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REPETITION DURATION INFLUENCES RATINGS OF PERCEIVED EXERTION[1, 2]

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Summary.—This study investigated the effect of different repetition durations on ratings of perceived exertion (RPE) in active muscles (RPE-AM) and the overall body (RPE-O). 19 male volunteers (*M* age = 25.4 yr., *SD* = 3.5) performed strength training protocols with multiple sets matched by the number of sets and repetitions, intensity and rest interval but different repetition durations: 4 sec., 6 sec., or self-paced. Participants were asked to estimate their RPE-AM and RPE-O after each set. Training protocols with a 6-sec. repetition duration produced distinct responses on RPE during and after performance compared to 4-sec. and self-paced durations. However, there were no significant differences between 4-sec. and self-paced durations.

Ratings of perceived exertion (RPE) have become a topic of interest in strength training research. Gearhart, Goss, Lagally, Jakicic, Gallagher, and Robertson (2001) found a linear RPE response using a Borg 15-Category Scale and strength training protocols of high and low intensities, with higher RPE observed in training protocols with higher intensities. This response has been found in strength training protocols that use single (Gearhart, Goss, Lagally, Jakicic, Gallagher, Gallagher, *et al*., 2002; Lagally, Robertson, Gallagher, Goss, Jakicic, Lephart, *et al*., 2002) and multiple sets (McGuigan, Egan, & Foster, 2004; Focht, 2007), training protocols that include only one exercise (Lagally, McCaw, Young, Medema, & Thomas, 2004), and protocols with more than one exercise (Day, McGuigan, Brice, & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004). However, this response is not consistent between studies.

Egan, Winchester, Foster, and McGuigan (2006) evaluated the RPE in different training protocols using the squat exercise in which the number of sets, number of repetitions, and rest intervals were standardized across protocols. The training protocols contained differences in repetition durations (i.e., time spent on performing the concentric and eccentric muscle actions during a repetition). A training protocol with 80% of one repetition maximum (1RM) was performed with the "traditionally" recommended repetition duration for strength training (this value was not reported), but

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a protocol with 55% of 1RM was performed with a repetition duration of 20 sec. These authors found that the training protocol using an intensity of 80% of 1RM did not produce a higher mean for the RPE compared to the protocol using 55% of 1RM. Similarly, Hatfield, Kraemer, Spiering, Häkkinen, Volek, Shimano, *et al*. (2006) recorded the RPE at 60% and 80% intensities of 1RM using the squat and shoulder press exercises. Volunteers were asked to perform a single set with the maximum number of repetitions for both exercises and intensities at repetition durations of 20 sec. and self-paced (this value was not reported). No significant differences in the RPE were observed between protocols.

Considering the studies of Egan, *et al*. (2006) and Hatfield, *et al*. (2006), it could be expected that protocols that had a higher intensity also presented higher values of RPE, especially if one takes into account the previously mentioned results of Gearhart, *et al*. (2002) and Lagally and Amorose (2007). However, the results did not confirm this hypothesis. Thus, other variables in the training protocols of Egan, *et al*. (2006) and Hatfield, *et al*. (2006) probably influenced RPE, so that there were no differences between protocols with different intensities.

Hatfield, *et al*. (2006) investigated protocols with different number of repetitions. The literature has already pointed out that a greater number of repetitions can increase the RPE response (O'Connor, Poudevigne, & Pasley, 2002, Woods, Bridge, Nelson, Risse, & Pincivero, 2004) and it may explain part of the results obtained by Hatfield, *et al*. (2006). Another variable that was also amended by Egan, *et al*. (2006) and Hatfield, *et al*. (2006) was the repetition duration. However, no data are available from studies investigating the RPE protocols with repetition duration as an independent variable.

