Acute and Long-term Responses to Different Rest Intervals in Low-load Resistance Training

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Abstract
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We investigated the effects of low-load resistance training to failure performed with different rest intervals on acute hormonal responses and long-term muscle and strength gains. In the acute study, 14 participants were assigned to either a short rest (S, 30 s) or long rest (L, 150 s) protocol at 40 % one-repetition maximum. Blood samples were taken before and after the workout. Both groups showed significant ($p < 0.05$) increases in growth hormone and insulin-like growth factor 1 immediately post-workout. In the longitudinal study, the same protocol as in the acute study was performed 2 times per week for 8 weeks by 21 volunteers. Both groups showed significant increases in triceps (S: 9.8±8.8 %, L: 10.6±9.6 %, $p < 0.05$) and thigh (S: 5.7±4.7 %, L: 8.3±6.4 %, $p < 0.05$) cross-sectional area. One-repetition maximum also significantly increased for the bench press (S: 9.9±6.9 %, L: 6.5±5.8 %, $p < 0.05$) and squat (S: 5.2±6.7 %, L: 5.4±3.5 %, $p < 0.05$). In conclusion, our results suggest that acute hormonal responses, as well as chronic changes in muscle hypertrophy and strength in low-load training to failure are independent of the rest interval length.

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Introduction
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In the search for optimal resistance training (RT) protocols to maximize muscle hypertrophy and strength gains, RT parameters such as training load and rest intervals between sets have been widely investigated [4, 24, 29]. A recent meta-analysis showed that high-load resistance training (RT) (> 65 % 1RM) and low-load RT (< 60 % 1RM) performed to failure both lead to muscle hypertrophy and strength gains without significant differences among groups [31]. Indeed, previous studies demonstrated that low-load RT (~30 % 1RM) can produce similar muscle gains compared to high-load (~80 % 1RM) RT in the long run [14, 23, 29]. Further, low-load RT (30 % 1RM) was found to promote a greater prolonged duration of post-exercise muscle protein synthesis compared to high-load RT (90 % 1RM) [3]. It has been hypothesized that the key to results is training to muscular failure based on the premise that muscle fiber recruitment is similar irrespective of the load provided a comparable level of effort is exerted [6]. Alternatively, strength gains seem to be load related [24, 29] as larger strength increases

have been reported with high- as compared to low-load RT [9, 24, 29].

Research investigating the optimal length of rest intervals between sets for maximizing muscular adaptations has been contradictory. While some studies conducted with medium to heavy loads indicate superior hypertrophic effects for longer rest intervals [4, 30], others show either no differences [1] or even improved body composition and performance [33] with shorter rest intervals. These discrepancies may be due to differences in the experimental designs. Indeed, studies supporting the benefits of longer rest intervals were performed partially or totally to failure [4, 30], resulting in different training volumes that potentially confounded results. On the other hand, studies that have observed similar or even superior results for the short rest protocols were volume-matched experiments [1, 33]. When RT is performed to failure, longer rest intervals will lead to increased time under tension and volume, translating into greater mechanical stress. On the other hand, shorter rest intervals should lead to increased metabolic stress, which may promote muscle hypertrophy via improved muscle fiber recruitment, intrinsic responses and muscle

swelling [28]. Acute growth hormone (GH) responses have been shown to be related to metabolic stress in RT [10] and might therefore be used as indicator for the level of metabolic stress experienced in a given RT protocol.

The effect of rest interval length on strength increases also remains equivocal. Buresh et al. [4] found similar strength increases in both conditions while Schoenfeld et al. [29] reported greater 1RM increases for the long vs. the short rest group (squat: 15.2 vs. 7.6%, bench press: 12.7 vs. 4.1%). Thus, further research is needed to determine the relationship between rest interval length and strength gains.

The purpose of the present study was to compare the acute and long-term effects of different rest intervals on muscle and strength gains during performance of low-load RT to failure. We hypothesized that shorter rest interval lengths would enhance the hypertrophic response by differentially affecting mechanical and metabolic stress and muscle damage. On the other hand, since strength seems to be load-related [9,29], we speculated similar strength increases in both conditions.

