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Original Research

Exercise Variability Did Not Affect Muscle Thickness and Peak Force for Elbow Flexors After a Resistance Training Session in Recreationally-Trained Subjects

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ABSTRACT

International Journal of Exercise Science 14(3): 1294-1304, 2021. The purpose of this study is to measure the acute effects of exercise variability on muscle thickness and physical performance after two resistance training (RT) protocols using the same or different exercises in recreationally-trained subjects. Fifteen resistance-trained men (23.1 ± 2.6 years, 83.4 ± 16.6 kg, 173.5 ± 8.3cm) performed one of two RT protocols: SINGLE: six sets of 10RM/two-minutes rest of the unilateral biceps curl exercise using cables or MIX: six sets of 10RM/two-minutes rest for the unilateral biceps curl exercises (cable: three sets and dumbbells: three sets, randomly). Muscle thickness (MT) and peak force (PF) were measured ten-minutes before (control), pre-RT session, and post-RT (immediately after and 15-minutes after). All acute RT variables were measured during both RT protocols: the maximal number of repetitions (MNR), the total number of repetitions (TNR), time under tension (TUT), and rating of perceived exertion (RPE). Two-way ANOVA (2 x 4) was used to test differences between RT protocol (SINGLE and MIX) and time (control, pre-test, post0, and post15) for MT and PF. Two-way ANOVAs (2 x 6) were used to test differences between RT protocol (SINGLE and MIX) and sets for MNR, RPE_{set}, and TUT. For PF and MT, there were significant differences in time for both RT protocols ($p < 0.05$), however, there were not statistical differences between RT protocols. For MNR, RPE_{set}, and TUT, there were significant differences in time ($p < 0.05$), however, there were not statistical differences between RT protocols. In conclusion, both RT protocols induced a similar increase in MT for elbow flexors and a reduction in peak force.

KEY WORDS: Exercise selection, strength, performance, muscle pump

INTRODUCTION

Exercise selection is considered one important component of the resistance training (RT) session and RT program design. Based on the characteristics of the RT session and its specificity, the exercise choice has a fundamental role in defining the prime movers (muscle activation), the number of joints involved (multi- or single-joint), the pattern of movement (technique), type of equipment (cables, machines, free-weight, etc.), and motivation (adherence) (7, 11).

The variability principle states that to prolong muscle adaptations it is necessary to systematically manipulate the exercise and load variables over time to modify the training stimulus (9, 14, 16). Additionally, the American College of Sports Medicine (14) recommends greater variability of load and exercises for more advanced lifters. A few studies have reported the chronic effects of the exercise variation on strength and hypertrophy (2, 6, 17). Rauch et al. (17) demonstrated that varying exercise selection via auto-regulation produced modestly greater increases in lean body mass and strength compared to a fixed exercise protocol for strength-trained subjects. Fonseca et al. (6) reported a greater regional-specific hypertrophy of the quadriceps femoris when the exercises were changed every two weeks. On the other hand, Baz-Valle et al., (2) compared an eight-week RT program using a fixed exercise selection or exercises randomly varied each session by a computerized app. Both groups presented similar gains in strength (bench press and back-squat one repetition maximum) and muscle thickness (vastus lateralis and rectus femoris), however, the exercise variation increased motivation when compared to the fixed exercise protocol.

To the best of the author's knowledge, no study was conducted to measure the acute effects of RT protocols with or without exercise variation. Therefore, the primary purpose of this study is to measure the acute effects of exercise variability on muscle thickness, peak force, and physical performance after two RT protocols using the same or different exercises for elbow flexors in recreationally-trained subjects. It is hypothesized that greater exercise variability induces increments in muscle thickness and reductions in peak force for elbow flexors. For the acute variables, it is hypothesized that 1) both RT protocols decrease the maximum number of repetitions and the total number of repetitions, 2) both RT protocols increase the time under tension, and 3) RPE (session and set) will remain constant for both RT protocols.