The manipulation of repetition duration in strength training programs produces different acute and chronic adaptations (Gillies, Putman, & Bell, 2006; Tanimoto & Ishii, 2006; Goto, Ishii, Kizuka, Kraemer, Honda, & Takamatsu, 2009). Longer repetition durations result in a smaller number of repetitions for a given intensity (percentage of 1RM test performance) than shorter repetition durations, which suggests that the manipulation of the repetition duration differently affects performance (measured by training volume) (Lachance & Hortobagyi, 1994; Hatfield, *et al*., 2006; Sakamoto & Sinclair, 2006). It has also been found that higher repetition durations result in higher physiological responses in blood lactate concentration (Mazzetti, Douglass, Yocum, & Harber, 2007) and in electromyography activity (Burd, Andrews, West, Little, Cochran, Hector, *et al*., 2012) than protocols with lower repetition durations and matched by intensity and number of repetitions. In the effort model proposed by Borg, the response to an exercise stimulus involves three effort continua: physiological, perceptual, and performance, with a functional link between them (Borg, 1970). As such, perceptual responses likely provide much of the same information about exercise performance, as do selected physiological responses (Robertson & Noble, 1997). Reinforcing this perspective, Lagally, *et al*. (2002) found that for strength training, increased RPE occurred in protocols that also had increases in blood lactate and EMG activity. Thus, considering the influence of repetition duration in effort continua (physiological and performance), it is relevant to investigate whether the repetition duration will cause a change in RPE. Furthermore, the effect of different repetition durations on RPE in strength training protocol with multiple sets is important to investigate because the RPE significantly increases during multiple set protocols that use the same repetition duration (Woods, *et al*., 2004; Focht, 2007). No investigation has examined the efficacy of the Borg RPE scale for differentiating strength training protocols using multiple sets and distinct repetition durations. If the RPE scale is sufficiently sensitive to repetition duration variations during and after the protocol, then this scale may be used to monitor training load.

The RPE in active muscles (RPE-AM) exhibits higher values than the overall body RPE (RPE-O) (Lagally, *et al*., 2002; Lagally, *et al*., 2004), but the difference between RPE-AM and RPE-O is greater at high intensity (90% 1RM) compared to low intensity (30% 1RM) (Lagally, *et al*., 2002). However, these results require verification in training protocols with multiple sets and different repetition durations.

This study examined the effect of different repetition durations on overall body RPE and active muscle RPE using matched strength-training protocols with multiple sets.

Hypothesis 1. Training protocols with longer repetition duration will have higher local and overall body RPE compared with protocols with shorter repetition duration.

Hypothesis 2. Active muscle RPE will be higher than overall RPE, regardless of the training protocol.

Method

Participants

Participants included 20 men (*M* age = 25.4 yr., *SD* = 3.5; *M* body mass = 80.3 kg, *SD* = 9.5; *M* height = 177.7 cm, *SD* = 6.5). All volunteers performed a minimum of six months of uninterrupted strength training (*M* frequency = 4.1 training sessions for week, *SD* = 1.1) and obtained an average performance of 100.5 (±13.5) kg in the 1RM test on the Smith machine bench press. The volunteers exhibited no history of muscle-tendon injuries in the shoulder joints, elbows, or wrists. One volunteer was excluded from the analyses because he was not able to complete all of the proposed repetitions for one of the protocols.

The volunteers received information about the objectives and the methodological process, and they were aware that they could cease participation in this research at any time. The local Ethics Committee approved this study in accordance with international standards. All participants signed an informed consent form.

Measures

All experimental sessions were performed using a Smith machine with a flat bench. Weight plates of known mass were measured on a digital balance with an accuracy of 0.01 kg, and these plates were used to adjust the external resistance to be lifted by the volunteers.

An electrogoniometer (Biovision, Wehrheim, Germany) was attached to the elbows of volunteers, and this device recorded the range of motion, allowing the determination of concentric and eccentric muscle action durations. A specific computer program (Dasylab 4.0, Ireland) was used to record and analyze the data. A metronome assisted in the maintenance of the proper durations for repetitions.

Procedure

This study was designed using repeated-measures. Each volunteer attended the laboratory on five different days (Sessions 1 to 5) separated by at least 48 hr. The volunteers performed 1 repetition maximum (1RM) tests during Sessions 1 and 2. The 1RM test was performed during the first and second sessions to familiarize the volunteers with its procedures and determine the weight for the following sessions, respectively. The volunteers performed the training protocols in Sessions 3, 4, and 5.

