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Self-Selected Vs Fixed Repetition Duration: Effects On Number Of Repetitions And Muscle Activation In Resistance-Trained Men

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ABSTRACT

The aim of the present study was to compare the effects of self-selected and fixed repetition duration (RD) on resistance exercise (RE) volume, muscle activation, time under tension (TUT) per repetition and per session. Twelve resistance-trained men participated in the study. A randomized cross-over design was utilized and each participant performed two high-intensity RE protocols in a balanced order: 1) three sets of RE with self-selected RD (SELF); 2) three sets of RE with fixed RD (2 sec concentric, 2 sec eccentric [FIX]). Muscle activation was assessed through surface electromyography (EMG) of the vastus lateralis and vastus medialis throughout RE sessions. Overall RE volume was significantly greater for SELF (P = 0.01), while TUT per repetition was significantly greater for FIX (P = 0.0001). No significant differences between protocols were detected for TUT per session. Between-protocol comparisons revealed significantly greater EMG amplitude for SELF compared to FIX at S1 (P = 0.01), S2 (P = 0.03) and S3 (P = 0.03). Both SELF and FIX protocols produced significant increases in EMG amplitude from 25% to 100% (P < 0.001) of set completion. Between-protocol comparisons revealed significantly greater EMG amplitude for SELF compared with FIX at 75% (P = 0.03) and 100% (P = 0.01). In conclusion, self-selected RD resulted in greater volume and muscle activation compared to fixed RD in a RE session.

KEY WORDS: repetition duration, training volume, time under tension, electromyography.

INTRODUCTION

Resistance exercise (RE) is widely recommended for increasing muscle mass (i.e., muscle hypertrophy) (2). In order to maximize muscle hypertrophy, RE variables such as volume (sets x repetitions), intensity (load), exercise type, weekly frequency, rest, muscle action and repetition duration (RD) can be manipulated (1). Concerning RD, it represents the tempo of each repetition (29) and it is usually expressed in seconds, in either a two- or three-digit arrangement (e.g., 2:2 or 2:0:2) (1, 29). The first and last numbers represent the duration of the concentric and eccentric actions, respectively; while the number in the middle represents the duration of the isometric phase (29). Studies suggest that RD can affect RT-induced changes in neural (11), hypertrophic (31) and metabolic (21) responses. For instance, a moderate RD (e.g., 2:2) results in greater muscle hypertrophy when compared with slower RDs (i.e., > 3:3) (1). Despite current recommendation for RD control during RE (1), in real practice little control is observed, with most practitioners performing repetitions with self-selected durations (i.e., uncontrolled RD). However, the effects of self-selected RD on RE variables are mostly unknown. To the best of our knowledge, only one study has directly compared the effects of fixed RD vs. self-selected RD (i.e., a duration deemed comfortable by the practitioner, with no external control) (17). LaChance and Hortobagyi (17) compared the effects of three different durations (self-selected, 2:2 and 2:4) on the number of repetitions (i.e., RE volume) of two different exercises (push-ups and pull-ups). Results showed that number of repetitions was higher when exercises were performed with self-selected RD than fixed RD. However, each individual underwent a single protocol (inter-subject design), which greatly increases the variability of the RE volume (20). On the other hand, the use of crossover designs (intra-subject design) to reduce inter-subject variation in human research studies is particularly attractive when primary outcomes are dependent on the parameters selected by the individuals (20).

As RE volume seems to have a positive association with muscle mass accretion (7, 16, 24, 25, 28, 32), studies using self-selected RD with more appropriate designs are in need.

An important muscle variable deemed to be directly affected by RD is the amplitude of electromyographic (EMG) signal (i.e., muscle activation), which could be an indicative of motor unit (MU) recruitment (3). According to Newton's second law, $F = m.a$, in which F stands for force, m for mass and a for acceleration (22). Considering that acceleration is the derivative of velocity with respect to time (22), significant increases in velocity in a fixed range of motion has to enhance acceleration and, therefore, force production. In turn, this higher force production results in greater muscle activation, therefore, EMG amplitude (3, 13). Thus, it is plausible to suggest that the lower RD of a self-selected RD protocol (17) would increase EMG amplitude compared with fixed RD. Taking into consideration the association between muscle activation and muscle hypertrophy after RE protocols (33-35), research on whether self-selected RD indeed increases EMG amplitude compared to fixed RD could provide valuable insight for RE prescription.

