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Effects of intra-set rest on the ability to repeat work at maximal isometric strength

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ABSTRACT

BACKGROUND: The aim of this paper was to analyze how the rest between interval repetitions in intra-set training (at maximal isometric loads) could affect the ability to repeat maximal contractions in subjects with different levels of performance and different experience in strength development work.

METHODS: Twenty subjects were divided randomly into two different groups depending on their sport characteristics: ten subjects were trained in strength development work (Group Strenght - 23.1±4.6 years; 172.0±5.3 cm; 79.9±12.1 kg; 2175.6±490.8 N; 46.9±4.9 mL/kg.min), and ten subjects were trained in endurance work (Group Endurance- 21.3±4.5 years; 172.4±4.1 cm; 60.0±4.6 kg; 815.5±206.5 N; 67.4±4.9 mL/kg.min). To assess the ability to repeat maximal efforts, 20 repetitions of 5 seconds were performed in a half-squat position, with 1 minute of rest between repetitions.

RESULTS: For both groups, four different phases were observed in the Interval Maximal Force test during the 20-repetition assessment: potentiation, maintenance, moderate loss, and significant loss. For the GE, the loss in maximum strength capacity began in the fourth repetition (GS_{4th}: 3.4%, ns, Effect Size: 0.09 *vs.* GE_{3th}: 1.6%; ns; ES: 0.06) and reached a statistically significant value in the twelfth repetition (GS_{12th}: 12.7%, P=0.03, ES: 0.35 *vs.* GE_{7th}: 12.5%; P=0.01; ES: 0.49). The number of repetitions at which the strength began to decrease depended on the subject's sport characteristic and performance level.

CONCLUSIONS: This study shows how an appropriate intra-set rest inclusion can significantly increase the work performed in every set without changing the muscle contraction characteristics, thus delaying muscle fatigue and maintaining the desired training objective.

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The rest between intervals (interval rest) is thought to be a fundamental parameter, along with intensity, number of sets and repetitions, exercise order, movement velocity, and training frequency, in the load design for strength development work.[1] The duration of the interval rest must ensure the maintenance of all of the following: the designed movement pattern for each exercise, the hold execution speed and the strength rate necessary to successfully perform a sportive gesture.[2] This requires control of the fatigue level, which will depend on the training goal (strength, power, hypertrophy, and muscular endurance), regardless of the source (neural, metabolic, or muscular) or load magnitude.[3]

Adapting the rest intervals between multiple sets (inter-set rest periods) to different training goals is a common strategy followed by athletes and coaches. Generally, it is accepted that loads higher than 90% of 1RM can improve the neuromuscular maximal strength but require large recovery times (5 minutes) between sets. Loads lower than 90% of 1RM with 3-5 minutes rest between sets allow greater strength increases. A minimum of 2-5-minute rest should be prescribed between sets when training for muscular power at medium loads, so that complete rest is achieved between sets. Incomplete recoveries (30-60 seconds) between consecutive sets are used for muscular hypertrophy, and shorter rest intervals (*e.g.*, 30 seconds) are used for muscular endurance.

Over the last several years, many athletes (bodybuilders, power lifters, weightlifters, etc.) have rediscovered the previous strategy of including rests with different durations between every set repetition (intra-set rest).[4, 5] The intra-set method is also known as intra set rest-pause training or cluster training, and the rest duration changes depending on the training goal.

This training strategy aims to maintain kinetic and kinematic variables during the whole set. In addition, it allows for the replenishment of phosphate stores, decreases the anaerobic lactic pathway and controls fatigue levels. As a result, the athlete can maintain higher velocities and high strength rate production and increase the number of efficient repetitions in every set.

Traditionally, an intra-set rest ranges from 10-30 seconds, although it can also last 60 seconds when the load intensity is maximal or when the athletes' strength level is low or moderate. Willardson[3] suggests different uses of intra-set training strategies, depending on the training aim. The basic method could be to include recovery between each set repetition or between every two or three set repetitions. In the first case, 20-second rest are proposed, while 50-second recoveries are indicated for double sets and 100-second recoveries are indicated for triples. Additionally, intra-set rest can be used with the traditional recovery model (inter-set rest) (*e.g.*, 8 continued repetitions, adding 2-3 repetitions with pauses between them).

