Maximum number of repetitions in isotonic exercises: influence of load, speed and rest interval between sets

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ABSTRACT

Introduction: Very little is known about the effects of movement velocity and rest intervals between sets of resistance exercise. **Purpose:** To compare the maximum number of repetitions to volitional fatigue (REPS) on a knee extension machine with the dominant leg for different loads, velocities and rest intervals between sets. **Methods:** Nine volunteers (35.8 ± 10.8 years; 74.2 ± 16.7 kg; 171.0 ± 10.0 cm) reported to the laboratory to determine 1RM and REPS under six conditions, randomly determined and separated by at least 48 h: 1 set with 60% 1RM at $80°•s^{-1}$ and $25°•s^{-1}$; 1 set with 80% 1RM at $25°•s^{-1}$; 3 sets with 80% 1RM at $80°•s^{-1}$ and rest intervals of 3 min, 1 min and one that allowed recovery or stabilization of muscle oxygenation (RMox), measured by near infrared spectroscopy (NIRS). **Results:** Dependent samples t-test showed that REPS was significantly ($p < 0.05$) larger for the lighter than the heavier load, for slow (light = 8.8 ± 1.3; heavy = 5.9 ± 0.9) and fast velocities (light = 16.3 ± 3.9; heavy = 9.4 ± 1.9), and significantly larger for the fast than the slow velocity, for both loads. The 3x3 ANOVA did not show differences among intervals on set 1 (3 min = 9.4 ± 1.9; 1 min = 10.8 ± 3.2; RMox = 10.1 ± 3.0), however, there were significant differences on sets 2 and 3 between 3 min (set 2 = 7.0 ± 1.7; set 3 = 6.4 ± 1.3) and 1 min (set 2 = 5.6 ± 1.1; set 3 = 4.8 ± 1.2), but not between RMox (set 2 = 6.4 ± 1.7; set 3 = 6.1 ± 1.5) and the other intervals. For all three intervals, REPS on set 1 was significantly larger than on the other sets. **Conclusions:** Performance in resistance exercise is affected by load, velocity and rest interval between sets and is independent of muscle oxygenation recovery. Exercise prescription and assessment of performance should take these variables into consideration in view of the specific aims.

Keywords: Intensity. Knee extension. Performance. Fatigue.

INTRODUCTION

Tests of maximum number of repetitions until volitional fatigue are commonly used in the exercise sciences field. Lighter loads result in more repetitions, although the exact number may vary according to the exercise being performed. Hoeger *et al.*[1] compared the maximum number of repetitions with 40%, 60% and 80% of one maximum repetition (1 RM) in seven different upper and lower body exercises. Significant differences were observed in the number of repetitions among the exercises for the same % of 1 RM both for untrained and trained males as well as females. The findings also showed significant differences between males and females, and trained and untrained.

Less evident in the literature is the fact that, lifting the same load, more repetitions will be performed with slower than faster movement speeds. The paucity of evidence in this respect is most probably due to the fact that most velocity-related studies are conducted with isokinetic dynamometers, where speed is controlled, but resistance and the applied force will vary. It is clear, though, that speed influences performance. Presently, the only evidence that velocity of movement influences performance during resistance exercises is reported in a study using push-ups and pull-ups[2] and in studies from our own laboratory using squatting and chest press exercises[3-4].

Concerning the number of repetitions in multiple sets, again there are not many reports in the literature about isotonic exercises. The influence of between-sets rest intervals in performance has been mostly investigated with isokinetic dynamometers, and the results show that shorter intraset rest intervals are responsible for decreases in performance of the subsequent sets[5-7]. Studies from our laboratory using isotonic bench press exercise have shown decreases in the number of repetitions in subsequent sets, and that shorter rest intervals (1 min) result in greater decreases than longer ones (2 or 3 min)[8-10]. The physiological explanation for the decrease in performance in multiple sets when, in theory, there is enough time for recovery of the energy substrates, is still not clear.