Thus, the aim of this study was to compare the effects of fixed and self-selected RDs on RE volume and muscle activation. Additionally, time under tension (TUT) was also compared among protocols. We hypothesized that self-selected RD would result in increased volume and muscle activation compared with fixed RD, due to shorter RDs and, consequently, less TUT per repetition.

METHODS

Experimental Approach to the Problem

The present study used a randomized crossover design to test the effects of RD on RE total volume, time under tension and muscle activation. Participants were requested to visit the laboratory between four or five times (i.e. two or three familiarization sessions, and two experimental sessions), on 72-hour intervals. Initially, equipment adjustments were performed and subjects' positioning were recorded and reproduced on the other visits. Following, subjects performed a 1-RM test on the 45° leg press exercise. To minimize the learning effect, 1-RM tests were performed every seventy-two hours until a variation < 5% was obtained between testing days (18). The 1-RM value of the last testing day was considered for the actual experimental sessions. Participants performed two RE protocols in a randomized and balanced order: 1) RE with self-selected RD (SELF); 2) RE with fixed RD (FIX). Maximal voluntary isometric contraction (MVIC) was assessed immediately before protocol initiation on both visits. Muscle activation was assessed through surface EMG of the vastus lateralis (VL) and vastus medialis (VM) muscles during the two RE sessions (19) and the average of the two muscles was used for analysis.

Participants

Initially, sixteen resistance-trained young men aged between 18 and 30 years old (age, 23.6 ± 3.8 years; body weight, 78.9 ± 10.4 kg, height, 176.0 ± 4.0 cm, 45° leg press 1-RM, 498 ± 48.7 kg; data expressed in mean ± SD) were recruited for the study. Four participants abandoned the study for reasons unrelated to the protocols. Twelve completed all experimental procedures and were considered for statistical analysis. As inclusion criteria, participants had to be free from neuromuscular and/or skeletal muscle injuries or disorders on the lower limbs, not use drugs or medications that could affect physical performance and have resistance training experience (i.e., consistently lifting weights at least 2 times per week for a minimum of 1 year and regularly performing the 45° leg press exercise). The average training experience of the participants was 3.6 ± 1.4 years, with a range of 1.6-5.0 years.

The study was conducted in accordance with the Declaration of Helsinki, and ethical approval was granted by the ethics committee of the local university.

Maximal dynamic strength test

Maximal dynamic strength was assessed using the 1-RM test on the 45° leg press machine (NKR Effort; NakaGym, Diadema, SP, Brazil) following previously described criteria (4). Initially, participants performed a general warm-up on a cycle ergometer at 25W 60RPM for 5 min, followed by specific warm-up sets of 45° leg press exercise. Participants seated in the leg press machine and placed both feet in a self-selected position. Colored markers were placed on the platform to keep record of each participant's selected placement. Foot placement was reproduced throughout the study. For platform displacement tracking, the machine was unlocked and participants were instructed to lower the platform until a relative knee angle of 90° was obtained using a manual goniometer. The position of the leg press platform at the knee angle of 90° was marked on the platform's track. A plastic device was fixed at this position to reproduce the platform displacement in the experimental sessions. Following, participants performed 8 repetitions with a load corresponding to 50% of their estimated 1-RM. In the second set, they performed 3 repetitions at 70% of their estimated 1-RM. A 2-min interval was allowed between warm-up sets. After warming-up, participants performed the leg-press 1-RM test protocol. Participants had up to 5 attempts to achieve an estimation of the leg press 1-RM, with 3-min intervals between attempts.

The repetition started at complete knee extension, and participants lowered the platform until it touched the plastic device and then returned to full extension. The coefficient of variation (CV) and absolute typical error (TE) between maximal dynamic strength tests were 1.79% and 8.12kg, respectively.