These intra-set times are often proposed for training at submaximal loads and for enhancing either power or muscular hypertrophy. The ideal inter-repetition recovery time when working at maximal loads for maximal neuromuscular strength development is unknown. Thus, the purpose of this paper was to analyze and discuss how interval rest between repetitions during intra-set training using maximal isometric loads can affect the ability to repeat maximal contractions for subjects with different performance levels and strength training experience.

Materials and methods

Experimental approach to the problem

The ability to repeat maximal isometric strength in 20 university students who were physically active for at least the three years prior to the study was assessed. Subjects were organized in two groups depending on the characteristics of the sport for which they trained. Dependent variable was the ability to repeat maximal isometric strength. Independent variable was the duration of the intra-set rest.

Subjects

Two groups of athletes with differing physical characteristics were compared: endurance *vs.* strength. Ten subjects (Strength Group: 8 bodybuilders, 1 weightlifter, and 1 discus thrower) were regular strength practitioners (age: 26.1±3.5 years; height: 172.0±5.3 cm; weight: 79.9±12.1 kg; body fat: 10.1±2.6%) and the other 10 (Experimental Group: 7 athletes; 1 cyclist; 2 triathletes) were regular endurance practitioners (age: 21.3±4.5 years; height: 172.4±4.1 cm; weight: 60.0±4.6 kg; body fat: 8.1±2.2%) (Table I).

TABLE I.—*Mean and SD of the morphological parameters which characterized the subjects. Also P-value and ES are shown.*

Morphological parameters	Group GS	Group GE	p-value	Difference (%)
Height (cm)	179.9±12.1	172.4±4.1	Ns	0.02%
Body weight (kg)	79.9±2.1	60.0±4.6	P=0.003	24.9%
Body Fat (%)	10.1±2.6	8.1±2.2	Ns	19.8%
Lean mass total (kg)	64.1±11.2	48.2±3.8	P=0.002	24.8%
Lean mass legs* (kg)	22.3±3.5	17.1±1.4	P=0.007	23.3%

*Sum of both legs' values.

All of the subjects read and signed an informed consent document and were asked not to participate in any resistance exercise other than that prescribed for the current study. The experimental procedures were approved by the Ethics Committee of the State of Rio de Janeiro Federal University, in accordance with the regulations of resolution 196/96 of National Council on Ethics in Human Research and in accordance with the Declaration of Helsinki.

Procedures

Initially, over the course of two weeks, all of the subjects were introduced to the materials and the assessment criteria. Then, on four different days and with a minimum of 72 hours for recovery, their physical fitness (aerobic test, anaerobic test and dynamic strength) and body composition were assessed in a laboratory, and they performed the maximal isometric strength repeated test.

AEROBIC TEST

An incremental exercise test was used to assess the subjects' aerobic capacity (VO_{2max} and anaerobic threshold). After a warm-up (6 minutes at 40 W and 70 RPM on a cycle ergometer and subsequent rest of three minutes), the tests were performed on a cycle ergometer (Monark 818, Varberg Sweden) beginning at 40 W (90 RPM) and increasing by 40 W every 3 minutes. Respiratory gas analysis was conducted with a CPX-D Medical Graphics Corporation system (St Paul, Minnesota, USA).

BLOOD LACTATE ANALYSIS

The lactate in blood samples from fingertip capillaries was analyzed using a YSI 1500 Sport Lactate Analyzer (Yellow Spring Instrument, OH, USA), which was calibrated to 15 and 30 mmol/L lactate solutions (YSI 2328 y YSI 1530). The blood lactate analyzer was calibrated after every five blood samples. The measurements were performed at the end of the "*all-out*" test: a 90 RPM cadence on the cycle ergometer with a load individualized to be 10% above the maximal load reached by each subject during the incremental test. Once the test was finished, the lactate concentration was assessed after 2.5, 5, 7.5, and 10 minutes to examine the subjects' maximal response after anaerobic exercise.

