained low-velocity and/or isometric muscle actions of the elbow flexors (Hunter, 2016b, 2016a). If characterising EQI-RE as both isometric and low-velocity (Oranchuk et al., 2019), sex-differences in fatiguability were present in the current study, as females were able to sustain EQI-RE set 1 and set 2 longer than males.

Previous research suggests that males and females experience similar relative reductions in isometric torque (Senefeld et al., 2013), peak concentric torque (Gentil et al., 2017), time to task failure (Yoon et al., 2015), and concentric power (Senefeld et al., 2013) after and across multiple sets of concentric elbow flexions, although these studies used training intensities well below traditional resistance exercise practices (e.g., 20% maximal isometric torque). Conversely, when utilising a self-selected repetition velocity, and a similar intensity (75% 1-RM) and inter-set rest period (2-minutes) as the current study, Ratamess et al. (2012) observed a significant reduction in repetitions performed by men, but not women, after 2 sets of bench press. Similarly, Voskuil et al. (2024) observed that resistance-trained males performed significantly less repetitions and exerted less isometric strength and associated sEMG amplitudes compared to females across 4 sets of unilateral bicep curls to volitional fatigue at 50% 1RM. In comparison, the current study did not reveal sex-differences in the number of TRD-RE repetitions performed during set 1 or set 2 (Table 2), nor differences in normalised muscle activity. Indeed, while the presence of time under tension, but not repetition differences between males and females during TRD-RE in the current study could be explained by differences in repetition cadence with neuromuscular fatigue (e.g., Refalo et al., 2023), the current study also revealed no sex-differences in normalised muscle activity during TRD-RE, which may suggest that observed differences in muscle fatigue are due to sex-related contractile mechanisms (Nuzzo, 2024). However, when sEMG data were broken down by type, set and sex, a complex muscle excitation response appears to be present.

Under the broad assumption that motor unit recruitment threshold is inversely related to size, and greater sEMG amplitude indicates higher threshold motor units are being excited (Henneman, 1957; Henneman & Olsen, 1965; Kamen & Gabriel, 2010; Lawrence et al., 1983), LEpeak data suggests that TRD-RE results in greater excitation of high threshold motor units than EQI-RE. Notably, females displayed similar LEpeak and iEMG values between sets for both TRD-RE and EQI-RE, whereas males LEpeak significantly decreased between sets when performing TRD-RE, and slightly increased between sets for EQI-RE. Coupled with a high initial LEpeak value, the large set-to-set decrease in males could suggest greater initial involvement of high threshold motor units in set 1 (Bigland-Ritche et al., 1983; Carr et al., 2021; Carr & Ye, 2020), which is followed by either a large reduction in the number, size, and/or firing rate of motor units during set 2. Furthermore, the smaller drop-off in males' iEMGabs and slight increase in males' LEpeak from set 1 to set 2 during EQI-RE could suggest EQI-RE progressively, albeit slightly, recruited additional and presumably high threshold motor units in males with multiple sets (Adam & De Luca, 2003; Carr et al., 2021). In contrast, the lack of set-to-set differences and similar behaviour of females' LEpeak for both TRD-RE and EQI-RE could suggest that females utilise similar motor unit recruitment strategies regardless of resistance exercise type. As is the case with our previous work, however, specific motor unit behaviours cannot be revealed with the current methods.

Previous works have suggested that males could experience greater decreases in muscle excitability during isotonic resistance exercise for the elbow flexors (Nuzzo et al., 2023; Voskuil et al., 2024). Although the current study suggests that EQI-RE may not excite motor units as quickly as TRD-RE, when compared to the large set-to-set decrease in LEpeak for TRD-RE, the slight increase in LEpeak for males when performing EQI-RE may suggest that males are better able to maintain excitability (e.g., Adam & De Luca, 2003) with EQI-RE, and therefore are less fatigued relative to TRD-RE. As the ability to excite high threshold motor units would theoretically benefit muscle force output, the data of the current study would fit with the results of Oranchuk et al. (2020), who observed a smaller decrease in maximal voluntary isometric torque in resistance-trained males after performing EQI-RE. Therefore, these data may loosely support claims that EQI-RE results in less fatigue than isotonic or isometric resistance exercise (Seedman, n.d.-a, n.d.-b). While muscle fatigue can limit performance, it is relevant to note that it represents an important stimulus for creating neuromuscular and muscle morphological adaptations (Hunter, 2016b). In the context of sport-specific training or strength and conditioning, the principle of specificity would require high-threshold and highly fatigable motor units to be sufficiently stimulated and recruited to create progressive overload and adaptation. As discussed by Oranchuk et al. (2019), collectively these data may therefore suggest that EQI-RE has limited application for improving the neuromuscular aspects of muscle strength or power, as these motor units would experience a reduced stimulus when performing EQI-RE compared to TRD-RE.