Experimental Sessions 1 and 2.—The body mass and height were measured, and the electrogoniometer was fixed to the elbow of the volunteers. The placement of this device was marked using a pen to allow the same placement during subsequent experimental sessions. The electrogoniometer was previously calibrated against a plastic manual goniometer (Carci, Brazil) and fixed to the right elbow of the volunteers using double-sided adhesive tape and elastic bands. The rotation axis of the electrogoniometer was centered over the lateral epicondyle of the humerus. The distal arm of the electrogoniometer was oriented to the medial point between the styloid process of the ulna and radius, and the proximal arm was directed to the rotation axis of the humeral head. These procedures were similar to Mookerjee and Ratamess (1999). The coefficient of variation of intra-individual range of motion during Sessions 3, 4, and 5 were 2.8% (±1.1) and 2.7% (±1.1) for eccentric and concentric muscle actions, respectively. The previously observed values were approximately 2.4% and 2.2% for the reliability of this procedure in a repeated-measures design (Mookerjee & Ratamess, 1999). The same researcher created all reference points and markings using a pen during all experimental sessions.

The volunteers were positioned on the Smith machine to match the approximate position of their bench press performance during their training routine, and the handgrip, body position in relation to the bench, and the range of motion were standardized. The volunteers performed a few repetitions without extra weight on the bar. All markings on the bar and bench were made using adhesive tape, and these markings were maintained throughout the five experimental sessions.

The low anchors for the RPE records over the experimental sessions were established as suggested by Gearhart, *et al*. (2001). The volunteers performed an eccentric muscle action during this procedure, which lowered the free bar (10.5 kg) until it touched the sternum. A concentric muscle action was performed until a full extension of the elbows was reached. The standardized instructions were read prior to and after this repetition. Volunteers were asked to attribute a value of 7 on the Borg 15-Category Scale for the perceived exertion of one repetition with the bar.

The volunteers performed the 1RM test after this procedure. The test was initiated from an eccentric muscle action for a maximum of six attempts, rest intervals of 5 min., and weight progressions of at least 2 kg. An average of 2.75 ($\pm$1.33) and 2.50 ($\pm$0.76) attempts was required for performance of the 1RM test on experimental Sessions 1 and 2, respectively. All volunteers performed at least one trial with a weight that was 2 kg higher than the value of the 1RM. This procedure was adopted to ensure that the volunteers actually reached the maximum weight that they could lift.

The procedure for the establishment of the high anchors for each individual's perceived exertion was read to volunteers during the 1RM test when volunteers began to perform attempts with greater difficulty that likely approached the 1RM value. If the next attempt was the 1RM value, the volunteers were asked to attribute a value 19 on the Borg 15-Category Scale to the sensations perceived during this attempt. In this manner, volunteers established a perceptual relationship for the 7 to 19 range on the Borg 15-Category Scale based on the sensations that they perceived during the performance of one repetition with the free bar and 1RM.

The volunteers were familiarized with the metronome as the final procedure during experimental sessions 1 and 2 by randomly performing one of the training protocols that required the control of the repetition durations to be executed in subsequent experimental sessions.

Experimental Sessions 3, 4, and 5.—The training protocols consisted of three sets of six repetitions at 60% 1RM (as measured in Session 2) and 3 min. of rest intervals between sets. These training protocols were determined in a pilot study, which verified that the volunteers could not complete the entire protocol for greater repetition durations using a greater number of sets, repetitions, or intensity. The order of performance of the different training protocols in Sessions 3, 4 and 5 was determined in a balanced and randomized manner.

One of three different repetition durations was performed in Sessions 3, 4, and 5: (1) 6 sec., with 2 sec. for the concentric muscle actions and 4 sec. for the eccentric; (2) 4 sec., with 2 sec. for the concentric muscle actions and 2 sec. for the eccentric; and (3) self-paced, where the volunteers determined the time of each muscle action, and were allowed to change the time during the session and during sets. A metronome assisted in the maintenance of proper repetition durations (e.g., 4 sec. or 6 sec.) during training protocols. The metronome was adjusted to beep every second. The sets were discontinued if a volunteer could not maintain the time established for each muscle action for two consecutive repetitions, performed an incomplete range of motion (e.g., no extension of the elbows and/or no touching of the bar to the chest) and/or the lifting of their body (e.g., lumbar spine or gluteus) from the bench.