MAXIMAL ISOMETRIC STRENGTH REPEATED

For the IMF assessment, two cell loads (Sesotec 3132) that were connected by chains and muskets to a weight-lifting Salter bar (20 kg) were used. The barbell was placed into a machine specifically designed to avoid antero-posterior plane displacements. To assess the subjects' ability to repeat maximal efforts, 20 repetitions of 5 seconds were performed in a half-squat position (90º in the hip and knee joints) with 1-minute rests. The maximal isometric strength was determined at the highest value reached by the subject, regardless of the repetition to which it corresponded. During the IFM test, the knee and hip flexion angles were controlled using a Lafayette goniometer to adapt the initial test position to each participant. Between repetitions, the subject left the bar standing in front of it for up to 15 seconds before the next repetition was performed. After this, the subject stood under the barbell for 5 seconds before the next lift. Once the rest was initiated and after repetition numbers 5, 10, 15 and 20 were performed, a blood test was performed to assess the lactate concentrations.

DYNAMIC STRENGTH

The dynamic strength was assessed in two high jump tests: a squat jump and a repeated countermovement jump (60 seconds). The jumping tests were evaluated with a contact platform connected to a digital timer (±0.001 second accuracy) (Ergo-jump Bosco System), which recorded the flight time and the contact time of each single jump.

BODY COMPOSITION ASSESSMENT

The total and regional body composition were assessed by dual-energy x-ray absorptiometry (DXA) (Hologic QDR-1500, Hologic Corp., software version 7.10, Waltham, MA, USA). The lean mass and body mass were calculated using whole-body scans. Whole-body scans were submitted to a regional analysis to determine arm, leg and trunk lean mass, bone mass, and body fat mass. The results shown in this paper are from the values in the leg region, including the foot and the lower and upper leg. The lean mass is the total mass minus the bone and fat mass.

Statistical analysis

The statistics shown in this paper were calculated using the Statistical Package for Social Sciences (SPSS, v. 17.0 for WINDOWS; SPSS Inc., Chicago, IL, USA). The descriptive statistics used were the mean, standard deviation and mean error for comparing the two groups based on morphological and functional parameters. The groups were assessed using Student's *t*-test. ANOVA was used for repeated measures to detect significant differences between the repetitions in the strength test and in the blood lactate concentrations. Prior to the comparisons, normality tests (Shapiro-Wilks) and homogeneity tests (Levene test) were performed. The values are reported as the mean±SD and values $P \leq 0.05$ were considered significant. Additionally, in recognition of the potential effects of the sample size and variance, the effect size (ES) was assessed to enhance the comparison of strength changes between repetitions, following a protocol proposed by Rhea (6) and using reference values for recreationally trained subjects (trivial: <0.35; small: 0.35-0.80; moderate: 0.80-1.50; large: >1.50).

Results

Tables I, II show the morphological parameters and the statistical (mean and SD) performance parameters (IMF and VO_{2max}) that were used to characterize the groups. In addition, probability values to determine the meaning between analyzed groups are shown.

The two performance groups were most clearly differenciated by their morphological parameters (body weight and muscle mass).

Table II shows the relevant differences in all of the performance analyzed parameters, except for the dynamic strength endurance test (5.1%; NS). Two parameters were found to have the largest differences, thus best explaining and differentiating the groups: IMF (60.9%; P=0.000) and VO_{2max} (30.6%; P=0.000). These values explain the significant differences that were observed between the two groups in the lean total mass and in the lean leg mass. The IMF values in the GS were correlated to values of SQ (r=0.87), LM_T (r=0.88) and LM_L (r=0.76). In contrast, for the GE, only a moderate negative correlation was found between VO_{2max} and body fat (r=-0.43).