It has been suggested that insufficient tissue oxygenation may be in some way related to fatigue. Moreover, there seems to be a dose-response correlation between force measured with electrical stimulation and muscle oxygenation[11] and a relation between the rate of decrease in strength occurring with ischemia and oxygen availability, since this decrease was similar between the ischemia and hypoxia conditions without blood flow interruption[12]. Therefore, it could be hypothesized that an intraset rest interval sufficient to recover muscle oxygenation would allow maintenance or smaller performance decrease of the sets following the first one.

Therefore, the purpose of this study was to compare the maximum number of repetitions to volitional fatigue for unilateral leg extension using a conventional isotonic weight-lifting machine in the following situations: 1) different loads (60% and 80% 1 RM); 2) different speeds ($25°•s^{-1}$ and $80°•s^{-1}$); 3) different rest intervals (1 min, 3 min and until stabilization of muscle oxygenation measured by near-infrared spectroscopy). The hypotheses tested were that there would be differences in the number of repetitions performed at different conditions, i.e.: 1) different percentages of 1 RM; 2) different movement speeds; 3) different recovery intervals.

METHODS

Nine (6 males and 3 females; 35.8 ± 10.8 years; 74.2 ± 16.7 kg of body mass; 171.0 ± 10.0 cm of height), physically active and free from cardiopulmonary and orthopedic disorders volunteers,

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Approved in 7/10/06.

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participated in this study. All subjects have received verbal explanations of the study procedures and signed a written consent form prior to the beginning of testing. Study procedures were conducted according to the institutional guidelines and the Helsinki Declaration.

Testing procedures

At least two days after the 1 RM load has been determined, subjects reported to the laboratory on six different days, separated by at least 48 h, when they performed the following tests of maximum number of repetitions: 1) one set with 60% of 1 RM at $80^{\circ}\cdot s^{-1}$; 2) one set with 60% of 1 RM at $25^{\circ}\cdot s^{-1}$; 3) one set with 80% of 1 RM at $25^{\circ}\cdot s^{-1}$; 4) three sets with 80% of 1 RM at $80^{\circ}\cdot s^{-1}$ and 3 min rest between sets; 5) three sets with 80% of 1 RM at $80^{\circ}\cdot s^{-1}$ and 1 min rest between sets; 6) three sets with 80% of 1 RM at $80^{\circ}\cdot s^{-1}$ and a rest interval between sets that allowed muscle oxygenation stabilization (RMox). Tests order was randomly determined. All testing was performed on a knee extension machine (Righetto Fitness Equipment, Campinas, SP, Brazil).

Muscle oxygenation recovery was determined by near-infrared spectroscopy (NIRS). NIRS is a non-invasive optical technique which determines relative oxy- and deoxy-hemoglobin blood concentrations through the different absorbance properties of these chromophores in the near-infrared spectrum (700 to 1000 nm). Detected signal primarily originates, from the small circulation, representing the balance between supply and oxygen uptake in the monitored tissue. A two-wave length continuous NIRS device (MicroRunman, Philadelphia, PA, USA) has been used in this study, with the probe positioned over the dominant (as reported by the subject) vastus lateralis muscle, approximately 16 cm measured from the femur lateral epicondyle. Data obtained by NIRS represent the phenomenon under the measured site, and detect, as in this case, what occurs in that specific region of one of the muscles strongly involved in the knee extension movement. The moment when the oxygenation curve (computed as subtraction of 760 nm and 850 nm signals[13]) stabilized was considered the muscle oxygenation recovery (figure 1).