Methods
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Study design

The study comprised 2 separate experiments. In experiment 1, we measured the acute hormonal changes (growth hormone (GH), testosterone (T) and insulin-like growth factor 1 (IGF-1)) in response to 2 low-load RT protocols (4 sets of bench press and 4 sets of back squat) performed to failure with different rest intervals. In Experiment 2, we compared muscle and strength gains after 8 weeks of 2 weekly RT sessions (short vs. long rest intervals). This study was approved by the Ethics Committee of the Nippon Sports Science University in accordance with the international standards of the Declaration of Helsinki for Human Research [13].

Experiment 1
Subjects

14 young athletes (18–22 years) volunteered to participate in this study. The short rest group (S, n=7, age; 20.0±0.6 years, height; 169.4±1.9cm, weight; 64.5±2.0kg) trained with 30-s rest intervals while the long rest group (L, n=7, age; 20.0±0.4 years, height; 170.5±2.0cm, weight; 64.0±2.1kg) trained with 150-s rest intervals. Participants were not involved in RT for at least 2 years before the experiment but were regularly exercising for different sports and agreed to refrain from participating in any other formal strength training for the duration of the experiment. All participants also refrained from participating in any other strength training for the duration of the experiment. Participants were informed about the potential risks of the experiment and gave their written consent to participate in the study. The sample size was calculated (GPower 3.1, Dusseldorf, Germany) [8] a priori as follows: Effect size f=0.25, α err prob=0.05, power=0.8. The required total sample size was estimated to be n=10 (n=5 for each group).

Resistance training

Training in both groups consisted of 4 sets of bench press followed by 4 sets of squats. The participants were told to perform each repetition with a fast movement (1 s) on the concentric and a slow movement (2 s) on the eccentric component at 40% 1RM. Each set was carried out to muscular failure,

operationally defined as the inability to perform another concentric repetition while maintaining proper form. One-repetition maximum (1RM) measurements for the bench press and back squat were assessed one week prior to the experiment and the training load was then established at 40% 1 RM for each exercise in both groups. The only variable differing among groups was the rest interval duration between sets (30 s for the S group and 150 s for the L group). RT sessions were supervised by qualified personal trainers in order to ensure correct execution of the exercises.

Measurements

Blood collection and analyses: Blood samples were drawn from the antecubital vein with a winged static injection needle before (B), immediately after (P0), 15 min after (P15), 30 min after (P30) and 60 min after (P60) the RT sessions. The subjects were instructed to have their last meal no later than 4h before the start of training. After blood collection, the vials were kept at room temperature for 30–60 min. The blood was then centrifuged at 3 000 RPM for 5 min and plasma was immediately deep frozen at −80°C. The blood samples were subsequently sent to a laboratory (SRL Inc. Tokyo, Japan) for analysis (GH, T, IGF-1). GH and T were assessed via the electrochemiluminescence method and IGF-1 via immunoradiometric assay.

Total training volume: The total training volume (expressed as the total number of repetitions performed across the 4 sets) for each exercise was recorded during a single RT session.

Statistical analyses

Data are displayed as mean±SD. We used 2-way analysis of variance (ANOVA) (time x groups) to test for significance and post-hoc Bonferroni tests when appropriate (SPSS for Macintosh version 22). We also calculated the effect size (ES) [7] for each group. The significance level was set at $p < 0.05$.

Experiment 2
Subjects

21 young athletes (18–22 yrs) volunteered to participate in this study (S group: n=11, age; 20.2±0.3 years, height; 169.3±1.0cm, weight; 64.7±2.0kg, L group: n=10, age; 20.2±0.5 years, height; 166.5±1.1cm, weight; 59.5±1.7kg). Participants were not involved in RT for at least 2 years before the experiment but were regularly exercising for different sports and agreed to refrain from participating in any other formal strength training for the duration of the experiment. All the participants were informed about the potential risks of the experiment and gave their written consent to participate in the study. The sample size was calculated (GPower 3.1, Dusseldorf, Germany) [8] a priori as follows: Effect size f=0.25, α err prob=0.05, power=0.8. The required total sample size was estimated to be n=16 (n=8 for each group).