Tables III, IV show each group's IMF evolution (mean, SD) during the repeated maximal strength 20-repetition test. In the case of the GS, the maximal strength was produced from the 3rd repetition on and reached statistically significant values from the 12th repetition on. For both cases, the existence of four different IMF phases during the 20 maximal repetitions is noted. In the first phase, an improvement in the performance phase is observed, which indicates a postactivation potentiation (PAP) state. It has been previously suggested that the inclusion of high-intensity resistance exercise during warm-up routines before strength and power training, during competitive events or during training loads with appropriate recovery may induce short-term improvements in motor performance.[7] At the maximal strength level, the second phase tends to remain at a stable level or decrease slightly. In the third test phase, the IMF levels decrease, without significant changes. However, these decreases must be taken into consideration when designing training loads. The number of repetitions for which the strength losses are not particularly relevant changes for each group, depending on the group members' characteristics and their performance levels. In constrast, during the 3rd test phase, the repeti-

TABLE II.—*Mean and SD for the morphological and performance parameters that allowed us to characterize the subjects. The percentage difference between the groups (GS vs. GE) and the statistical probability (P-value) for the differences are also included. Also P-value and ES are shown.*

Performance parameter	Group GS	Group GE	P value	Difference (%)
Isometric maximal strength * (N)	2175.6±490.8	851.5±206.5	P=0.00	60.9%
Squat jump (cm)	42.2±4.2	33.3±3.8	P=0.025	21.1%
Repeated countermovement jump ** (%)	50.7±5.7	48.1±1.3	NS	5.1%
VO_2 max (ml/kg/min)	46.8±4.9	67.4±4.9	P=0.000	30.6%

*IMF corresponds to the maximal value reached at any of the 20 repetitions.
**The loss of the jump ability between 0-15 seconds and 45-60 seconds in the CMJ repeated test.

TABLE III.—*Mean and standard deviation of the maximal isometric strength (Newtons) for each repetition in the strength sample group (GS). Also p-value and ES are shown.*

Repetitions N.	MIS-Strength Group (GS)			
	Mean-SD (N)	P-value	ES	%
1ª	1897.1±726.2	NS	0.16	5.9
2ª	1892.7±755.6[a]	NS	0.17	6.1
3ª	2015.8±728.7[a]	--	--	--
4ª	1947.3±723.9[b]	NS	0.09	3.4
5ª	1944.2±711.1[b]	NS	0.10	3.6
6ª	1866.9±658.4[c]	NS	0.20	7.4
7ª	1881.8±645.4[c]	NS	0.18	6.7
8ª	1900.6±659.6[c]	NS	0.16	5.7
9ª	1820.1±651.6[c]	NS	0.27	9.7
10ª	1873.0±654.8[c]	NS	0.20	7.1
11ª	1795.2±634.7[c]	NS	0.30	10.9
12ª	1760.8±609.6[d]	0.03	0.35	12.7
13ª	1664.9±619.6[d]	0.01	0.48	17.4
14ª	1694.6±617.7[d]	0.04	0.44	15.9
15ª	1714.9±621.4[d]	0.05	0.41	14.9
16ª	1622.9±606.2[d]	0.01	0.54	19.5
17ª	1640.1±620.9[d]	0.02	0.52	18.6
18ª	1665.0±604.5[d]	0.01	0.48	17.4
19ª	1740.5±621.9[d]	0.04	0.38	13.7
20ª	1708.6±599.6[d]	0.04	0.42	15.2

[a] Postactivation potentiation phase; [b] phase in which the strength losses are ≤5%; [c] phase in which the strength losses show no significant differences; [d] phase in which the strength losses show statistically significant differences of $P \leq 0.05$.

TABLE IV.—*Mean values and standard deviation of maximal isometric strength (Newtons), for each repetition, in GE. Also P-value and ES are shown.*