Standard instructions for the use of the RPE were read to the volunteer prior to the initiation of training protocols. These instructions were based on the recommendations of Gearhart, *et al*. (2001). The volunteers estimated their effort sensations using the Borg 15-Category Scale for measurements. A value of 6 was assigned to every perceived exertion that was smaller than the exertion experienced during the performance of one repetition without additional weight on the free bar. A value of 20 was assigned for every perceived exertion that was higher than the experienced exertion during that participant's 1RM.

As described by Lagally, *et al*. (2002) and Lagally, *et al*. (2004), participants were asked to assign RPEs for the local effort from the active muscles (RPE-AM) and the overall effort from the whole body (RPE-O). These subjective perceptions were recorded immediately after the end of each set.

Electrogoniometer data.—The data from the electrogoniometer were synchronized and converted from analog to digital signals using an A/D converter (Biovision) at a sampled frequency of 1.000 Hz. The raw data for angular displacement were low-pass filtered (10^{th} order Butterworth filter) using a cutoff frequency of 2 Hz. The time of the eccentric and concentric muscle actions was determined as the time interval that corresponded to the angular displacement for each muscle action. The time of each repetition was determined as the sum of the time spent for each eccentric action and the subsequent concentric action. The volunteers were provided feedback about the time of each concentric and eccentric muscle action after the end of each set for the controlled repetition durations (4 sec. and 6 sec.). Only the eccentric and concentric muscle action times were recorded in the training protocol using self-paced repetition duration, and no feedback was provided to volunteers.

Statistical Analysis

The normality and homogeneity of variances were verified using Shapiro-Wilks and Levene tests, respectively. A non-normal distribution was observed for the RPE. Therefore, the median was used as an indicator of central tendency, and the quartile indicated RPE-AM and RPE-O dispersion across experimental sessions. A nonparametric procedure (ANOVA-type statistics) suggested by Brunner, Domhof, and Langer (2002) and Brunner and Langer (2000) was used to check the response of RPE-AM and RPE-O during and after the training protocols for the main effects of repetition durations, sets, and RPE, as well as the interactions between these factors. Dunn's test was used as a *post hoc* test. This procedure was performed using R software. The tests of homogeneity and normality were performed using the Statistical Package for the Social Sciences (SPSS 12.0). The ANOVA-type statistics were performed using SAS 9.2.

An analysis of the response of repetitions and muscle action repetition durations across experimental sessions was necessary because the repetition duration was an independent variable, and a significant difference between the experimental protocols should be found. Therefore, the normality and homogeneity of variances were verified using Shapiro-Wilks and Levene tests, respectively. A two-way (repetition duration × muscle actions) ANOVA with repeated-measures verified the responses of the eccentric and concentric times in each experimental session (STATISTICA 5.1). A Scheffé test was performed for *post hoc* analyses to assess differences. A one-way ANOVA with repeated-measures verified the responses of repetition times followed by a *post hoc* Scheffé test.

A $p < .05$ was considered significant for all tests.

Results

ANOVA-type statistics indicated significant differences of the main effects for RPE values ($H_1 = 275.34$, $p = .003$, $\delta = 0.58$) and repetition durations ($H_2 = 119.28$, $p < .0001$; $\delta = 0.53$). No significant effects were observed for the main effect of sets ($H_2 = 5.29$, $p = .07$, $\delta = 0.46$) or interactions (repetition duration × sets × RPE) ($H_{10} = 0.69$, $p = .96$, $\delta = 0.12$). Dunn's test indicated a significantly higher RPE response for the 6 sec. protocol compared to self-paced and 4 sec. protocols. No other significant differences were observed in comparisons of different repetition durations. Furthermore, RPE-AM values were significantly higher than RPE-O for the same set and repetition duration. Table 1 presents the median, the first and third quartiles of each measured RPE, and the results from inferential analyses.