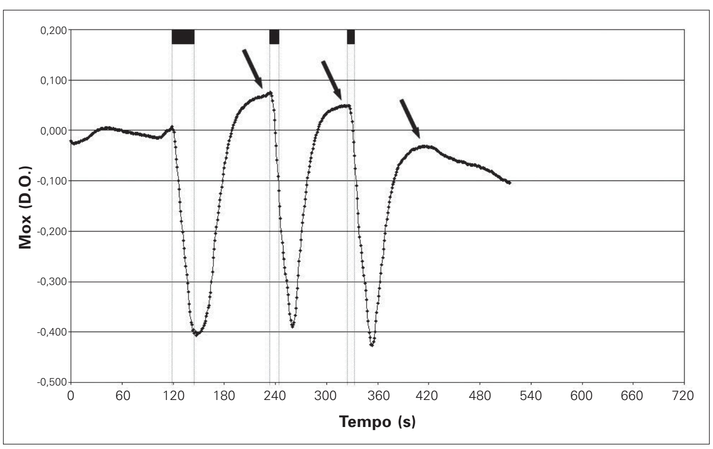

***Figure 1** – Graphic representation for a typical muscle oxygenation subject during three sets of maximum repetitions of dominant knee extension at 80% of 1 RM and $80^{\circ}\cdot s^{-1}$ with rest interval between sets sufficient to stabilize muscle oxygenation (arrows indicate the moment of muscle oxygenation stabilization; black boxes represent contraction periods)*

Speeds were determined using a metronome set at 132 bpm. Slow speed used six beats for each phase of the movement, whereas fast speed used two beats. The knee extension machine was adapted so that range of motion could be monitored, and a repetition was considered valid if the subject extended the knee to at least 70°, and not more than 90°. It resulted in average speeds per set varying from 25 to $29^{\circ}\cdot s^{-1}$ (average $26.6^{\circ}\cdot s^{-1}$) and 73 to $91^{\circ}\cdot s^{-1}$ (average $81.4^{\circ}\cdot s^{-1}$) for the slow and fast speeds, respectively.

One tester would control the extension angle and the other the movement cadence. The subject was verbally instructed to further extend the knee or speed up or down whenever he/she, in one repetition, did not attain the 70° minimum angle or was out of cadence, respectively. If the following repetition was still not within the breadth or rhythm set, the test was then ended. During the test, subject's stabilization was attained by two testers, one holding the subject's hips against the seat, and the second immobilizing the counter lateral leg.

Subjects first underwent a 10 repetitions warm-up using the cadence of the test to be performed with a load of approximately 40-50% of the test load. Seven minutes rest was allowed before the maximum test repetitions.

Data analysis

Paired t-tests have been used to compare the maximum number of repetitions performed in the following tests: a) the single set at 60% of 1 RM and $80^{\circ}\cdot s^{-1}$ with the first set at 80% of 1 RM and $80^{\circ}\cdot s^{-1}$, 3-min rest interval; b) the single set at 60% of 1 RM and $25^{\circ}\cdot s^{-1}$ with the single set at 80% of 1 RM and $25^{\circ}\cdot s^{-1}$; c) the single set at 60% of 1 RM and $25^{\circ}\cdot s^{-1}$ with the single set at 60% of 1 RM and $80^{\circ}\cdot s^{-1}$; d) the single set at 80% of 1 RM and $25^{\circ}\cdot s^{-1}$ with the first set at 80% of 1 RM and $80^{\circ}\cdot s^{-1}$, 3-min rest interval. A 3x3 (sets x intervals) ANOVA for repeated measurements test was used to compare the maximum number of repetitions for the different rest intervals and sets. In case significance was found, *post hoc* analyses one-way ANOVA with repeated measurements tests were used, individually comparing each interval and each set. Differences among intervals for the decrease in number of repetitions from the first to the last set were determined by a one-way ANOVA for repeated measurements. Significance level was established at $p < 0.05$.

RESULTS

The maximum number of repetitions performed in one set with different loads and speeds are shown in figure 2. Maximum repetitions were significantly greater for the lighter than the heavier load, for both slow ($p = 0.0001$; light = 8.8 ± 1.3; heavy = 5.9 ± 0.9) and fast speeds ($p = 0.0002$; light = 16.3 ± 3.9; heavy = 9.4 ± 1.9) and significantly greater for the fast than the slow speed, for both lighter ($p = 0.0001$) and heavier loads ($p = 0.0000$).