Repetitions nº	MIS-Endurance Group (GE)			
	Mean-SD (Newtons)	P-value	ES	%
1ª	792.2±189.5	NS	0.08	2.1
2ª	809.4±208.7[a]	--	--	--
3ª	796.6±228.4[b]	NS	0.06	1.6
4ª	784.0±199.3[b]	NS	0.12	3.1
5ª	771.2±180.0[b]	NS	0.18	4.6
6ª	732.1±183.9[c]	NS	0.37	9.6
7ª	708.1±182.4[d]	0.01	0.49	12.5
8ª	722.0±182.0[d]	0.01	0.42	10.8
9ª	722.1±182.0[d]	0.01	0.42	10.9
10ª	714.3±127.1[d]	0.05	0.46	11.8
11ª	707.6±137.6[d]	0.01	0.49	12.6
12ª	683.1±162.6[d]	0.00	0.61	15.6
13ª	703.4±195.3[d]	0.00	0.51	13.1
14ª	722.2±191.9[d]	0.03	0.42	10.8
15ª	729.0±228.6[d]	0.02	0.39	9.9
16ª	713.1±231.6[d]	0.00	0.46	11.9
17ª	715.5±167.2[d]	0.01	0.45	11.6
18ª	708.9±205.8[d]	0.00	0.48	12.4
19ª	722.6±218.7[d]	0.01	0.42	10.7
20ª	702.6±226.2[d]	0.00	0.51	10.7

[a] Postactivation potentiation phase; [b] phase in which the strength losses are ≤5%; [c] phase in which the strength losses show no significant differences; [d] phase in which the strength losses show statistically significant differences $P \leq 0.05$.

tion value at which the best mean strength value was reached showed signficant drops.

Table III shows the mean and the standard deviation of the maximal isometric strength (Newtons) for each repetition in the strength sample group (GS). In addition, significant values (P-value) for the mean differences and the effect size (ES) of each repetition regarding to maximal values and changes (%) are included.

For the GS, the maximal values are reached in the 3rd repetition (2015.8±728.7 N) with a 5.9 % increase compared to the first repetition. Beginning with the 12th repetition, the strength losses are statistically significant (12.7 %; ES:0.35). The lowest value occurred in the 16th repetition (19.5 %; ES:0.54). However, a decrease of more than 5% compared to the maximal values occurs beginning with the 6th repetition. This decrease is relevant to the practical application of designing training loads (Table IV).

This behavior was slightly different from the case of the GE: the maximal strength value occurred earlier (2nd repetition) and its increase was lower (2.1 %) than in the GS. In addition, significant power losses occur earlier (7th repetition) than in the strength group, although losses that were greater than 5% occurred in the same repetition (5th repetition) (Table V).

There were no significant increases in anaerobic lactic metabolism for GE: the lactate values were quite different from their maximal values (from 21-28%). A higher blood lactate rate (55-65% of the maximal values) was observed in the GS during the maximal strength repeated performance. For this group, the increases were statistically significant from the 5th repetition on, reached their maximal values from the 10th repetition on and moderately decreased during the remainder of the test.

Discussion

Muscular strength and power output are reduced with fatigue, especially during high-intensity activities that require heavy loads or sustained muscle contractions.[8, 9] However, in agreement with Vogiatzis *et al.*,[10] our study shows how intra-set rest allows significant increases in intra-set work without changing the muscular contraction characteristics. The rests delay muscle fatigue and allow for maintenance of the training aim.

It is well known that the interval rest magnitude between sets or repetitions is crucial when evaluating maximal strength because it must be individually adjusted to ensure the test's reliability. Some authors suggest that when working at loads of at least 90% 1RM, using recovery times of 1 to 2 minutes between repetitions is enough to achieve this aim.[11] When designing different orientation training loads, the same care must be taken. Moreover, a high number of repetitions must determine the number of repetitions without significant changes during performance (velocity, power, strength, etc.).

In our study we noticed how in both groups, the IMF showed a similar evolution, which could be organized into the four phases described in the results section: potentiation, maintenance, moderate loss and significant loss.

Muscular potentiation represents an improved functional capacity as a consequence of a prior contractile activity.[12] This entails both physiological changes (for example, the activation of synapses and motor engrams or the phosphorylation of the regulatory light chains of myosin) and functional changes (the creation of myosin and actin bridges) which affect the mechanical muscular response.