Maximal voluntary isometric contraction (MVIC)

MVIC was assessed on both experimental sessions. Following a 5-min warm-up on a cycle ergometer at 25W 60RPM, participants were positioned in a 45º leg press machine and placed both feet in a self-selected position with knees at 90º. The platform of the 45º leg press machine was locked so no significant movement was produced. Participants were asked to gradually build force within 2 seconds and hold it at maximal force for additional 3 seconds. Three trials were performed, with 1 min rest between trials, and the highest RMS value attained was used to normalize EMG signals.

Resistance exercise protocols

For SELF protocol, participants performed 3 sets to muscle failure at 80% 1-RM and self-selected RD (i.e., determined voluntarily by the individual, with no researcher intervention). A 1-minute rest period was granted between sets for both protocols. During FIX, participants also performed 3 sets to muscle failure at 80% 1-RM, with the same between-sets rest intervals. However, RD was controlled using a metronome, with both concentric and eccentric actions lasting 2 seconds (2:2). For all protocols, muscle failure was defined as the inability to move the 45° leg-press platform through the range of motion of 90 degree (15). Furthermore, for the FIX protocol, the exercise was interrupted if participants could no longer maintain appropriate RD (2:2) for more than 2 repetitions.

Time under tension (TUT) per session and per repetition

A stopwatch was used to assess TUT. The stopwatch was initiated at the moment participants unlocked the 45° leg press machine platform and was stopped as soon as participants failed to comply with the RE protocol, as described above. To assess TUT per repetition, an electrogonyometer was fixed at the knee joint to determine flexion and extension endpoints (i.e. maximal and minimal knee angles, respectively) and durations. The axis of the electrogoniometer (EMG System®, São José dos Campos, SP, Brazil) was aligned with the center of rotation of the knee and its rods were fixed with Velcro© straps along the longitudinal axis of the shank and thigh so that the 0° position of the goniometer corresponded to the full knee extension (180°). Sets were then divided into quartiles (25, 50, 75 and 100% of set completion) and the number of repetitions performed in each quartile was divided by quartile duration. The average of all sets was also used for the analyzes.

Muscle activation

Muscle electrical activity (surface electromyography [EMG]) was recorded using an eight-channel electromyography system (EMG System®, São José dos Campos, SP, Brazil) with an acquisition frequency of 2,000 Hz and band-pass filter of 20-500 Hz. Prior to electrodes placement, participants were prepared by shaving the region of interest, followed by skin abrasion and cleansing with alcohol 70% to decreases skin impedance. A single differential arrangement was used in which two 36mm diameter electrodes (Ag-Ag/CI - Kendal®, São Paulo, SP, Brazil) were placed on the belly of the VL and VM muscles of the dominant thigh and aligned in parallel with the expected muscle fiber orientation. For the VL, electrode was placed at two thirds of the distance between the anterior superior iliac spine and the upper edge of the lateral side of the patella.

For the VM, the center of the electrode pair was placed at 80% of the line between the anterior superior iliac spine and anterior border of the medial knee ligament (30). The reference electrode was fixed on the opposite lateral malleoli. Similar to TUT, the electrogoniometer data was used to determine the concentric phase of the lift.

The raw electromyographic signals were digitally filtered (4^{th} order Butterworth, band pass 20-500Hz) and RMS was calculated for each concentric contraction and normalized by the value obtained on the MVIC using a 500ms window. The number of repetitions performed on each set was divided into quartiles (25%, 50%, 75% and 100% of set completion). Average EMG data on each quartile was used for the analysis.

Statistical analysis

After a visual inspection of the data, the normality of the data was assured using the Shapiro-Wilk test. Then a mixed-model analysis was performed, assuming RD (SELF and FIX), sets (1^{st}, 2^{nd} and 3^{rd} sets) and percentage of set completion (25%, 50%, 75% and 100%) as fixed factors and the subjects as random factor for the EMG and TUT per repetition on each quartile. In case of a significant *F value*, Tukey's adjustments were performed for multiple comparisons. Additionally, Paired samples t-tests were used to compare differences in volume, TUT per session and TUT per repetition (average of all sets) between SELF and FIX protocols. *P* values < 0.05 were considered significant.