The RMox interval ranged 1.6 ± 0.6 min, varying between 1.1 and 2.3 min, and was significantly ($p < 0.01$) different from the other two. Figure 3 shows the number of repetitions performed on the three sets of the three different rest intervals. Results of

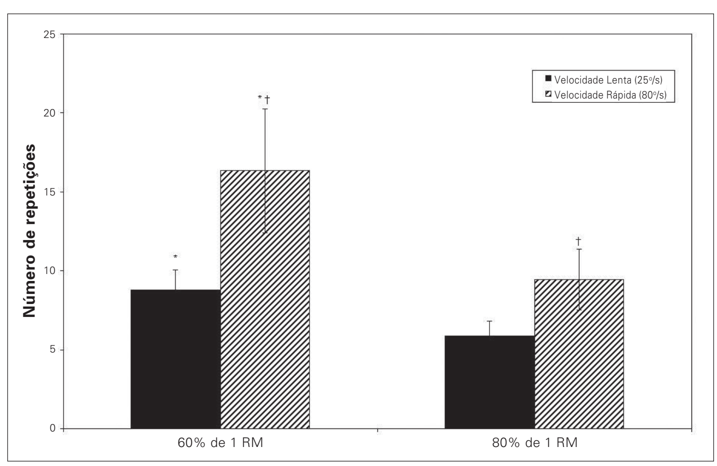

***Figure 2** – Maximum repetitions (mean ± SD) in one set of unilateral knee extension with different movement speeds and different loads*

* dependent samples t-test significantly ($p < 0.05$) greater than at 80% of 1RM for the same speed

† dependent samples t-test significantly ($p < 0.05$) greater than at $25^{\circ}\cdot s^{-1}$ for the same load

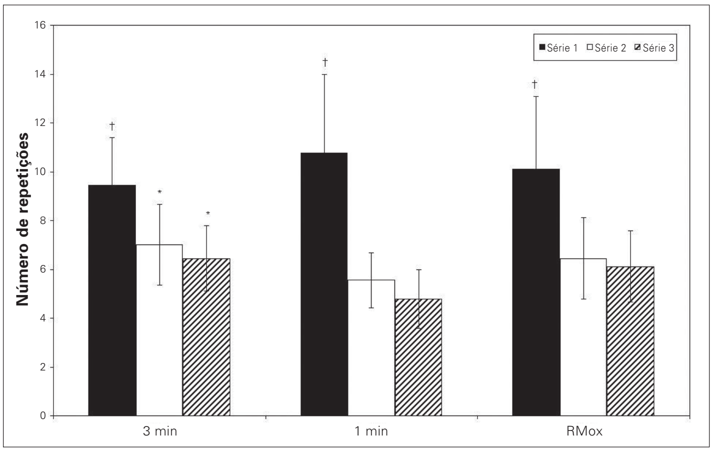

Figure 3 *– Maximum repetitions (mean ± SD) in three sets of unilateral knee extensions at 80% of 1 RM and 80°•s⁻¹, with different rest intervals between sets*

RMox – muscle oxygenation recovery

* repeated measures ANOVA significantly ($p < 0.05$) greater than the same set with 1-min interval

† repeated measures ANOVA significantly ($p < 0.05$) greater than the other sets with the same interval

the 3x3 ANOVA indicated significant set x interval interaction (p = 0.0022) and set main effect (p = 0.0000). Subsequent analyses did not identify differences in number of repetitions among the first sets of each interval (3 min = 9.4 ± 1.9; 1 min = 10.8 ± 3.2; RMox = 10.1 ± 3.0); however, there were significant differences on the second and third sets between 3-min (set 2 = 7.0 ± 1.7; set 3 = 6.4 ± 1.3) and 1-min (set 2 = 5.6 ± 1.1; set 3 = 4.8 ± 1.2) intervals, with no differences between RMox (set 2 = 6.4 ± 1.7; set 3 = 6.1 ± 1.5) and 3-min or RMox and 1-min. For all three rest intervals, maximum repetitions on the first set were significantly greater than those on the second (3-min, p = 0.0017; 1-min, p = 0.0003; RMox, p = 0.0127) and third sets (3-min, p = 0.0002; 1-min, p = 0.0005; RMox, p = 0.0041), with no differences between these two.