As EQI-RE is purported to result in greater agonist-antagonist co-contraction/activation, and subsequent improvements in muscle stiffness, stabilisation, and coordination (Morrison, 2016; Oranchuk et al., 2019b; Seedman, n.d.-a, n.d.-b; Sinicki, 2019), we examined iEMG CoA of the triceps brachii and biceps brachii. The current study did not reveal a main effect of resistance exercise type on CoA. When data were examined within each sex, however, CoA was higher during EQI-RE in females only, and males in the current study had higher CoA than females when performing TRD-RE but not EQI-RE. Given studies that observed no difference in CoA and/or similar triceps brachii sEMG amplitude between sustained holding and yielding isometrics, but differences in time to task failure (Rudroff et al., 2007, 2011; Schaefer & Bittmann, 2017), the lack of CoA differences between TRD-RE and EQI-RE are not necessarily surprising. However, the observed sex-differences in CoA when performing TRD-RE contrasts with the paucity of research suggesting that females may exert greater and/or similar triceps activation than males when performing sub-maximal isokinetic elbow flexions. For example, researchers have suggested that the increased metabolic and neuromuscular demand of recruiting additional motor units of the antagonist musculature may be detrimental to muscular endurance (Jodoin et al., 2023a; Schaefer & Bittmann, 2017; Yoon et al., 2013). As females produced substantially more time under tension than males during EQI-RE despite having greater CoA, and males produced equivalent, if not longer time under tension during TRD-RE while having greater CoA than females, the current study suggests a limited contribution of CoA to sex-differences in muscle fatigue during TRD-RE or EQI-RE.

To remove the influence of external factors that may affect results irrespective of sex, such as muscle strength, body composition, height, etc. (Halaki & Ginn, 2012) and examine relative differences, we examined relative muscle activity (iEMG%) alongside absolute muscle activity (iEMGabs). In the current study, iEMG% was not statistically different between males and females when performing TRD-RE and from these data, it would appear that sex-differences in iEMGabs during TRD-RE could therefore be attributed to differences in strength and/or anthropometry between males and females. With EQI-RE, however, females produced significant, albeit slightly greater iEMG% during set 1 even though males and females were not statistically different for iEMGabs. As differences were present when expressed relatively, this could suggest that there are sex-specific mechanisms involved in maintaining force output and motor unit recruitment during EQI-RE, but not TRD-RE. As such, sex-differences in iEMG% are perhaps due to differences in motor unit recruitment strategies or substrate metabolism between males and females (Hunter, 2014; Nishikawa et al., 2017; Pradhan et al., 2020), which would not be revealed using the current methods. Beyond suggesting that factors intrinsic of sex may influence EQI-RE more so than TRD-RE, further speculation is beyond the scope of the current investigation.

The results of the current study lend initial support to our theory that chronic EQI-RE will lead to sex-differences in muscle hypertrophy and strength that would be different from TRD-RE. Current data suggests that untrained males and females experience similar relative increases in muscle mass from chronic TRD-RE (Roberts et al., 2020), although females may have a small advantage when it comes to improving strength (Roberts et al., 2020). Assuming mechanical tension or mechanotransduction is the primary driver of muscle hypertrophy (Haun et al., 2019; Schoenfeld, 2010) the limited sex-differences in time under tension when performing acute TRD-RE in the current study would fit with these data, as relative volume would theoretically be similar across a resistance exercise program. As females exerted substantially more time under tension and absolute muscle activity during EQI-RE compared to males and TRD-RE, however, it remains reasonable that females may experience greater relative muscle hypertrophy (Schoenfeld et al., 2017) than males with EQI-RE. Furthermore, while EQI-RE produced significantly smaller LEpeak than TRD-RE for males (set 1: -293%, set 2: -225%) and females, the magnitude of difference was much smaller in females (set 1: -180%, set 2: -174%), suggesting that there may be more significant differences between TRD-RE and EQI-RE in males with respect to neuromuscular and/or strength outcomes.