RESULTS

Volume, time under tension (TUT) per session and time under tension (TUT) per repetition

RE volume was significantly greater for SELF (25.50 ± 6.10 reps vs 16.50 ± 4.42 reps; *P* = 0.01) (Figure 1A), while no significant differences between protocols were detected for TUT per session (*P* = 0.06; Figure 1B). However, TUT per repetition was significantly smaller for SELF (2.60 ± 0.95 s vs 4.00 ± 0.0 s; *P* = 0.0002) (Figure 1C).

- PLEASE INSERT FIGURE 1 HERE –

Time under tension (TUT) per repetition per quartile

Despite no significant protocol set by percentage of set completion interaction (*P* = 0.87), a significant protocol by set interaction (*P* = 0.01) was observed for TUT per repetition (Figure 2A). SELF protocol showed significantly smaller TUT at S2 compared to S1 (*P* < 0.0001) and S3 (*P* < 0.003). As expected, no significant differences were detected between sets for the FIX protocol (*P* = 1.000 for all comparisons). Between-protocol comparisons revealed significantly smaller TUT for SELF compared to FIX at S1 (*P* = 0.0001), S2 (*P* = 0.0001) and S3 (*P* = 0.0001).

Yet, a significant protocol by percentage of set completion interaction (*P* = 0.003) was observed for TUT (Figure 2A). Intra-protocol comparisons showed that SELF protocol significantly increased TUT from 25% to 75% (*P* < 0.03) and 100% (*P* < 0.0001) of set completion. SELF also showed significant increases in TUT from 50% to 100% (*P* < 0.0001) and from 75% to 100% (*P* = 0.0001) of set completion. As expected, no significant differences were detected between sets for the FIX protocol (*P* = 1.000 for all comparisons).

Between-protocol comparisons revealed significantly smaller TUT for SELF compared to FIX at 25% ($P < 0.0001$), 50% ($P < 0.0001$), 75% ($P < 0.0001$) and 100% ($P = 0.001$) of set completion for all sets.

Muscle activation

No significant protocol by set by percentage of set completion interaction was detected ($P = 0.81$). However, a significant protocol by set interaction ($P = 0.002$) was observed for EMG (Figure 2B). SELF protocol showed significantly smaller EMG amplitude in S3 compared with S2 ($P < 0.001$) and S1 ($P < 0.0001$). However, no significant differences were detected between sets for the FIX protocol (S1 vs. S2, $P = 0.61$; S1 vs. S3, $P = 0.37$; S2 vs. S3, $P = 0.16$). Between-protocols comparisons revealed significantly greater EMG amplitude for SELF compared with FIX at S1 ($P = 0.01$), S2 ($P = 0.03$) and S3 ($P = 0.03$).

Significant protocol by percentage of set completion interaction ($P = 0.003$) was observed for EMG amplitude (Figure 2B). Intra-protocol comparisons showed that SELF and FIX protocol produced significant increases in EMG amplitude from 25% to 50% ($P < 0.0001$ for both), to 75% ($P < 0.0001$ for both) and to 100% ($P < 0.01$; $P < 0.0001$, respectively) of set completion. SELF also showed significant increases in EMG amplitude from 50% to 75% ($P = 0.006$) and to 100% ($P < 0.001$) and from 75% to 100% ($P = 0.01$) of set completion, while FIX only showed significant increases in EMG amplitude from 50% to 100%. Between-protocol comparisons revealed significantly greater EMG amplitude for SELF compared with FIX at 75% ($P = 0.03$) and 100% ($P = 0.01$) of set completion for all sets.

- PLEASE INSERT FIGURE 2 HERE -

DISCUSSION

Our findings show that the protocol with self-selected repetition duration (i.e., determined by the individual [SELF]) resulted in higher RE volume and EMG amplitude compared with fixed repetition duration (i.e., 2:2 [FIX]). In addition, TUT per repetition was lower for SELF compared to FIX.