Resistance training

The RT program was the same as in Experiment 1 with training carried out 2 times per week for 8 weeks.

Dietary adherence

Participants were asked to maintain their usual eating habits during the period of the experiment. In order to equalize food intake after RT, the participants ingested a protein shake composed of 22.9 g of protein, 5.0 g of carbohydrates and 2.2 g of fats

(Protein Whey 100, Dome corporation Tokyo, Japan) immediately after each workout.

Measurements

Muscle CSA: Participants underwent magnetic resonance imaging (MRI) (AIRIS II, Hitachi, Ltd., Tokyo, Japan) scans of the right upper arm (biceps, brachialis and triceps) and thigh (quadriceps and hamstrings) muscles during the week before the start of the RT program and the week after the last training session (week 9). To ensure accuracy of the measurements, markers filled with water were placed exactly at half-distance of each participant's upper arm (measured from the lateral epicondyle of the humerus to the acromion process of the scapula) and thigh (measured from the lateral condyle of the femur to the greater trochanter of the quadriceps femoris), respectively. The following parameters were used to acquire 20 axial scans: repetition time/echo time, 460/26 ms; field of view 20 cm, phase/frequency, 320; slice thickness, 3 mm; gap, 10 mm. The images showing the markers were then analyzed via imageJ (National Institutes of Health) and the square area of each cut was calculated twice by the same investigator and the mean value was used for calculations. A reliability test showed an intraclass correlation coefficient (ICC) of >0.9 for our CSA calculations.

Muscle strength: 1RM tests were conducted during the week before and after the training period for the bench press and back squat based on recognized guidelines [12]. A team of qualified trainers supervised the tests and assured correct execution of the exercises. The squat was considered a success if the trainee reached parallel and the bench press was considered a success if the barbell was in a full lock-out position with head, upper back and buttocks on the bench and both feet flat on the floor [29]. After 2 warm-up sets (50% 1RM×5reps, 60–80% 1RM×2–3 reps), 1RM was assessed within 5 repetitions with a 3-min rest between sets for each participant. ICC was >0.9 for 1RM measurements.

Total training volume: The total training volume (expressed as the total number of repetitions performed in the 4 sets) for each exercise and RT session was recorded for the 8-week study period (16 RT sessions in total).

Statistical analyses

Statistical analysis was performed using the same model as Experiment 1.

Results

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Experiment 1
Blood analysis

Both groups showed significant ($P < 0.05$) increases in GH and IGF-1 immediately post workout (◘ **Fig. 1**). 2-way ANOVA analysis showed main effects (time) for GH (F=15.35, p<0.001) and IGF-1 (F=18.05, p<0.001). No significant between-group differences were observed for each hormone.

Total training volume

Significant differences among groups for the average number of repetitions during a single RT session could be observed for both exercises in sets 2–4, with marked reductions in volume noted in the S group compared to the L group (p<0.01) (◘ **Table 1**).

Experiment 2

A total of 21 participants completed the study (11 participants in S and 10 participants in L). Average participation rate was >90% in both groups.

Muscle CSA changes (◘ Fig. 2, ◘ Table 2)

The triceps CSA in the S group changed 9.8±8.8% (p<0.05) compared to 10.6±9.6% (p<0.05) for the L group. The thigh CSA changed 5.7±4.7% (p<0.05) in the S group compared to 8.3±6.4% (p<0.05) for the L group. Although no significant between-group differences were observed with respect to CSA changes in the thigh, the ES favored longer compared to shorter rest periods (0.93 vs. 0.58, respectively).