There are important limitations of the current study that should be considered when interpreting our results. Although EQI-RE and TRD-RE limbs were not statistically different with respect to lean mass and strength, the left arm may be more susceptible to electrocardiogram (ECG) contamination than the right arm, while neurological effects resulting from resistance exercise by the first limb may carry over to the second limb (Aboodarda et al., 2016; Halperin et al., 2014). As limb assignment was counterbalanced, and the overall contribution of ECG to signal power is relatively small (Kamen & Gabriel, 2010), however, it is expected that this would have minimal effect on our results. Furthermore, rapid changes in muscle length underneath bipolar sEMG electrodes can contribute to observed LEpeak and iEMG values (Kamen & Gabriel, 2010), which could affect TRD-RE to a greater degree than EQI-RE due to repeated and higher repetition velocity. Additionally, the current study was limited to two resistance exercise sets using untrained individuals, who had only recent exposure to TRD-RE and EQI-RE. As such, these results may not reflect those of resistance-trained or more experienced individuals, or those that might be expected for intensities above or below 70% 1-RM. The current study does have the advantage of being the first examination of EQI-RE using an ecologically valid model of resistance exercise, and not an isokinetic dynamometer (e.g., Henderson et al., 2023; Oranchuk et al., 2020, 2021). Most importantly, the current study does not address nor imply that EQI-RE or TRD-RE are more advantageous for muscle hypertrophy or muscle strength, as sEMG is poorly associated with muscle hypertrophy (Vigotsky et al., 2022).

Although the current study does not address long-term adaptations to TRD-RE or EQI-RE it has meaningful implications for practice. For one, it is apparent that males and females have different fatigue responses to TRD-RE and EQI-RE, and that the number of repetitions or sets performed may be relevant depending on the sex of the individual and desired training effects. With 2-minutes of rest between sets, males accrue less time under tension than females during EQI-RE and may experience a more significant decline in TRD-RE time under tension than females when performed to volitional fatigue. Additionally, males may require multiple sets of EQI-RE to recruit the entirety of the motoneuron pool, and experience a larger drop-off in muscle excitation after 2 sets of TRD-RE. Furthermore, although the current study only had participants perform 2 sets of TRD-RE and EQI-RE, there is reason to believe that performing EQI-RE at the end of a resistance exercise session may have significantly different effects than what was observed in the current study. For example, recent work (Jodoin et al., 2023b) suggests that females may lose their fatiguability advantage over males when sustained isometric muscle actions are preceded by maximal eccentric muscle actions, which is associated with a significant increase in female antagonist activation. It should be noted that the EQI-RE data in the current study, as well as in previous studies (Henderson et al., 2023; Oranchuk et al., 2020, 2021), has been highly variable, however, this is not unexpected in resistance exercise studies of untrained individuals (Mann et al., 2014), and thus individual responses to EQI-RE may vary greatly.

Conclusion

The current study suggests there are relevant sex and set differences in the sEMG and time under tension response to TRD-RE and EQI-RE of the biceps brachii and triceps brachii that are theoretically relevant for long-term muscle hypertrophy. Overall, TRD-RE likely results in quicker recruitment and fatigue of motor units compared to EQI-RE, with similar and/or small differences in time under tension and relative muscle activation between males and females. Conversely, females appear to produce significantly more time under tension, absolute and relative muscle activity than males during EQI-RE, along with greater triceps brachii-biceps brachii CoA, suggesting the involvement of fatigue mechanisms intrinsic to sex. More generally, males and females completed the same number of repetitions when performing unilateral isotonic dumbbell curls, although time under tension varied slightly. Based on these findings, future studies should examine whether these acute sex-differences would manifest in long-term muscle hypertrophy, strength, and/or neuromuscular adaptations between males and females, TRD-RE and EQI-RE.

Contributions

Contributed to conception and design: ZJH, 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, TDS

Acknowledgements

We would like to thank participants for volunteering their time, as well as undergraduate field-work students for their assistance.

Funding information

TDS and research infrastructure was supported by the Canadian Foundation for Innovation John R. Evans Leaders Fund and Research Manitoba Canadian Foundation for Innovation Matching Funds Program. ZJH PhD studies were supported by a NSERC-CGS-D scholarship.

Data and Supplementary Material Accessibility

Data sets can be found at
https://osf.io/sfxun/?view_only=8ae76e6252724a32a1b7dd18472383b0.

Supplementary materials are found in Appendix A.

References

Aboodarda, S. J., Šambaher, N., & Behm, D. G. (2016). Unilateral elbow flexion fatigue modulates corticospinal responsiveness in non-fatigued contralateral biceps brachii. *Scandinavian Journal of Medicine and Science in Sports*, *26*(11), 1301–1312. https://doi.org/10.1111/sms.12596

Adam, A., & De Luca, C. J. (2003). Recruitment order of motor units in human vastus lateralis muscle is maintained during fatiguing contractions. *Journal of Neurophysiology*, *90*(5), 2919–2927. https://doi.org/10.1152/jn.00179.2003

Barbero, M., Merletti, R., & Rainoldi, A. (2012). *Atlas of Muscle Innervation Zones Understanding Surface Electromyography and Its Applications*. Springer.

Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: a new frontier in chronic disease prevention. *Sports Medicine - Open*, *6*(1). https://doi.org/10.1186/s40798-020-00271-w

Canadian Society for Exercise Physiology. (2013). *Physical Activity Training for Health*.