TABLE 1
Descriptive Values and Inferential Analyses of RPE-AM and RPE-O For Training Protocols ($N=19$)

		RPE-AM			RPE-O*		
		Self-paced	4 sec.	6 sec.†	Self-paced	4 sec.	6 sec.†
First set	*Mdn*	12.0	12.0	13.0	9.0	11.0	10.0
	Q1	11.0	11.5	12.0	8.5	9.0	9.5
	Q3	12.0	13.0	14.5	11.0	11.0	12.0
Second set	*Mdn*	12.0	12.0	13.0	10.0	11.0	12.0
	Q1	11.5	12.0	12.5	9.0	9.5	10.0
	Q3	13.0	13.0	14.5	11.0	11.5	12.5
Third set	*Mdn*	12.0	13.0	14.0	10.0	11.0	12.0
	Q1	12.0	12.0	12.5	9.0	9.5	10.0
	Q3	13.0	14.0	15.0	11.0	12.0	13.0

Note.—RPE-AM = RPE in active muscles; RPE-O = RPE in the overall body, *Mdn*=Median, Q1=First Quartile, Q3=Third Quartile. *Significantly different from the RPE-AM for the same repetition duration and set, $p<.05$. †Significantly different from the self-paced and 4 sec. protocols for the same RPE and set, $p<.05$.

A two-way ANOVA demonstrated significant main effects for protocol ($F_{2,36}=106.5$; $p<.001$; $\eta^2=0.85$) and muscle actions ($F_{1,18}=306.9$; $p<.001$; $\eta^2=0.94$). Scheffé *post hoc* test indicated a significant difference across protocols (6 sec.>4 sec.>self-paced, *p*s<.001), and RPEs for eccentric muscle actions were greater than concentric ($p<.001$). The interaction between factors was also significant ($F_{2,36}=162.2$; $p<.001$; $\eta^2=0.90$). One-way ANOVA identified a significant main effect of protocol ($F_{2,36}=108.4$; $p<.001$; $\eta^2=0.86$). Table 2 presents the means and standard deviations of RPE by muscle actions and repetition durations for the different training protocols and the *post hoc* results of one- and two-way ANOVA interactions.

Discussion

This study demonstrated that strength training protocols matched by the number of sets and repetitions, intensity, and rest interval but with different repetition durations (self-paced, 4 sec., 6 sec.) produced different responses in RPE-AM and RPE-O during and after protocol completion. The hypothesis that strength-training protocols with longer repetition durations would yield higher responses on the RPE-AM and RPE-O during and after its performance was partly supported: only the 6 sec. repetition duration protocol produced higher RPE-AM and RPE-O values compared

TABLE 2
COMPARISON OF MEANS AND STANDARD DEVIATIONS OF ECCENTRIC, CONCENTRIC, AND REPETITION DURATIONS FOR SELF-PACED, 4 SEC., AND 6 SEC. TRAINING PROTOCOLS ($N = 19$)

	Protocol					
	Self-paced		4 sec.		6 sec.	
	M	*SD*	*M*	*SD*	*M*	*SD*
Eccentric muscle action (sec.)	1.93	0.75	2.24*	0.13	4.01*†	0.18
Concentric muscle action (sec.)	1.38	0.35	1.87*	0.11	2.06*	0.16
Repetition	3.31	1.02	4.11*	0.13	6.07*†	0.21

*Significantly higher than self-paced repetition duration ($p < .005$). †Significantly higher than 4 sec. repetition duration ($p < .001$).

to the 4 sec. repetition duration and self-paced protocols. Furthermore, a higher response in the RPE-AM compared to the RPE-O was observed in all sets for each of the strength-training protocols.

Robertson and Noble (1997) demonstrated that the response to an exercise stimulus involves three primary effort continua: physiological, perceptual, and performance. A functional link between these three effort continua is presumed. Strength training protocols with longer repetition durations are associated with greater physiological demands (e.g., higher lactate concentrations) than protocols with shorter repetition durations [Tanimoto & Ishii, 2006 (7 sec. × 3 sec.); Mazzetti, *et al.*, 2007 (4 sec. × 3 sec.)]. Furthermore, repetition durations influence strength performance because the execution of protocols with longer repetition durations produces fewer maximal repetitions than shorter repetition durations [Lachance & Hortobágyi, 1994 (6 sec. × 4 sec. × self-paced); Sakamoto & Sinclair, 2006 (5.6 sec. × 2.4 sec. × 1.9 sec. × ballistic)]. Therefore, a distinct perceptual response with different repetition durations (self-paced, 4 sec., 6 sec.) would be expected due to the effect of repetition duration on physiological and performance responses.