METHODS

Participants

The number of participants was determined by a pilot study conducted previously, based on a significance level of 5% and a power of 80% derived from the muscle thickness of individuals with the same characteristics used in the present study (5). Fifteen resistance-trained men were recruited to this study [age 23.1 ± 2.6 years, total body mass 83.4 ± 16.6 kg, height 173.5 ± 8.3 cm, Unilateral Cable Biceps Curl exercise (10 repetition maximum, RM) 12.9 ± 2.3 kgf, Unilateral Dumbbell Biceps Curl exercise (10 repetition maximum, RM) 15.0 ± 3.2 kgf]. All participants were regularly engaged in a RT program for more than one year, were familiar with hypertrophy-type training, and were familiar with both standing cable and dumbbell biceps curl exercises. They had 3 ± 1 years of RT experience (at least three times a week), with no previous surgery or history of injury with residual symptoms (pain) in the upper limbs or spine within the last year. The IRB approved this study (#FY19-425), the participants were informed of the risks and benefits of the study prior to any data collection. All participants provided written informed consent prior to participation and the Institutional Review Board at California State University, Northridge approved the protocol. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (15).

Protocol

This study used a randomized and counterbalanced design. Participants attended two laboratory sessions and refrained from performing upper-body exercises other than activities of daily living for at least 48 hours prior to testing. A within-subject approach was used in which each participant performed a RT protocol. Each RT protocol was performed unilaterally. The protocols were defined as follows: 1) SINGLE protocol: only one exercise (unilateral biceps curl exercise) or 2) MIX protocol: two different exercises (unilateral biceps curl with cable and dumbbells). For the first session, participants were asked to identify their preferred arm for writing, which was considered their dominant arm (13). Then, anthropometric data were evaluated (height, weight, and upper limb length). Next, all participants performed a familiarization and specific warm-up. The warm-up followed the following procedure: one set of 15 repetitions without external load, followed by one set of 1ten repetitions with 5 kgf for each exercise, with one minute and five minutes of rest interval were given between sets and exercises, respectively. Then, the participant's arms were randomly allocated within one specific RT protocol (SINGLE or MIX) and the exercise order (for the MIX protocol) was randomized for each participant. Afterward, all participants performed ten repetition maximum (RM) testing for both exercises (SINGLE or MIX), and five minutes between exercises. The 10RM testing was based on the Guidelines of the National Strength and Conditioning Association (NSCA) to determine individual initial training loads for each exercise (unilateral biceps curl with dumbbells and cable). Attempts were performed to progressively increase the external loads until they reach the maximal capacity to perform 10RM with the correct technique. The movement velocity in each exercise was self-selected.

During the second session, all participants remained seated on a bench and all measures were carried out (muscle thickness and peak force) ten-minutes before both RT protocols (control). Then, participants performed one of two RT protocols (SINGLE or MIX), in addition to performing a pre-established exercise order on the MIX protocol (randomly defined in the first session) (Figure 1). First, the same measures were carried out (muscle thickness and peak force) in one arm (pre-test) and the RT protocol was performed until muscular failure. All post-test measures were carried out (muscle thickness and peak force) immediately after and 15-minutes after the RT protocol. All participants reported the rating of perceived exertion (RPE_{set}) for all sets and the session RPE (sRPE) 30-minutes after the RT protocol. In the same session, 60-minutes after the first RT protocol with one arm/exercise order, all pre-test measures were carried out (muscle thickness and peak force) on the contralateral arm and the participants performed the complementary RT protocol. Both RT protocols were performed in the same session because there was no influence between members for the variables analyzed as observed in the pilot study and other studies carried out by the same laboratory (12). All post-test measures were carried out (muscle thickness and peak force) immediately after and 15-minutes after the RT protocol. All participants reported the rating of perceived exertion (RPE_{set}) for all sets and the session RPE (sRPE) 30-minutes after the RT protocol. All participants received verbal encouragement during all sets and RT protocols, and all measurements were performed between 1 PM and 5 PM, by the same researcher.

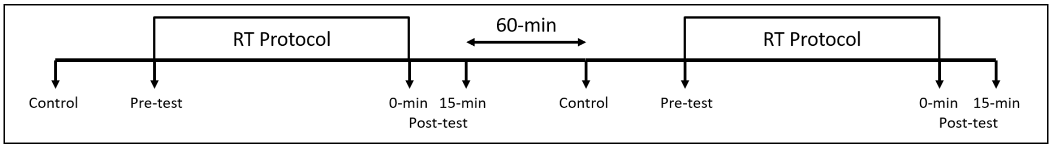

Figure 1. Experimental Procedures. Legend: RT – resistance training, min – minutes.