Canadian Society for Exercise Physiology. (2017). *Pre-Screening for Physical Activity: Get Active Questionnaire*. https://csep.ca/2021/01/20/pre-screening-for-physical-activity/

Carr, J. C., Ye, X., & Tharp, H. M. (2021). Biceps brachii muscle length affects force steadiness with and without fatigue. *Journal of Science in Sport and Exercise*. https://doi.org/10.1007/s42978-020-00102-0

Csapo, R., Alegre, L. M., & Baron, R. (2011). Time kinetics of acute changes in muscle architecture in response to resistance exercise. *Journal of Science and Medicine in Sport*, *14*(3), 270–274. https://doi.org/10.1016/j.jsams.2011.02.003

Dankel, S. J., Laurentino, G. C., Loenneke, J. P., Buckner, S. L., Mattocks, K. T., Jessee, M. B., Counts, B. R., & Mouser, J. G. (2017). Can blood flow restriction augment muscle activation during high-load training? *Clinical Physiology and Functional Imaging*, *38*(2), 291–295. https://doi.org/10.1111/cpf.12414

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Field, A. (2009). *Discovering Statistics Using SPSS* (3rd ed.).

Gentil, P., Compos, M. H., Soares, S., De Conti Teixeira Costa, G., Paoli, A., Bianco, A., & Bottaro, M. (2017). Comparison of elbow flexor isokinetic peak torque and fatigue index between men and women of different training level. *European Journal of Translational Myology*, *27*(4), 246–250. https://doi.org/10.4081/ejtm.2017.7070

Gomes, M., Santos, P., Correia, P., Pezarat-Correia, P., & Mendonca, G. V. (2021). Sex differences in muscle fatigue following isokinetic muscle contractions. *Scientific Reports*, *11*(1), 1–12. https://doi.org/10.1038/s41598-021-87443-0

Halaki, M., & Ginn, K. (2012). Normalization of EMG Signals: To Normalize or Not to Normalize and What to Normalize to? In *Computational Intelligence in Electromyographic Analysis - A Perspective on Current Applications and Future Challenges*. Intech Open. https://doi.org/10.5772/49957

Halperin, I., Aboodarda, S. J., & Behm, D. G. (2014). Knee extension fatigue attenuates repeated force production of the elbow flexors. *European Journal of Sport Science*, *14*(8), 823–829. https://doi.org/10.1080/17461391.2014.911355

Haun, C. T., Vann, C. G., Roberts, B. M., Vigotsky, A. D., Schoenfeld, B. J., & Roberts, M. D. (2019). A critical evaluation of the biological construct skeletal muscle hypertrophy: Size matters but so does the measurement. *Frontiers in Physiology*, *10*(MAR), 1–23. https://doi.org/10.3389/fphys.2019.00247

Henderson, Z. J., Wang, S., Cornish, S. M., & Scribbans, T. D. (2023). Exploring the acute muscle fatigue response in resistance trained individuals during eccentric quasi-isometric elbow flexions—a cross-sectional comparison of repetition and sex. *Sports Biomechanics*, 1–23. https://doi.org/10.1080/14763141.2023.2269543

Henneman, E. (1957). Relation between the size of neurons and their susceptibility to discharge. *Science*, *126*, 1345–1347.

Henneman, E., & Olsen, C. B. (1965). Relations between structure and function in the design of the skeletal muscles. *Journal of Neurophysiology*, *28*, 581–593.

Hunter, S. K. (2014). Sex differences in human fatigability: Mechanisms and insight to physiological responses. *Acta Physiologica*, *210*(4), 768–789. https://doi.org/10.1111/apha.12234

Hunter, S. K. (2016a). Sex differences in fatigability of dynamic contractions. *Experimental Physiology*, *101*(2), 250–255. https://doi.org/10.1113/EP085370

Hunter, S. K. (2016b). The relevance of sex differences in performance fatigability. *Medicine and Science in Sports and Exercise*, *48*(11), 2247–2256. https://doi.org/10.1249/MSS.0000000000000928

Janssen, I., Heymsfield, S. B., Wang, Z., & Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *Journal of Applied Physiology*, *89*, 81–88. http://www.jap.org

Jodoin, H. L., Hinks, A., Roussel, O. P., Contento, V. S., Dalton, B. H., & Power, G. A. (2023a). Eccentric exercise-induced muscle weakness abolishes sex differences in fatigability during sustained submaximal isometric contractions. *Journal of Sport and Health Science*, *12*(4), 523–533. https://doi.org/10.1016/j.jshs.2023.02.001

Jodoin, H. L., Hinks, A., Roussel, O. P., Contento, V. S., Dalton, B. H., & Power, G. A. (2023b). Eccentric exercise-induced muscle weakness abolishes sex differences in fatigability during sustained submaximal isometric contractions. *Journal of Sport and Health Science*, *12*(4), 523–533. https://doi.org/10.1016/j.jshs.2023.02.001

Kamen, G., & Gabriel, D. A. (2010). *Essentials of Electromyography*. Human Kinetics.