In this study, the potentiation phase (PA), except for some cases, was detected between the 1st or 2nd and the 4th repetition. In previous work, it was found that when working at a submaximal dynamic [13] or during maximal voluntary isometric contractions,[14] PA achievement is possible if an appropriate recovery is included between each repetition. However, the manner and intensity in which PA is manifested will depend on the strength

TABLE V.—*Shows the mean values and SDs for both groups (GS and GE) before the maximal strength test and after the 5th,10th,15th and 20th repetition. In addition, the maximal lactate concentration values (La_{Max}) are shown for the same subjects, after performing the maximal test (all-out) on the cycle ergometer.*

	La_{Pre}	La_{Rep5}	La_{Rep10}	La_{Rep15}	La_{Rep20}	La_{Max}
GS – lactate (mmol/L)	2.1±0.6	6.8±2.3*	7.9±2.8[1]	7.6±2.9[1]	7.3±3.1[1]	12.1±1.6
GE – lactate (mmol/L)	2.0±2.2	2.6±4.4	2.5±4.3	2.9±4.2	3.1±4.2	11.4±1.7

*P≤0.001.

and training levels of the assessed subjects and on their muscle characteristics and twitch composition.[15] Some authors even suggest the possibility that some subjects may not respond to PA.[16] Variations in PA, the moment at which higher intensity was reached and interindividual differences were also detected in this study by analyzing the repetition number at which the subject reached IMF. In our study, higher and longer PA was shown in GS subjects than in GE subjects.

From the PA and on, the IMF remains stable or slightly decreases in the following repetitions: 4th-5th for the GS and 4th-6th for the GE. This implies a state of pre-fatigue that progressively affects the mechanical muscular response and its capacity to generate strength.

In subsequent repetitions, the IMF decreased progressively until the strength loss showed significantly different values ($P \leq 0.05$) as a consequence of accumulating fatigue when performing repetitions (GS: 12th-20th, GE: 17th-20th). Muscular fatigue depends on the type, duration and intensity of the exercise, on the type of muscular fiber recruited, on the level to which the subject has trained and on the environmental conditions in which the exercise is carried out. Muscular fatigue is a complex phenomenon with multifactorial origin (peripheral and central fatigue) that is not fully understood and is clearly manifested in a mechanical response as a reduction in the maximal strength of voluntary contractions. Peripheral fatigue refers to exercise-induced processes that trigger a reduction in strength levels as a consequence of alterations that take place beyond the neuromuscular nexus (for example, changes in pH, the accumulation of the products of muscular metabolism, etc.) while central fatigue refers to a progressive exercise-induced failure of voluntary activation of the muscle as a consequence of alterations in the nervous system (for example, alterations to neurotransmitters).[9]

During maximal isometric exercise, muscular blood flow is affected in a significant way.[17] Because of reduced blood flow in the active muscular zone, the cell receives insufficient oxygen and nutritive substances. In strength training, these deficiencies are particularly significant among all potential fatigue causes. Thus, muscular strength and fatigue have a linear and inverse relationship with intramuscular pressure and muscle blood flow.[18] This is especially relevant when performing maximum isometric contractions. Under these circumstances, a decrease in the induced strength can also be caused by an impairment within muscle fibers and particularly by changes in Ca^{2+} [19] handling and changes in the neuromuscular system efficiency.[20] However, fatigue will depend on the load used in the task and magnitude.[21]

During maximal isometric muscular contractions, similar to the ones used in the present study, intramuscular pressure in the main worked muscles (*e.g.*, quadriceps) increased significantly. Pressure compresses the microcirculation vessels, which completely or partially reduces the blood flow to active muscles. For each repetition, this compression causes a rapid ejection of venous blood and restricts arterial inflow into the muscle. Consequently, we can conclude that isometric exercise causes important ischemia during the contraction. This situation is inverted during the exercise rest phase, when there is a significant increase in blood flow towards the muscle,[22] which can even be greater than the blood flow values at rest before exercise.