RT protocols: To perform the SINGLE protocol, all participants performed six sets of 10RM and two-minute rest intervals for unilateral cable biceps curl exercise. All participants were positioned standing in front of the cable pulley machine, with a supinated grip on a handle. They lifted the weight stack from complete elbow extension to complete elbow flexion (concentric phase), and then returned to a full elbow extension (eccentric phase). To perform the MIX protocol, all participants performed six sets of 10RM and two-minute rest intervals for unilateral biceps curl exercise using three sets with cables and three sets with dumbbells, randomly. For the unilateral cable biceps curl exercise, all participants were positioned standing in front of the cable pulley machine, with a supinated grip on a handle. They pulled the weight stack from complete elbow extension to complete elbow flexion (concentric phase), and then returned to a full elbow extension (eccentric phase). For the unilateral dumbbell biceps curl exercise, all participants were positioned standing holding a dumbbell, with a supinated grip. They lifted the free weight from complete elbow extension to complete elbow flexion (concentric phase), and then returned to a full elbow extension (eccentric phase). All exercises were directly supervised by a research assistant (CSCS) to ensure proper performance and technique.

Acute Resistance Training Variables: The total number of repetitions (TNR) of each RT protocol was counted for further analysis. The maximal number of repetitions (MNR of each set and RT protocol was counted for further analysis. The time under tension (TUT) was measured by a chronometer during each set for both RT protocols. Then, in order to define the TUT, the set duration in seconds was divided by the MNR by the following formula: TUT = $duration_{set}$ (sec) / MNR (repetitions). Regarding, Rating of Perceived Exertion per set (RPE_{set}) and Session RPE (sRPE), the RPE was assessed with a CR-10 scale using the recommendations of Sweet et al. (21). Participants were asked to use an arbitrary unit (AU) on the scale to rate their overall effort for each RT protocol. A rating of 0 was associated with no effort and a rating of ten was associated with maximal effort and the most stressful exercise ever performed. All participants answered the following question based on CR-10 scale: "How was your workout?" The RPE_{set} was asked after each set for both RT protocols and the sRPE was asked after 30-minutes of each RT protocol.

Measurements: The Peak Force (PF): was measured by a digital load cell acquisition system (SF-912 Industrial Crane Scale, Klau Digital Hanging Scale, TX, USA / Capacity: 300 kg / Accuracy: 0.1 kg). For both RT protocols (SINGLE and MIX), all participants were positioned standing in front of the cable pulley machine, with a supinated grip on a handle. Subjects performed three maximal voluntary isometric contractions (MVIC) at 90° of elbow flexion before and after each RT protocol. Each MVIC was performed for three seconds and 15 seconds of rest. The highest (peak) value among the three MVICs was used for further analysis.

Muscle Thickness (MT): Ultrasound imaging was used to obtain measurements of MT. A trained technician performed all testing using an ultrasound imaging portable unit (Hitachi

Noblus; Hitachi Medical Corporation, Tokyo, Japan). Following a generous application of a water-soluble transmission gel (Cskin, Medics Medical Products LLC., NY, USA) to the measured site, a 7.5-MHz linear array probe (L55 Probe) was placed perpendicular to the tissue interface without depressing the skin. Equipment settings were optimized for image quality according to the manufacturer's user manual and held constant among testing sessions. When the quality of the image was deemed to be satisfactory, the image was saved to the hard drive and MT dimensions were obtained by measuring the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per methods used by Abe et al. (1). Measurements were taken on both sides of the body at the elbow flexors. The upper arm measurements were conducted while participants were standing position. For the elbow flexors, measurements were taken at 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula. To maintain consistency between pre- and post-intervention testing, each site was marked with ink. To further ensure the accuracy of measurements, at least three images were obtained for each side. If measurements were within 1mm of one another the figures were averaged to obtain a final value. If measurements were more than 1mm of one another, a fourth image was obtained and the closest measurement was then averaged. The test-retest ICC from our lab for MT is 0.98 and the intra-rater reliability was 0.96.