Muscle strength

Both groups significantly increased bench press 1 RM (S: 9.9±6.9%, L: 6.5±5.8%, p<0.05) and back squat 1RM (S: 5.2±6.7%, L: 5.4±3.5%, p<0.05) (◘ **Fig. 2**, ◘ **Table 3**). No significant between-group differences were observed with respect to muscle strength changes.

Total training volume

Total training volume for each RT session and exercise was significantly greater (p<0.05) in the L group as compared to the S group (◘ **Fig. 3**).

Discussion

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Our study is the first to directly compare the effects of different rest intervals on acute hormonal responses and long-term muscular adaptations using low-load RT to failure with all other variables kept constant. We showed that both short- and long-rest intervals between sets in low-load RT to failure induce similar acute hormonal responses immediately post-workout (Experiment 1). In regard to longitudinal responses, both groups displayed marked increases in muscle CSA and strength without significant differences noted between groups (Experiment 2).

Previous research observed elevated physiologic responses including stress markers (plasma epinephrine, norepinephrine, dopamine, cortisol, lactate, heart rate and RPE) after heavy load RT (10RM) with short rest intervals (10 s) [15]. However, it is unclear whether the high load or the extremely short rest intervals triggered these physiologic responses. In line with previous studies investigating hormonal responses in low-load RT with short rest intervals (30 s) [25], we noted significant acute increases in GH and IGF-1 immediately post-exercise in both groups without differences between conditions. In our study, GH and IGF-1 increased between 33.7–33.8 and 27.7–29.9 ug/l, respectively, compared to 8.82 and 30 ug/l, respectively in previous research [25]. The differences in GH increases might be due to the nature of exercises used in each study (bench press and back squat vs. leg press). However, the same level of increases in both groups in our study point to similar metabolic stress levels regardless of rest intervals during low-load RT. From these results we can hypothesize that rest interval duration is not a major factor affecting metabolic stress with low-load RT performed to failure. Further, the increases observed in our study for GH and IGF-1 (~30 ug/L) are similar or higher compared to the results of previous research investigating the effects of medium- to high-load RT on acute hormonal responses (~20–30 ug/L) [16,26,34,35]. Since no significant post-exercise
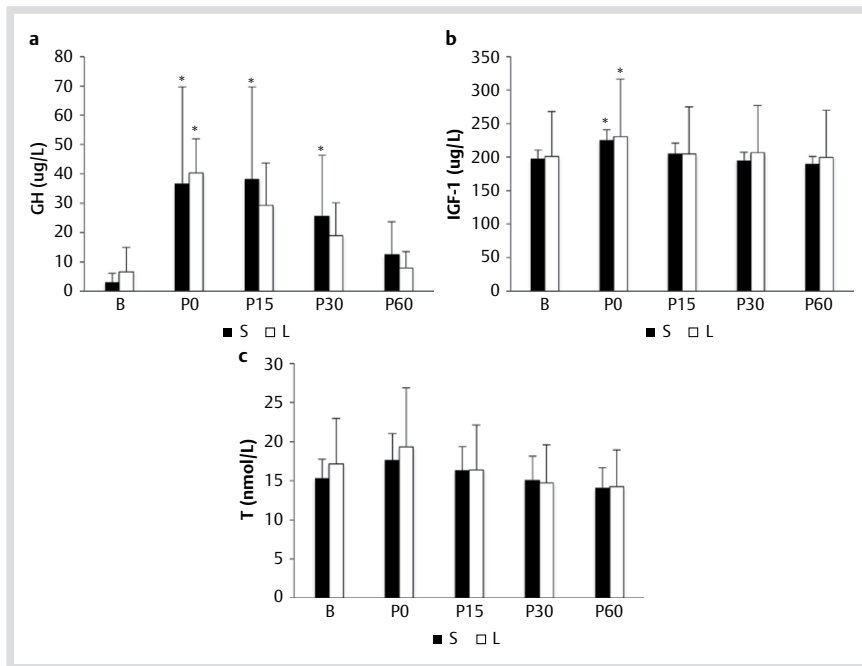
Fig. 1 Average changes (±SD) in **a** serum growth hormone (GH), **b** insulin-like growth factor 1 (IGF-1) and **c** testosterone (T) before (B) and immediately after (P0), 15 min (P15), 30 min (P30) and 60 min (P60) after a single bout of RT.
* $p < 0.05$ vs. B

Table 1 Average total number of repetitions.