RD can affect RE performance either increasing (17) or decreasing (26) the volume per exercise. In the present study, SELF (2.6s RD) resulted in higher RE volume compared to FIX (4.0s RD). Our results are in accordance with current literature. Lachance and Hortobagyi (17) utilized an inter-subject design to compare the effects of three different RDs (self-selected [<1.3:1.3], 2:2 and 2:4) on RE volume (i.e., number of repetitions). Results showed higher volume for self-selected RD compared with 2:2 and 2:4. The main mechanism behind the increase in RE volume during SELF may be the release of elastic energy in the transition from the eccentric to the concentric phase (5, 6). The release of elastic energy enhances the system kinetic energy lowering the metabolic cost to perform mechanical work (5, 6). Thus, when exercise is performed with shorter RD (i.e., self-selected RD), energy expenditure may be reduced, allowing to increase RE volume (14, 36).

Concerning muscle activation, to the best of our knowledge, no previous study compared the effects of self-selected RD and fixed RD on EMG amplitude. However, our results are consistent with a previous study showing that shorter RD promotes greater EMG amplitude compared to longer RD (27). After investigating the effects of different RDs (1.9s, 2.8s, 5.6s and maximum velocity per repetition) on muscle activation, Sakamoto and Sinclair (27) stated that lower RD increased EMG amplitude.

In the present study, TUT per repetition remained significantly smaller in SELF compared to FIX for all sets and quartiles, supporting a lower RD for the SELF protocol. A negative relationship between MU and peak velocity seems to exist, indicating that high threshold MUs can be recruited when repetitions are performed with short RDs (8, 10, 12), which can increase EMG amplitude.

Importantly, the FIX protocol was interrupted when participants could no longer maintain a RD of 2:2. Such control most likely prevented participants from reaching muscle failure. It has been suggested that, when repetitions are performed to failure, increased MU recruitment may occur (35). Consequentially, a no-failure protocol would result in reduced EMG amplitude compared to a protocol performed to failure. However, when protocols are performed to a point close to failure (e.g., 3-5 repetitions before failure), no significant differences in EMG amplitude seem to occur (9). Additionally, a study from our laboratory also found similar muscle activation between failure and no-failure protocols (~3 repetition before muscle failure) (23). Considering that the difference in number of repetitions between FIX and SELF was of ~ 3 repetitions per set, we believe that muscle failure was not a major confounding variable in this study.

In conclusion, self-selected RD results in greater RE volume and muscle activation compared with fixed RD in a RE session.

PRACTICAL APPLICATIONS

Despite current recommendation for RD control during resistance exercise, in real practice little control is observed. This does not seem to be a problem, since the results of this study indicate that using self-selected RD is a more effective mean to increase muscle activation and resistance exercise volume than fixed RD (2:2). However, further research is required to clarify whether self-selected RD also promotes greater muscle adaptation (e.g., muscle hypertrophy).