Lawrence, J. H., De Luca, C. J., & De, C. J. (1983). *Myoelectric signal versus force relationship in different human muscles*.

Levene, H. (1960). Robust tests for equality of variances. In I. Olkin, S. G. Ghurye, W. Hoeffding, W. G. Madow, & H. B. Mann (Eds.), *Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling*.

Ličen, U., Oranchuk, D. J., & Kozinc, Ž. (2024). Exploring the biomechanics and fatigue patterns of eccentric quasi-isometric muscle actions in the knee extensors and flexors. *European Journal of Applied Physiology*. https://doi.org/10.1007/s00421-024-05544-w

Lim, C., Nunes, E. A., Currier, B. S., McLeod, J. C., Thomas, A. C. Q., & Phillips, S. M. (2022). An evidence-based narrative review of mechanisms of resistance exercise-induced human skeletal muscle hypertrophy. *Medicine and Science in Sports and Exercise*, *54*(9), 1546–1559. https://doi.org/10.1249/MSS.0000000000002929

Lulic-Kuryllo, T., Thompson, C. K., Jiang, N., Negro, F., & Dickerson, C. R. (2021). Neural control of the healthy pectoralis major from low-to-moderate isometric contractions. *Journal of Neurophysiology*, *126*(1), 213–226. https://doi.org/10.1152/jn.00046.2021

Macinnis, M. J., McGlory, C., Gibala, M. J., & Phillips, S. M. (2017). Investigating human skeletal muscle physiology with unilateral exercise models: When one limb is more powerful than two. *Applied Physiology, Nutrition and Metabolism*, *42*(6), 563–570. https://doi.org/10.1139/apnm-2016-0645

Mann, T. N., Lamberts, R. P., & Lambert, M. I. (2014). High responders and low responders: Factors associated with individual variation in response to standardized training. In *Sports Medicine* (Vol. 44, Issue 8, pp. 1113–1124). Springer International Publishing. https://doi.org/10.1007/s40279-014-0197-3

McKendry, J., Stokes, T., McLeod, J. C., & Phillips, S. M. (2021). Resistance exercise, aging, disuse, and muscle protein metabolism. *Comprehensive Physiology*, *11*(3), 2249–2278. https://doi.org/10.1002/cphy.c200029

Moritani, T., & DeVries, H. (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. *American Journal of Physical Medicine*, *58*(3), 115–130.

Morrison, N. (2016). *The Russian Training Secret*. https://www.t-nation.com/training/qi-the-russian-training-secret/

Nishikawa, Y., Watanabe, K., Takahashi, T., Hosomi, N., Orita, N., Mikami, Y., Maruyama, H., Kimura, H., & Matsumoto, M. (2017). Sex differences in variances of multi-channel surface electromyography distribution of the vastus lateralis muscle during isometric knee extension in young adults. *European Journal of Applied Physiology*, *117*(3), 583–589. https://doi.org/10.1007/s00421-017-3559-3

Nuzzo, J. L. (2022). Narrative review of sex differences in muscle strength, endurance, activation, size, fiber type, and strength training participation rates, preferences, motivations, injuries, and neuromuscular adaptations. *The Journal of Strength and Conditioning Research*, *37*(2), 494–536. www.nsca.com

Nuzzo, J. L. (2024). Sex differences in skeletal muscle fiber types: A meta-analysis. *Clinical Anatomy*, *37*(1), 81–91. https://doi.org/10.1002/ca.24091

Nuzzo, J. L., Pinto, M. D., & Nosaka, K. (2023). Muscle strength and activity in men and women performing maximal effort biceps curl exercise on a new machine that automates eccentric overload and drop setting. *European Journal of Applied Physiology*, *123*(6), 1381–1396. https://doi.org/10.1007/s00421-023-05157-9

Oranchuk, D. J., Diewald, S. N., McGrath, J. W., Nelson, A. R., Storey, A. G., & Cronin, J. B. (2021). Kinetic and kinematic profile of eccentric quasi-isometric loading. *Sports Biomechanics*, *00*(00), 1–14. https://doi.org/10.1080/14763141.2021.1890198

Oranchuk, D. J., Nelson, A. R., Storey, A. G., Diewald, S. N., & Cronin, J. B. (2020). Short-term neuromuscular, morphological, and architectural responses to eccentric quasi-isometric muscle actions. *European Journal of Applied Physiology*, *121*, 141–158. https://doi.org/10.1007/s00421-020-04512-4