Statistical Analysis

The normality and homogeneity of variances were confirmed by the Shapiro-Wilk and Levene's tests, respectively. The mean, standard deviation (SD), delta percentage (Δ%) were calculated. A paired t-test was used to test differences for all dependent variables (sRPE, Exercise Load [10RM], and TNR). Two-way ANOVAs (2x4) were used to test differences between RT protocols (SINGLE and MIX) and time (control, pre-test, post0, and post15) for MT and PF. Two-way ANOVAs (2x6) were used to test differences between RT protocols (SINGLE and MIX) and sets (1 to 6) for MNR, RPE_{set}, and TUT. Post-hoc comparisons were performed with the Bonferroni test. Furthermore, the magnitudes of the difference were examined using the standardized difference based on Cohen's *d* units using effect sizes (d) (14). The *d* results were qualitatively interpreted using the following thresholds: < 0.35: trivial; 0.35 - 0.8: small; 0.8 - 1.5: moderate; > 1.5: large for recreationally trained (4). An alpha of 5% was used to determine statistical significance.

RESULTS

For Maximal Load (10RM), there was observed statistical difference between cable and dumbbell (12.9 ± 2.3 kgf x 15.0 ± 3.2 kgf, respectively, $p = 0.001$, $d = 0.75$ [small], Δ% = 14). For the total number of repetitions (TNR), there was observed statistical difference between RT protocols (SINGLE: 43.5 ± 9.3 repetitions and MIX: 48.2 ± 7.8 repetitions, respectively, $p = 0.019$, $d = 0.56$ [small], Δ% = 9.7) (Table 1). For the maximal number of repetition (MNR), there were significant main effects for RT protocol ($F = 7.07$, $df = 14$, $p = 0.019$) and sets ($F = 37.0$, $df = 5$, $p < 0.001$) (Table 1). There was not significant interaction between RT protocols and sets ($p = 0.102$). There were significant differences for SINGLE between sets: Set 1 x Set 4 ($p = 0.003$, $d = 2.08$ [large], Δ% = 35.8), Set 1 x Set 5 ($p < 0.001$, $d = 2.89$ [large], Δ% = 40.5), Set 1 x Set 6 ($p < 0.001$, *d*

= 3.57 [large], Δ% = 46.0); and for MIX between sets: Set 1 x Set 5 (p = 0.005, d = 2.02 [large], Δ% = 29.3), Set 1 x Set 6 (p = 0.001, d = 2.47 [large], Δ% = 38.0). There were not statistical differences between SINGLE x MIX protocols.

For time under tension (TUT) (Table 1), there was a significant main effect only for sets (F = 20.9, df = 5, p = 0.001). There was not significant interaction between RT protocols and sets (p = 0.623). There were significant differences for SINGLE between sets: Set 1 x Set 4 (p = 0.006, d = 1.16 [moderate], Δ% = 29.1), Set 1 x Set 5 (p < 0.001, d = 1.38 [moderate], Δ% = 30.6), Set 1 x Set 6 (p = 0.017, d = 1.28 [moderate], Δ% = 36.5); and for MIX between sets: Set 1 x Set 5 (p = 0.048, d = 0.75 [small], Δ% = 16.0), Set 1 x Set 6 (p = 0.022, d = 1.09 [moderate], Δ% = 23.2). There were not statistical differences between SINGLE x MIX protocols.

For sRPE, there was observed no statistical difference between RT protocols (SINGLE: 9.1 ± 0.8 A.U. and MIX: 9.0 ± 1.1 A.U., respectively; p = 0.77). For RPE_{set}, there were significant main effects for RT exercises (F = 7.35, df = 14, p = 0.017) and sets (F = 20.1, df = 5, p < 0.001) (Table 1). There was not significant interaction between RT exercises and sets (p = 0.535). There were significant differences for SINGLE between sets: Set 1 x Set 2 (p = 0.028, d = 0.54 [small], Δ% = 11.7), Set 1 x Set 3 (p = 0.003, d = 1.02 [moderate], Δ% = 18.1), Set 1 x Set 4 (p = 0.019, d = 1.37 [moderate], Δ% = 21.5), Set 1 x Set 5 (p = 0.009, d = 1.49 [moderate], Δ% = 21.8); Set 1 x Set 6 (p = 0.008, d = 1.49 [moderate], Δ% =22.6); and for MIX between sets: Set 1 x Set 2 (p < 0.001, d = 0.50 [small], Δ% = 13.6), Set 1 x Set 3 (p = 0.004, d = 1.00 [moderate], Δ% = 22.7), Set 1 x Set 4 (p = 0.019, d = 1.28 [moderate], Δ% = 24.4), Set 1 x Set 5 (p = 0.012, d = 1.40 [moderate], Δ% = 25.5), Set 1 x Set 6 (p < 0.001, d = 1.54 [large], Δ% = 27.1). There were not statistical differences between SINGLE x MIX protocols.