Both muscular activity and decreased blood flow towards the active zone lead to energy depletion, metabolite accumulation, increased metabolic acidosis (pH reduction), altered potassium homeostasis, decreased Ca^{2+} release, decreased sensitivity in myofilaments to Ca^{2+} and a lower membrane potential. This acute response alters the excitation-contraction coupling and the strength production capability.[23]

The main energy source for muscle fiber contraction during brief and intense work is phosphagen: adenosine triphosphate (ATP) and creatine phosphate (PCr). The amount of hydrolyzed ATP increases significantly. Thus, a muscle cell could significantly reduce its ATP reserves in just 2 or 3 seconds if there were not parallel regeneration pathways for energy consumption: adenylate and creatine kinase reactions [24] and purine nucleotide cycle activation.[25] However, PCr represents the most immediate reserve for ATP rephosphorylation and the fast rate of PCr resynthesis would make the most significant contribution to energy generation during the first minute of recovery. Full PCr recovery occurs between the 2nd min and the 4-6th minutes,[26] although the recovery can differ between individuals depending on the training level, muscle volume and composition and accumulated fatigue level. The resynthesis speed is not linear; it is biphasic, exhibiting fast (<20 seconds) and slow (>170 seconds) recovery components [27] that must be taken into consideration when programming the rest pauses to minimize lactic anaerobic metabolism effects.

Generally, consistent or repeated high-intensity muscular work is associated with an increase in adenosine diphosphate, inorganic phosphate (Pi), adenosine monophosphate, xanthine, hypoxanthine, ammonia, uric acid and lactic acid;[28] it is also related to a reduction in the stored oxygen levels in muscle (myoglobin) and blood (hemoglobin). ATP levels and PCr decrease at the end of each repetition.[29, 30]

These effects are especially concentrated when performing high-intensity exercise or when the blood flow is completely occluded. Consequently, it is not possible to achieve an appropriate level of PCr muscular rest,[31] especially in fast-twitch fibers, which are the most used muscle structures when performing work at very high intensities. Therefore, significant use of anaerobic lactic pathways is required.

However, adequate rest intervals would allow for partial restoration of muscle accessibility to oxygen, thus allowing more oxidative glycogen degradation with low muscle and blood lactate concentrations. In contrast, if recoveries between series or repetitions are not appropriate, anaerobic glycolysis activation will become higher, increasing the blood lactate levels, decreasing muscular pH and, as a consequence, negatively affecting muscular response. Metabolic acidosis, with high ADP and Pi accumulation, modifies the way in which motor units are recruited and reduces actin and myosin bridge fixation time [32] and myofilament ATP turnover.[33]

As shown in this study, the use of long recovery periods between repetitions (1 minute) ensures sufficient recovery and allows optimal performance without increasing metabolic acidosis. However, the anaerobic glycolysis response depends on the muscle volume and dominant fiber type. Hunter *et al.*[34] note that during intense exercise, having more active muscle mass causes greater increases in intramuscular pressure, blood flow occlusion, metabolite accumulation, heightened metaboreflex responses and oxygen delivery to muscle impairment with a higher anaerobic lactic metabolism. These effects are also evident in our study, where we observed that the GS subjects had higher lean body mass (P=0.002) than the GE subjects. Additionally, as shown in Table V, the GS subjects had a blood lactate rate that was 50-60% higher than the GE's (Rep-5: 43.9%, P=0.032; Rep-10: 46.0%, P=0.04; Rep-15: 44.6%, P=0.004; Rep-20: 42.5%, P=0.02).

A priori, we could thus conclude that intense and early fatigue occur among subjects that are heavier and have more muscle mass (*e.g.*, GS). However, this fatigue was not observed in our study. Thus, we can contemplate how including rest between repetitions does not cause high metabolic fatigue, which allows for a specific resistance enhancement (ability to repeat strength) between the stronger and well-trained subjects in this capacity. The predominant muscle fiber type should be taken into consideration but were not assessed in this study. Individuals with a higher proportion of fast-twitch muscle fibers should be capable of greater strength production; however, they are also usually less able to sustain strength production for extended periods of time.

Conclusions

In summary, moderately trained subjects can increase their strength and ability to repeat loads at maximal intensities incorporating recoveries between sets. However, pauses must be determined individually paying attention to athletes' experience and training level, size, body weight and muscular composition. Long recovery times (<1 minute) mitigate the impact of lactic anaerobic metabolism and the resulting decrease of the lactate rate in blood. The present study shows that one minute rest between repetitions appears to be sufficient to ensure recovery, guaranteeing significant increases in the work between sets at high loads without changing the training aim.

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