Oranchuk, D. J., Storey, A. G., Nelson, A. R., & Cronin, J. B. (2019). Scientific basis for eccentric quasi-isometric resistance training: A narrative review. *Journal of Strength and Conditioning Research*, *33*(10), 2846–2859. https://doi.org/10.1519/JSC.0000000000003291

Paz, G. A., Robbins, D. W., De Oliveira, C. G., Bottaro, M., & Miranda, H. (2017). Volume load and neuromuscular fatigue during an acute bout of agonist-antagonist paired-set vs. traditional-set training. *Journal of Strength and Conditioning Research*, *31*(10), 2777–2784. www.nsca.com

Pearson, S. J., & Hussain, S. R. (2015). A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. *Sports Medicine*, *45*(2), 187–200. https://doi.org/10.1007/s40279-014-0264-9

Piervirgili, G., Petracca, F., & Merletti, R. (2014). A new method to assess skin treatments for lowering the impedance and noise of individual gelled Ag-AgCl electrodes. *Physiological Measurement*, *35*(10), 2101–2118. https://doi.org/10.1088/0967-3334/35/10/2101

Portney, L. G., & Watkins, M. P. (2015). *Foundations of Clinical Research Applications to Practice 3rd Edition*. www.fadavis.com

Pradhan, A., Malagon, G., Lagacy, R., Chester, V., & Kuruganti, U. (2020). Effect of age and sex on strength and spatial electromyography during knee extension. *Journal of Physiological Anthropology*, *39*(1). https://doi.org/10.1186/s40101-020-00219-9

Ratamess, N. A., Alvar, B. A., Evetoch, T. K., Housh, T. J., Kibler, B., Kraemer, W. J., & Triplett, N. T. (2009). Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, *41*(3), 687–708. https://doi.org/10.1249/MSS.0b013e3181915670

Ratamess, N. A., Chiarello, C. M., Sacco, A. J., Hoffman, J. R., Faigenbaum, A. D., Ross, R. E., & Kang, J. (2012). The effects of rest interval length on acute bench press performance: The influence of gender and muscle strength. *Journal of Strength and Conditioning Research*, *26*, 1817–1826. www.nsca.com

Refalo, M. C., Helms, E. R., Hamilton, D. L., & Fyfe, J. J. (2023). Influence of resistance training proximity-to-failure, determined by repetitions-in-reserve, on neuromuscular fatigue in resistance-trained males and females. *Sports Medicine - Open*, *9*(1). https://doi.org/10.1186/s40798-023-00554-y

Roberts, B. M., Nuckols, G., & Krieger, J. W. (2020). Sex differences in resistance training: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research*, *34*(5), 1448–1460. https://doi.org/10.1519/JSC.0000000000003521

Rudroff, T., Barry, B. K., Stone, A. L., Barry, C. J., & Enoka, R. M. (2007). Accessory muscle activity contributes to the variation in time to task failure for different arm postures and loads. *Journal of Applied Physiology*, *102*, 1000–1006. https://doi.org/10.1152/japplphysiol.00564.2006.-Time

Rudroff, T., Justice, J. N., Holmes, M. R., Matthews, S. D., & Enoka, R. M. (2011). Muscle activity and time to task failure differ with load compliance and target force for elbow flexor muscles. *Journal of Applied Physiology*, *110*, 125–136. https://doi.org/10.1152/japplphysiol.00605.2010.-The

Schaefer, L. V., & Bittmann, F. N. (2017). Are there two forms of isometric muscle action? Results of the experimental study support a distinction between a holding and a pushing isometric muscle function. *BMC Sports Science, Medicine and Rehabilitation*, *9*(1). https://doi.org/10.1186/s13102-017-0075-z

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research*, *24*, 2857–2872. www.nsca-jscr.org

Schoenfeld, B. J. (2020). *Science and Development of Muscle Hypertrophy* (2nd ed.). Human Kinetics.

Schoenfeld, B. J., Ogborn, D., & Krieger, J. W. (2017). Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *Journal of Sports Sciences*, *35*(11), 1073–1082. https://doi.org/10.1080/02640414.2016.1210197

Seedman, J. (n.d.-a). *Eccentric Isometrics: The Ultimate Way to Strength Train Part 1*. Retrieved February 14, 2021, from https://www.advancedhumanperformance.com/eccentric-isometrics-the-ultimate-way-to-strength-train-part-1

Seedman, J. (n.d.-b). *Eccentric Isometrics: The Ultimate Way to Strength Train Part 2*. Retrieved February 14, 2021, from https://www.advancedhumanperformance.com/eccentric-isometrics-the-ultimate-way-to-strength-train-part-2

Senefeld, J., Yoon, T., Bement, M. H., & Hunter, S. K. (2013). Fatigue and recovery from dynamic contractions in men and women differ for arm and leg muscles. *Muscle and Nerve*, *48*(3), 436–439. https://doi.org/10.1002/mus.23836