Table 1. Mean ± Standard Deviation of the acute resistance training variables for both RT protocols (SINGLE AND MIX).

	SINGLE RT Protocol						**MIXED RT Protocol**					
Set	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
MNR (rep)	9.9±0.3	8.6±1.9	7.4±2.3	6.3±2.4$^+$	5.8±1.9$^+$	5.3±1.7$^+$	10.0±0.0	9.5±1.3	7.6±2.3	7.7±2.2	7.0±2.0$^+$	6.2±2.2$^+$
TUT (sec/rep)	2.1±0.6	2.5±0.6	2.9±1.0	3.0±0.9$^+$	3.1±0.8$^+$	3.4±1.2$^+$	2.3±0.4	2.7±0.7	2.9±0.8	3.0±0.9	2.9±0.6$^+$	3.1±0.9$^+$
RPE_{set} (A.U)	7.5±1.9	8.5±1.7$^+$	9.2±1.1$^+$	9.6±0.7$^+$	9.6±0.6$^+$	9.7±0.6$^+$	6.8±2.1	7.8±2.1$^+$	8.8±1.8$^+$	9.0±1.2$^+$	9.1±1.0$^+$	9.3±0.9$^+$
TNR	43.5±9.3*						48.2±7.8					

Legend: TNR-total number of repetitions per RT exercise; TUT-time under tension; RPE_{set}-rating of perceived exertion per set; MNR – maximal number of repetitions; rep-repetitions; sec- seconds; A.U-arbitrary units. *Differences between RT exercises. $^+$Differences between 1st set and all sets.

For Peak Force (PF), there was significant main effect for time (F = 20.4, df = 3, p < 0.001). There was not significant interaction between RT protocols and time (p = 0.06). There were statistical differences for SINGLE: pre-test x post 0-minutes (p = 0.001, d = 0.91 [moderate], Δ% = 17.5), post 0-minutes x post 15-minutes (p = 0.006, d = 0.90 [moderate], Δ% = 12.0) and for MIX: pre-test x post 0-minutes (p = 0.001, d = 1.08 [moderate], Δ% = 24.4), post 0-minutes x post 15-minutes

(p = 0.007, d = 0.63 [small], Δ% = 15.8). There were not statistical differences between SINGLE x MIX protocols (Figure 2a).

For muscle thickness (MT), there was significant main effect for time (F = 100.4, df = 3, p < 0.001). There was not significant interaction between RT protocols and time (p = 0.211). There were statistical differences for SINGLE: pre-test x post 0-minutes (p < 0.001, d = 0.97 [moderate], Δ% = 11.9), pre-test x post 15-minutes (p < 0.001, d = 0.59 [small], Δ% = 7.9), post 0-minutes x post 15-minutes (p = 0.004, d = 0.35 [small], Δ% = 4.4); and for MIX: pre-test x post 0-minutes (p < 0.001, d = 1.03 [moderate], Δ% = 13.6), pre-test x post 15-minutes (p < 0.001, d = 0.79 [small], Δ% = 10.0). There were not statistical differences between SINGLE x MIX protocols (Figure 2b).