Considering the set main effect, differences were found in the total number of repetitions between set 1 (30.3 ± 7.4) and the other sets (set 2 = 19.0 ± 4.1, p = 0.0002; set 3 = 17.3 ± 3.2, p = 0.0004), with no differences between these two. Intervals main effect was not significant (p = 0.1844), indicating that the total number of repetitions in the three sets (3-min = 22.9 ± 4.5; 1-min = 21.1 ± 5.1; RMox = 22.7 ± 5.0) was not different among intervals. However, when the number of repetitions from the first to the last set was compared, using ANOVA for repeated measurements, significant difference was found among intervals (p = 0.0019), which was identified between the 1-min (6.0 ± 2.7) and the other intervals (3-min = 3.0 ± 1.2, p = 0.0056; RMox = 4.0 ± 2.5, p = 0.0053).

DISCUSSION

This study had the aim to compare performance measured as the maximum number of repetitions, with different intensities, different speeds of movement, and different rest intervals between sets. The lighter load resulted in greater number of repetitions than the heavier one, and so did the faster speed when compared to the slower one. The intervals resulted in similar total number of repetitions; however, the shorter 1-min rest interval resulted in greater decreases in number of repetitions than the other intervals. When each set was individually compared, the longer rest interval (3-min) resulted in greater number of repetitions than 1-min (except for the first set). Nevertheless, muscle oxygenation recovery, with average duration of 1.6 min, did not result in a number of repetitions different from the other two rest intervals.

The greater number of repetitions for the lighter load was expected and agrees with the study by Hoeger *et al.*[1], in which the lighter the load, the greater the number of repetitions achieved for various exercises tested. In particular, for the knee extension exercise, these authors obtained between 13 and 18 repetitions at 60% of 1 RM approximately, and between 8 and 11 repetitions at 80% of 1 RM for both trained and untrained males and females. These outcomes are similar to those of the present study for the fast speed (approximately 16 repetitions at 60% of 1 RM and 9 repetitions at 80% of 1 RM), which is closer to that used when training this exercise with no movement speed control (86 ± 11°•s⁻¹)[14].

It is well known that strength decreases with the increase of movement speed, which is referred to as the force-velocity relationship. This relation is evident for isokinetic movements (when speed and resistance are externally controlled, whereas the exerted force is theoretically maximal throughout the entire range of motion)[15]. The same is true for isotonic movement with uncontrolled movement speed; the greater the load, the slower the speed in which exercise is performed[16]. When speed is voluntarily controlled during isotonic exercise and then, the maximal load that can be lifted is observed, this relation seems to be inverted, and a greater load is possible to be lifted with faster speeds[4]. According to this reasoning, it is possible to perform more repetitions for a steady load, with faster speeds, compared to slower ones[2-3]. The explanation for this fact is not clear, but it is probably related to the fact that, with faster speeds, once inertia is overcome, the load's *momentum* is greater and, thus, the force needed to be displaced may be reduced. In the present study, these findings were corroborated since, for both loads, the faster movement speed resulted in greater number of repetitions than the slower one.

This study's results have previously confirmed research from our laboratory[8-10] which demonstrated that, in resistance exercise, performance decreases in multiple sets, even with a 3-min rest interval. Moreover, performance with a 1-min rest interval is significantly ($p < 0.05$) lower than with 3-min. Performance after muscle oxygenation recovery was not different from that with the other two rest intervals for each set, indicating that from approximately 1.5 min to 3 min, recovery seems to be equivalent and that, even though, fatigue affects performance. The decrease in number of repetitions for the 3-min and RMox intervals was greater than that reported by Kraemer *et al.*[17] for knee extension with a 2-min rest interval between sets (set 1 = 9.5 ± 1.0; set 2 = 8.9 ± 2.0; set 3 = 7.9 ± 1.9). However, these authors used bilateral knee extensions and a speed of approximately 45°•s⁻¹, which is slower than the 80°•s⁻¹ of the present study. It is surprising the fact that values reported by Kraemer *et al.*[17] are greater, since it would be expected that with a slower speed the number of repetitions would be even smaller than with a faster one. Differences in results are probably partly due to the fact that those authors used bilateral movement, whereas this study used only the dominant leg.

Results of this study show that muscle oxygenation level considered as the moment when muscle oxygenation measured by NIRS stabilizes was not a determinant factor for activity performance. Studies by Murthy *et al.*[11] and Hogan *et al.*[12] that found an association between decrease in strength and muscle oxygenation were performed with electrical stimulation, which may result in performance different from that obtained through *in vivo* voluntary contraction.