Sinicki, A. (2019). *Advanced Isometric Training: Ballistic and Quasi Isometrics*. https://www.thebioneer.com/advanced-isometric-training-ballistic-quasi-isometrics/

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine*, *46*(10), 1419–1449. https://doi.org/10.1007/s40279-016-0486-0

Vigotsky, A. D., Halperin, I., Trajano, G. S., & Vieira, T. M. (2022). Longing for a longitudinal proxy-Acutely measured surface EMG amplitude is not a validated predictor of muscle hypertrophy. *Sports Medicine*, *52*(2), 193–199. https://doi.org/10.1007/s40279-021-01619-2

Voskuil, C. C., Dudar, M. D., & Carr, J. C. (2024). Sex differences in fatiguability during single-joint resistance exercise in a resistance-trained population. *European Journal of Applied Physiology*. https://doi.org/10.1007/s00421-024-05445-y

Yitzchaki, N., Zhu, W. G., Kuehne, T. E., Vasenina, E., Dankel, S. J., & Buckner, S. L. (2020). An examination of changes in skeletal muscle thickness, echo intensity, strength and soreness following resistance exercise. *Clinical Physiology and Functional Imaging*, *40*(4), 238–244. https://doi.org/10.1111/cpf.12630

Yoon, T., Doyel, R., Widule, C., & Hunter, S. K. (2015). Sex differences with aging in the fatigability of dynamic contractions. *Experimental Gerontology*, *70*, 1–10. https://doi.org/10.1016/j.exger.2015.07.001

Yoon, T., Schlinder-Delap, B., & Hunter, S. K. (2013). Fatigability and recovery of arm muscles with advanced age for dynamic and isometric contractions. *Experimental Gerontology*, *48*(2), 259–268. https://doi.org/10.1016/j.exger.2012.10.006

Zabaleta-Korta, A., Fernandez-Pena, E., & Santos-Concejero, J. (2020). Regional hypertrophy, the inhomogeneous muscle growth: A systematic review. *Strength and Conditioning Journal*. www.nsca-scj.com

Appendix A

Supplementary Table 1

ANOVA Table - Main Effects

ANOVAs

Time Under Tension	df		Type III SS	*F*	*p*	η_p^2
TYPE	1	25	103861.41	81.92	< .001	0.77
SET	1	25	33715.21	78.68	< .001	0.76
SEX	1	25	1966.36	4.66	0.041	0.16
Lepeak						
TYPE	1	25	7840283.57	118.51	< .001	0.83
SET	1	25	94162.24	7.80	.010	0.24
SEX	1	25	1294248.86	14.01	.001	0.36
iEMGabs						
TYPE	1	25	382040064.93	5.73	.025	0.19
SET	1	25	986944634.16	50.37	< .001	0.67
SEX	1	25	98436851.57	2.11	0.158	0.08
iEMG%						
TYPE	1	25	146334824.92	95.08	< .001	0.79
SET	1	25	19422339.84	68.24	< .001	0.73
SEX	1	25	1460510.74	2.83	.105	0.10
CoA						
TYPE	1	25	0.06	0.66	.426	0.03
SET	1	25	0.0024	0.11	.744	0.00
SEX	1	25	0.0014	0.03	.861	0.00

Appendix A

Supplementary Table 2

ANOVA Table and Pairwise Comparisons – Two-Way Interactions

a.

ANOVAs				Contrasts											
LEpeak	*F*	*p*	ηp^2		TRD	EQI	Set 1	Set 2	M	Fe	mdiff	SE	*p*	78% CI	
TYPE*SET	11.50	.002	0.32	Set 1	1038.33	424.56					613.77	55.74	< .001	543.65	683.89
				Set 2	904.71	439.99					464.71	52.60	< .001	398.54	530.89
				TRD			1038.33	904.71			133.62	39.23	.002	84.27	182.98
				EQI			424.56	439.99			-15.43	17.95	.398	-38.01	7.15
TYPE*SEX	30.09	<.001	0.55	TRD					1326.46	616.58	709.88	142.09	< .001	531.13	88.63
				EQI					515.52	349.04	166.48	110.12	.143	27.96	305.02
				M	1326.46	515.52					810.94	68.74	< .001	724.45	897.42
				FE	616.58	349.04					267.54	71.34	< .001	177.80	357.29
SET*SEX	0.690	0.414	0.027	Set 1					959.33	503.57	455.76	128.63	.002	293.94	617.58
				Set 2					882.65	462.05	420.61	108.43	.001	284.20	557.01
				M			959.33	882.65			76.67	29.36	.015	39.74	113.60
				FE			503.57	462.05			41.52	30.46	.185	3.19	79.85

Appendix A

b.