However, the present study showed that only the 6 sec. repetition duration protocol yielded higher RPE-AM and RPE-O values than the self-paced and 4 sec. protocols. The RPE was not sensitive enough to distinguish matched training protocols using the same number of sets, repetitions, intensity, and rest intervals, but with self-paced vs 4 sec. repetition durations, which contrasts with sensitivity of other variables, such as electromyographic activity (Sakamoto & Sinclair, 2012) and blood lactate concentration (Mazzetti, *et al.*, 2007). However, it should be noted that in the self-paced protocol there was a high variability of repetition durations by volunteers (1.8 to 5.3 sec.). This may have contributed to the absence of differences in overall and active muscle RPE when compared to the 4 sec. protocol. The mechanisms that underlie these RPE results should consider only the interaction of the continuous dimensions of perceptual and physiological stress because the performance dimension remained constant in the present study (i.e., all of the volunteers attained all of the training protocols that were proposed). Future studies should investigate the RPE and physiological responses using matched strength-training protocols with closed differences between repetition durations.

An increase in RPE has been observed between sets when strength-training protocols were performed using multiple sets (Woods, *et al*., 2004; Focht, 2007). However, this response was not observed in the present study. One possible reason for these contradictory results is the difference in training protocols between these studies. The training protocol of Focht (2007) and Woods, *et al*. (2004) did not allow all of the volunteers to complete the proposed number of repetitions for the sets, which suggest that the volunteers made greater efforts. The participants completed the entire protocol, which suggests they exerted less effort than was required in the previously mentioned studies. However, it is not possible to ensure whether this difference between studies was responsible for the contradictory responses of the RPE between the sets of the protocols. Further studies are required to verify the possible influence of the training protocol configuration to the responses of the RPE between sets.

Previous studies have used different scales, such as the OMNI Scale, to investigate strength training (Gearhart, Lagally, Riechman, Andrews, & Robertson, 2008; Lagally, Amorose, & Rock, 2009; Gearhart, Lagally, Riechman, Andrews, & Robertson, 2011). However, the Borg 15-Category Scale and OMNI scales can be used interchangeably during resistance exercise (Lagally & Robertson, 2006). Therefore, the results of the present research were not likely influenced by the use of the Borg scale.

No significant interaction effect was observed between the RPE (active muscle and overall), sets, and repetition duration. Thus, the variation of the responses of RPE-AM and RPE-O between sets for different durations of repetition was similar. These results differ from Lagally, *et al*. (2002), who noted an increased responsiveness of RPE-AM compared to RPE-O with intensity increases. However, this study's results were consistent with the expectation that RPE-AM was significantly greater than RPE-O regardless of the training protocol. These results are also consistent with Lagally, *et al*. (2002), Lagally, *et al*. (2004), and Duncan, Al-Nakeeb, and Scurr (2006) using specific strength training exercises and exercises on a cycle ergometer and treadmill at different intensities (Hetzler, Seip, Boutcher, Pierce, Snead, & Weltman, 1991).

The strain sensations in active muscles arise from proprioceptors and mechanoreceptors, which may contribute to the expression of RPE (Mihevic, 1981). Therefore, the information from the active muscles presumably allowed for a higher response in RPE-AM than RPE-O. Lagally, *et al*.

(2002) demonstrated that the local sensations, discomfort, and strain that are felt in active muscles are more intense than the sensations that are experienced in the overall body. Furthermore, possible physiological indicators that are related to RPE, such as blood lactate concentration and electromyographic activity, exhibit higher responses in the stimulated muscle compared to other body parts (Robergs, Pearson, Costill, Fink, Pascoe, Benedict, *et al*., 1991; Lagally, *et al*., 2004). This fact may also explain the increase in RPE-AM compared to RPE-O. However, assessment of the mechanisms and the importance of this difference could not be tested by the design of the present study because the goal of the present study did not assess the mechanisms that influence RPE-AM and RPE-O.

The results of the present study demonstrated that matched strength with moderate intensity training protocols with large differences in repetition durations produced a differential response on perceived exertion during and after performance. However, RPE response was not different between training protocols that use close repetition durations. Additionally, the perceived exertion in active muscles exhibited a greater response magnitude than the perception of effort in the overall body.

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