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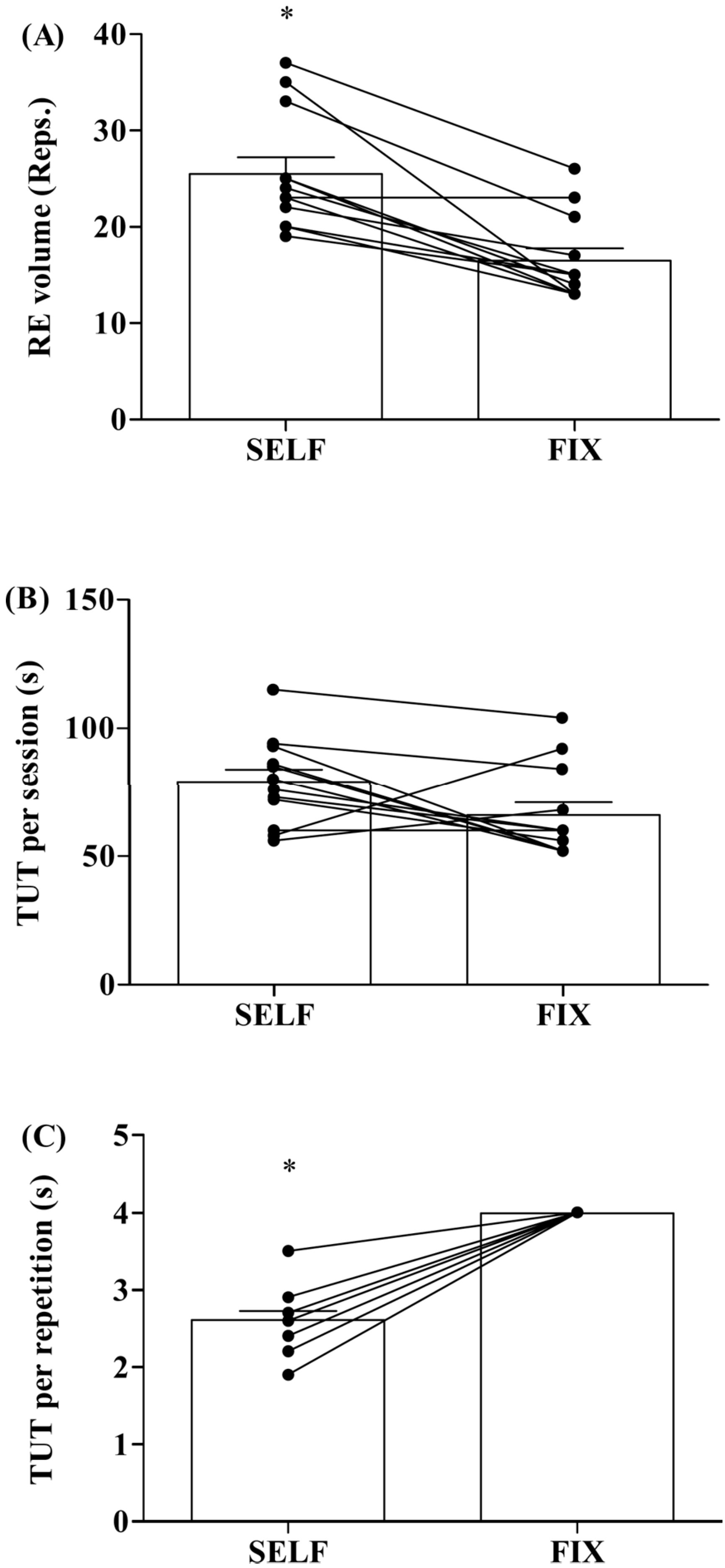
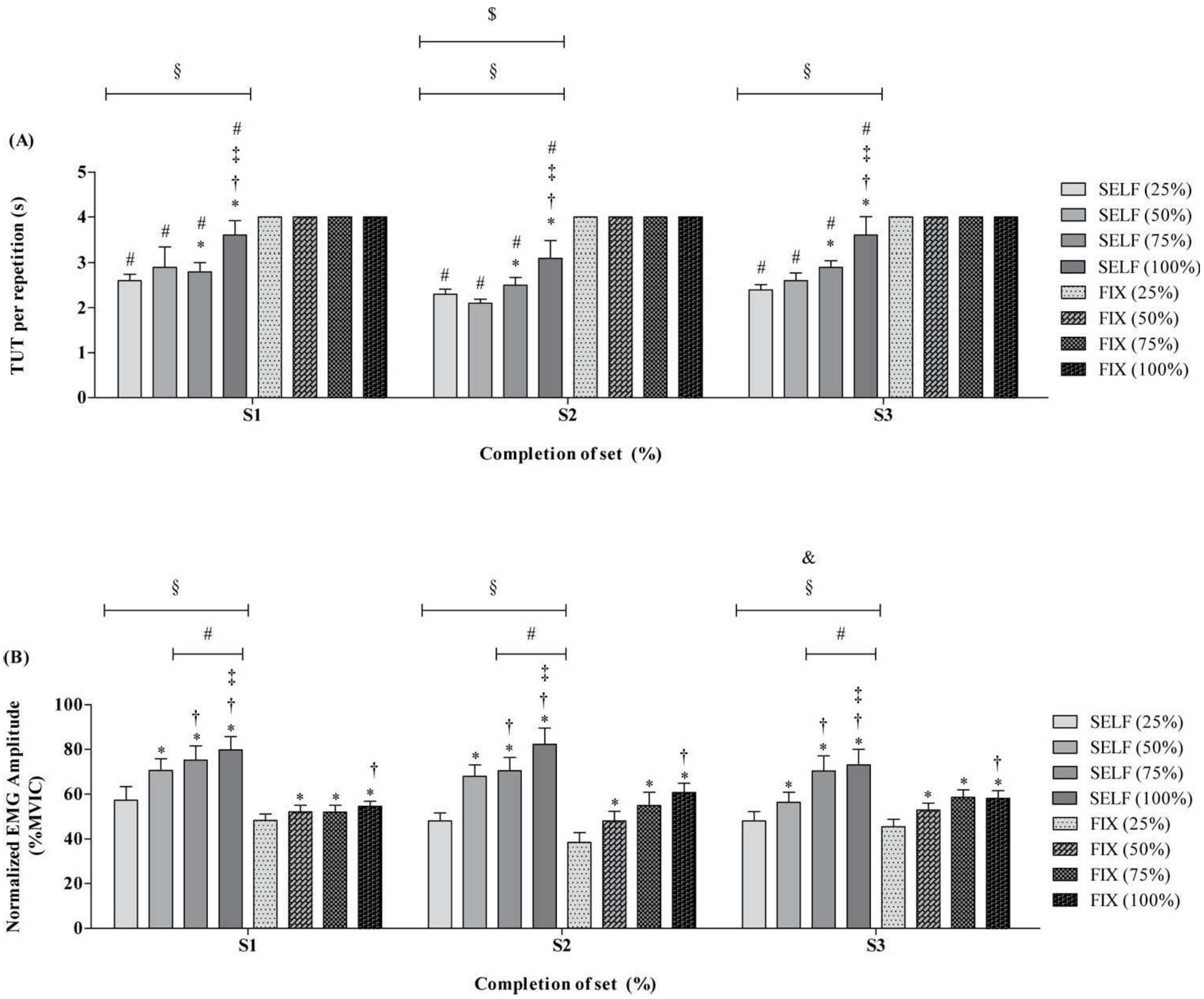
FIGURE LEGENDS