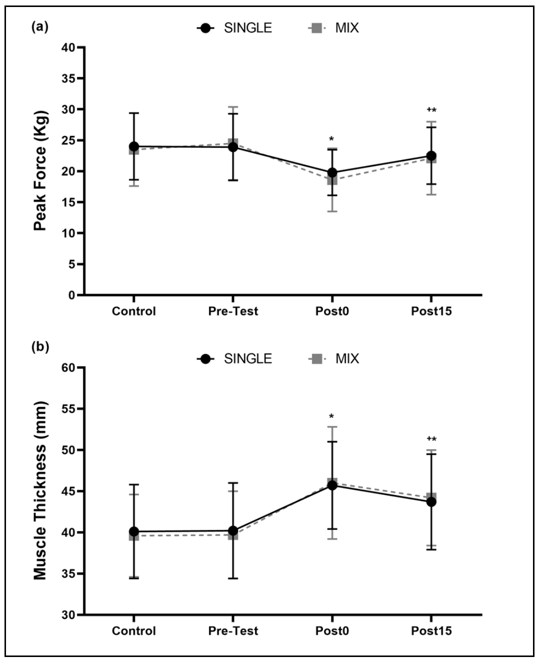

Figure 2. Mean ± standard deviation of (a) peak force and (b) muscle thickness for elbow flexors. *Significant difference with Pre-test, p < 0.001. #Significant difference with Post0, p < 0.001.

DISCUSSION

The aim of this study was to measure the acute effects of exercise variability on peak force, muscle thickness, and physical performance after two RT protocols using the same or different exercises for elbow flexors in recreationally-trained subjects. The main findings were that: 1) Both RT protocols presented similar increases in muscle thickness and reduction in peak force for elbow flexors; 2) Both RT protocols presented a reduction in the maximal number of repetitions and increase the time under tension; 3) The MIX protocol presented greater reductions in the total number of repetitions; 4) sRPE and RPE_{set} were similar for both RT protocols.

Based on the authors' knowledge no study compared the acute effects of different exercise variations for elbow flexors. In this study, SINGLE and MIX protocols were performed with a similar range of motion, removing the relative effect of this variable between RT protocols.

Initially, some acute RT variables were measured in order to track neuromuscular fatigue and physical stress during each RT protocol. These acute RT variables can help to understand the level of mechanical and metabolic stress imposed by each RT protocol, in addition to assisting in the proper planning of a RT session. Fundamentally, the exercise variation or not in a single RT session might, indirectly, help to understand the chronic effect of several accumulated RT sessions aiming at strength and hypertrophy (10).

Acute Resistance Training Variables: The maximal number of repetitions (MNR) was defined by the maximal complete repetitions in each set for both RT protocols, and the total number of repetitions (TNR) was defined by the sum of the MNR per set in each RT protocol (11). TNR and MNR might be used to characterize the muscle stress in each RT protocol. It was hypothesized that the variability of exercises will induce a greater reduction in the TNR and MNR performed. The present results corroborated the main hypothesis that both RT protocols would reduce the TNR, however, the reduction in TNR was greater for the SINGLE protocol when compared to the MIX protocol (9.7%, *d* = small). This greater reduction in TNR for the SINGLE protocol might be related to the non-variation of exercises, and consequently, the absence of mechanical changes in the exercises might affect the management of neuromuscular fatigue. Another possible comparison could be between the theoretical (60 repetitions per RT protocol) and real TNR in each RT protocol, which might affect the volume load in each RT protocol. Then, both RT protocols presented reduction in TNR [SINGLE: 27.5% (~16 repetitions) and MIX: 20.3% (~12 repetitions)].

Time under tension (TUT) is defined as the time for each repetition during each specific set, it is an important acute variable affected by velocity and range of motion and TUT has an important impact on acute responses and chronic adaptations in trained subjects (3, 11). In the present study, it was hypothesized that greater variability of exercises will induce an increase in the time under tension. However, TUT increased for both RT protocols with no significant differences between them, and these differences were observed between sets for each RT protocol (SINGLE: after the 4^{th} set; and MIX: after the 5^{th} set). This deleterious effect might be due to the accumulation of neuromuscular fatigue in the elbow flexors during both RT protocols, though, the MIX protocol presented a certain delay in neuromuscular fatigue observed in all acute variables (MNR, TUT, and RPE_{set}). Additionally, both RT protocols presented a reduction in movement velocity from the first set to the last set (SINGLE: 38.2% and MIX: 25.8%) with no statistical difference between RT protocols. Scientific evidence suggests that reductions in the movement velocity (mean concentric velocity between 20 - 40%) might produce greater acute responses (metabolic response and neuromuscular fatigue) and chronic adaptations (20). It appears that exercise variation may delay fatigue briefly and favor TNR. Also, the mechanical characteristics of both RT protocols might have similar levels of stress on the prime movers and it is well-known that the biceps curl exercise has a harder sticking region in the middle of the movement (around 90° of elbow flexion) to overcome the external load affecting the velocity of each repetition. In the present study, both exercises (cable and dumbbell) presented similar mechanical characteristics such as the action of synergistic muscles, external torque, range of motion, movement velocity, and sticking region. Additionally, it was observed that, in the present study, a two-minute rest interval in between sets presented a high impact in the neuromuscular fatigue for both RT protocols with no differences between them. In general, the indirect effect of neuromuscular fatigue can be seen in the rapid reduction in the MNR and an increase in the TUT for both RT protocols. However, for the SINGLE protocol, the reduction in the MNR and TUT occurred only at the 5th set, whereas for the MIX protocol a similar effect was observed only at the 5th set. This difference might be due to a change in the exercise for the MIX protocol that will lead to a brief delay in neuromuscular fatigue.