In the present study, recovery for beginning of the next set was considered as stabilization of the oxygenation curve, not return to baseline levels. It is possible that this was not sufficient for complete recovery since none of the subject of this study showed stabilization at baseline levels (figure 1), even after three minutes of recovery. Thus, future studies should investigate whether recovery of muscle oxygenation to baseline levels is determinant to maintain performance levels. Furthermore, decrease in performance with shorter rest intervals may be related to factors other than muscle oxygenation, such as increase in blood lactate concentration[18-19], related to increases in H^+ which in turn, reduces the force generating capacity[20].

Other studies have also reported differences in number of repetitions between sets and rest intervals. On the bench press exercise[21], the number of repetitions on the second and last set was significantly different among 1-min, 3-min and 5-min intervals, and smaller than that performed on the respective first sets. Hannie *et al.*[22] observed decreases in the number of repetitions in four sets of bench press after 2-min of either passive or active (cycle ergometer) rest intervals. Recent unpublished data from our laboratory corroborated the decrease in number of repetitions in three sets of knee extension with a 3-min rest interval, after different intensities of a specific warm-up routine. Surprisingly, Firmino *et al.*[23] hardly showed any decrease in performance on the *leg press* and knee extension, with 2-min rest intervals between sets, after subjects had performed different warm-up routines (aerobic or specific). It should be observed that on the second set of *leg press* after both warm-ups, the number of repetitions performed was exactly that which was expected (10RM) and the standard deviation was zero, indicating that all subjects performed the same number of repetitions.

It is possible that longer rest intervals between sets may allow better recovery. Willardson and Burkett[24], when comparing the total number of repetitions performed in four sets with 1-min, 2-min and 5-min intervals, on the squat and bench press, observed that the 5-min rest interval resulted in a greater number of repetitions than the other two recovery intervals for both exercises; however, for the squat, differences between 1-min and 2-min were not significant, whereas for the bench press, the 1-min rest resulted in a smaller total number of repetitions. Repetitions between sets were not statistically compared; nevertheless, decreases in mean values of 68 and 47% for the 1-min rest interval, of 49 and 40% for the 2-min, and 26 and 25% for the 5-min, for bench press and squat exercises, respectively, may be observed, suggesting that even five minutes may not be enough to maintain performance.

CONCLUSIONS

Performance in resistance exercise, measured as the maximum number of repetitions, is affected by load, speed of movement and rest interval between sets. Greater intentional movement speed allows greater number of maximum repetitions for a same load, no matter whether it is lighter (60% of 1 RM) or heavier (80% of 1 RM). Three-minute rest intervals between sets result in greater number of repetitions in multiple sets when compared to 1-min, although they are not sufficient to maintain the same performance of the first set. Similarly, stabilization of muscle oxygenation does not seem to be enough to maintain performance in multiple sets of resistance exercise. Further studies are needed to investigate whether complete muscle oxygenation recovery to baseline levels is necessary to allow better performance in multiple sets.

It is worth mentioning that NIRS technique is subject to limitations, including the fact that it detects oxygenation levels of an area underneath the site where the probe is positioned, and does not represent the whole muscle group responsible for knee extension. It is possible that different oxygenation levels obtained from other parts of the muscle or from synergistic muscles could better explain the differences in number of repetitions between sets.

According to the outcomes of this study, exercise prescription and especially performance assessment, more so for research purposes, should take into account load, speed and rest interval between sets in order to obtain the desired objectives. As for training, it is still early to say that using faster speeds in order to obtain greater number of repetitions is more efficient than slower speeds with a smaller number of repetitions, since an earlier study has demonstrated that training at $25^{\circ}\bullet s^{-1}$ and $100^{\circ}\bullet s^{-1}$ resulted in similar gains in strength[25].

ACKNOWLEDGMENTS

This study was partly supported by CAPES/Ministry of Education, FEPERJ (E-26/170.774/2003), and Righetto Fitness Equipment, Brazil.

All the authors declared there is not any potential conflict of interests regarding this article.

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