ANOVAs				Contrasts											
iEMGabs	*F*	*p*	ηp^2		TRD	EQI	Set 1	Set 2	M	Fe	mdiff	SE	*p*	78% CI	
TYPE*SET	1.45	0.24	0.06	Set 1	14129.05	17121.79					-2992.73	2062.91	.159	-5587.97	-397.50
				Set 2	7307.50	11843.13					-4535.63	1230.58	.001	-6083.75	-2987.51
				TRD			14129.05	7307.50			6821.55	812.38	< .001	5799.54	7843.56
				EQI			17121.79	11843.13			5278.65	1270.25	< .001	-3680.62	6876.68
TYPE*SEX	3.57	0.07	0.13	TRD					14115.59	7320.96	6794.62	1998.54	.002	4280.37	9308.88
				EQI					14906.57	14058.35	848.20	3842.65	.827	-3985.99	5682.43
				M	11415.59	14906.57					-790.98	2183.22	.720	-3537.56	1955.59
				FE	7320.96	14058.35					-6737.38	2265.63	.006	-9587.64	-3887.13
SET*SEX	0.58	0.45	0.02	Set 1					17861.44	13389.39	4472.04	3305.22	.188	313.93	8630.15
				Set 2					11160.72	7989.92	3170.81	2083.07	.141	550.22	5791.39
				M			17861.44	11160.72			6700.72	1183.00	< .001	5212.45	8188.99
				FE			13389.40	7989.92			5399.48	1227.66	< .001	3855.04	6943.93

Appendix A

c.

ANOVAs				Contrasts											
iEMG%	*F*	*p*	ηp^2		TRD	EQI	Set 1	Set 2	M	Fe	mdiff	SE	*p*	78% CI	
TYPE*SET	8.35	.008	0.25	Set 1	1372.44	3929.94					-2557.51	269.13	< .001	-2896.08	-2218.93
				Set 2	751.59	2853.36					-2101.79	232.73	< .001	-2394.57	-1809.00
				TRD			1372.44	751.57			620.87	51.99	< .001	555.46	686.27
				EQI			3929.94	2853.36			1076.58	175.64	< .001	855.62	1297.54
TYPE*SEX	1.85	.186	0.07	TRD					991.54	1132.47	-140.93	113.93	.228	-284.25	2.39
				EQI					2996.64	3786.60	-790.03	504.53	.130	-1424.75	-155.30
				M	991.54	2996.64					-2005.10	331.55	< .001	-2422.21	-1587.99
				FE	1132.47	3786.66					-2654.19	344.07	< .001	-3087.05	-2221.34
SET*SEX	2.464	.129	0.090	Set 1					2337.81	2964.56	-626.75	326.84	.067	-1037.93	-215.57
				Set 2					1650.36	1954.56	304.20	260.12	.253	-631.45	23.04
				M			2337.81	1650.36			687.45	142.59	< .001	508.07	866.83
				FE			2964.56	1954.56			1010.00	147.97	< .001	823.85	1196.15

Appendix A

d.

ANOVAs				Contrasts											
CoA	*F*	*p*	η²p		TRD	EQI	Set 1	Set 2	M	Fe	mdiff	SE	*p*	78% CI	
TYPE*SET	0.15	.701	0.01	Set 1	1.19	1.23					-0.04	0.06	.501	-0.12	0.04
				Set 2	1.17	1.22					-0.06	0.07	.406	-0.14	0.03
				TRD			1.19	1.17			0.02	0.03	.562	-0.02	0.06
				EQI			1.23	1.22			0.00	0.04	.969	-0.05	0.05
TYPE*SEX	4.77	.039	0.16	TRD					1.25	1.10	0.15	0.08	.075	0.05	0.25
				EQI					1.17	1.28	-0.12	0.12	.338	-0.27	0.03
				M	1.25	1.17					0.08	0.08	.332	-0.02	0.19
				FE	1.10	1.28					-0.18	0.09	.048	-0.29	-0.07
SET*SEX	1.15	.294	0.04	Set 1					1.23	1.18	0.05	0.07	.541	-0.05	0.14
				Set 2					1.19	1.20	-0.02	0.10	.870	-0.14	0.11
				M			1.23	1.19			0.04	0.04	.322	-0.01	0.09
				FE			1.18	1.20			-0.02	0.04	.611	-0.07	0.03

Appendix A

Supplementary Table 3

ANOVA Table – Three-Way Interactions

ANOVAs

Type*Set*Sex	df		Type III SS	*F*	*p*	η_p^2
Time Under Tension	1	25	1362.94	4.28	.049	0.15
LEpeak	1	25	85513.53	6.56	.017	0.21
iEMGabs	1	25	75132454.12	6.79	.015	0.21
iEMG%	1	25	724314.41	4.32	.048	0.15
CoA	1	25	0.02	1.98	.172	0.07