The rating of perceived exertion (RPE) is frequently used to quantify, indirectly, the level of effort after sets, exercises, different populations, and workouts (8, 11). RPE presents a relationship with physiological and performance measures, and assist in quantifying intensity and load (8). Based on the authors' knowledge no study compared the RPE (session and sets) between different exercise variations for elbow flexors. It was hypothesized that the RPE (session and set) will remain constant for both protocols, corroborating our results. It is well known that RPE is affected by the level of neuromuscular fatigue after each RT protocol (sRPE) and sets (REP_{set}) for recreationally-trained subjects, thus, the exercise variation might not affect the perception of effort, considering that both RT protocols reached muscle failure.

Regarding the acute responses, peak force (PF) was measured before (control and Pre-test) and after [immediately after (Post0) and after 15-minutes (Post15)] each RT protocol in order to understand the effects of neuromuscular fatigue. It was hypothesized that greater exercise variability induces a reduction in peak force. The results of this study partially corroborated the main hypothesis because both RT protocols presented similar reductions in PF (SINGLE: 17.5% and MIX: 24.4%, both with moderate effect sizes). Additionally, both RT protocols returned to pre-test values after 15-minutes.

Different RT protocols have been shown to induce acute cell swelling, the extent of which relies on the type of exercise, level of fatigue, volume, and intensity (18). This acute cell swelling can be measured by ultrasound imaging. The ultrasound imaging measures the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone for a specific muscle (1). Muscle thickness (MT) is defined as the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per method used by Abe et al. (1). MT was measured before (control and Pre-test) and after [immediately after (Post0) and after 15-min (Post15)]. It was hypothesized that a greater exercise induces increments in muscle thickness. The results of this study partially corroborated the main hypothesis because both RT protocols presented similar results immediately after (SINGLE: 11.9% and MIX: 13.6%, both with moderate effect sizes). The short time course (0 - 15-minutes after RT protocols) used in this study observed an increase in MT immediately after RT protocols and a subsequent reduction after 15-minutes. Interestingly, both RT protocols did not return to the baseline (pre-test) after 15-minutes, with values of 7.9% and 10% (SINGLE and MIX, respectively). This effect in MT might be explained as a result of a similar level of neuromuscular fatigue observed in both RT protocols. It is well-known that RT protocols until muscle failure can produce higher metabolic and mechanical stress and consequently, affect cell swelling after a RT session (18, 19). Based on the authors' knowledge, there are no studies that compared the acute responses of MT between RT protocols with different exercises, similar ROM, and recreationally-trained subjects.

The main results of this study may benefit recreational athletes and practitioners, and rehabilitation programs. Initially, it is essential to understand that the chronic adaptations of training are due to a succession of acute stimuli. Secondly, the results of this study support the notion that the varying or not exercises, with a similar range of motion, present similar results for muscle thickness and peak force after an intense RT session. Those engaging in RT can use both protocols (MIX or SINGLE) to stimulate the elbow flexors based on the practitioner's needs and main characteristics of a split or whole-body routine.

This study has some limitations that should be considered when interpreting the current results. First, the small sample size affected statistical power. Despite this limitation, the analysis of effect sizes provides a good basis for drawing inferential conclusions from the results. Second, both exercises presented similar mechanical demands, however, different exercises with different mechanical demands could affect the results. The findings of this study are specific to young resistance-trained men and, therefore, cannot necessarily be generalized to other muscle groups or different populations including adolescents, athletes, women, and the elderly.

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