Figure 1. Resistance exercise (RE) volume (number of repetitions [reps.]) (Panel A), time under tension (TUT) per session (Panel B) and time under tension (TUT) per repetition (Panel C) for self-selected (SELF) and fixed (FIX) repetitions duration. *Significant difference compared to FIX ($P < 0.05$). Values presented as mean ± SD.

Figure 2. Time under tension (TUT) per repetition (Panel A) and electromyography (EMG) amplitude normalized by maximal voluntary isometric contraction percentage (%MVIC) (Panel B) during 25, 50, 75 and 100% of set completion in the first (S1), second (S2) and third (S3) sets of resistance exercise with self-selected (SELF) and fixed (FIX) repetition duration. [$]Significant difference compared with S1 and S3 in the same protocol; [§]Significant difference compared with FIX in the same set; [&]Significant difference compared with S1 and S2 in the same protocol. [*]Significant difference compared to 25% of each set completion; [†]Significant difference compared to 50% of each set completion; [‡]Significant difference compared to 75% of each set completion. [#]Significant difference compared to the same time point of the FIX protocol. Values presented as mean ± SD.


(A)
RE volume (Reps.)
40
30
20
10
0
*
SELF
FIX
(B)
TUT per session (s)
150
100
50
0
SELF
FIX
(C)
TUT per repetition (s)
5
4
3
2
1
0
*
SELF
FIX



(A)
TUT per repetition (s)
0
1
2
3
4
5
S1
S2
S3
Completion of set (%)
SELF (25%)
SELF (50%)
SELF (75%)
SELF (100%)
FIX (25%)
FIX (50%)
FIX (75%)
FIX (100%)
(B)
Normalized EMG Amplitude (%MVIC)
0
20
40
60
80
100
S1
S2
S3
Completion of set (%)
SELF (25%)
SELF (50%)
SELF (75%)
SELF (100%)
FIX (25%)
FIX (50%)
FIX (75%)
FIX (100%)