	Bench press	Back squat
S	76.6±9.6	95.03±4.3
L	117.7±26.6 *	147.45±6.83 *

Mean total number of repetitions (±SD) for the bench press and back squat.
* $p < 0.05$ significant difference compared to S

increases were observed for T in any of the groups, our results confirm past results showing that higher-load RT may be necessary to induce higher acute T increases [2,11,16] whereas low-load RT might be superior for inducing GH and IGF-1 increases. It should be noted that a larger sample size might have improved the accuracy of our results. Further, our results with regard to metabolic stress could have been improved by adding measurements of acute stress and muscle damage such as plasma creatine kinase, muscle soreness, ratings of perceived exertion, thigh circumference/swelling and counter-movement jump height.

Our results support the results of previous studies showing that low-load RT can be an effective means to promote muscle hypertrophy [3,23,24,29]. We observed a CSA increase of 9.8 % (S) and 10.6 % (L) for the triceps. Previous research showed similar tricep CSA increases with low-load RT (9.8 %) after 6 weeks of bench press RT with 180-s rest between sets [24] and a 5.2 % increase after 8 weeks of RT with 90-s rest [29]. Our study showed thigh CSA increases of 5.7 % in the S group and 8.3 % in the L group. Although no significant between-group differences were noted with respect to CSA changes, the ES clearly favored L vs. S (0.93 vs. 0.58, respectively) indicating that shorter rest intervals may blunt muscle growth in the lower body during low-load RT. Previous research demonstrated a 9.5 % increase in muscle thickness after 8 weeks of low-load RT with 90s rest between sets [29] and 6.8 % CSA increase after 10 weeks with 120-s rest [22]. Interestingly, the aforementioned studies showing significant hypertrophic increases with low-load training all used either MRI or ultrasound imaging to assess changes in muscle growth.

On the other hand, studies showing no increases following low-load RT to failure employed muscle biopsy to assess hypertrophy [5,32]. As previously shown, single-site muscle biopsy may not reflect whole muscle hypertrophy [20], which in turn may have confounded the ability to detect significant changes in CSA over time. Moreover, it is possible that sarcoplasmic hypertrophy (increase of noncontractile proteins and fluid) might contribute to the CSA increases observed with low-load RT [19,27].

Even though a direct comparison between studies above cannot be made due to differences in study methodologies, the body of research indicates that low-load RT to failure produces similar hypertrophic increases at a variety of different rest interval lengths. Our direct comparative study confirmed these results, demonstrating that low-load RT to failure resulted in marked CSA increases regardless the length of rest between sets. Indeed, the similar hormonal responses between rest interval conditions indicate comparable levels of metabolic stress, which may have mediated muscle gains.

Previous studies showed superior CSA increases with longer rest intervals (1 vs. 3 min) [30] and decreased myofibrillar protein synthesis and intracellular signaling with shorter rest intervals (1 vs. 5 min) [21] in medium- to high-load RT [21]. However, our results suggest that findings may be different for low-load RT. The combination of short rest periods and high-load RT might hinder the ability to reach a volume threshold necessary to trigger anabolic pathways [36,37]. Specifically, the associated fatigue from short rest intervals results in a drop-off in the number of repetitions performed on subsequent sets that may conceivably result in an insufficient stimulus to maximize hypertrophic gains. In our study, the number of repetitions for the S group did not fall below 12 repetitions even in the last set. We propose that with low-load RT, the repetition threshold necessary to trigger a maximal anabolic response can be achieved throughout the sets even though rest intervals are very short, potentially via heightened metabolic stress. Therefore the length of rest intervals might affect muscle hypertrophy more in high-load RT compared to low-load RT, particularly in the upper body musculature.
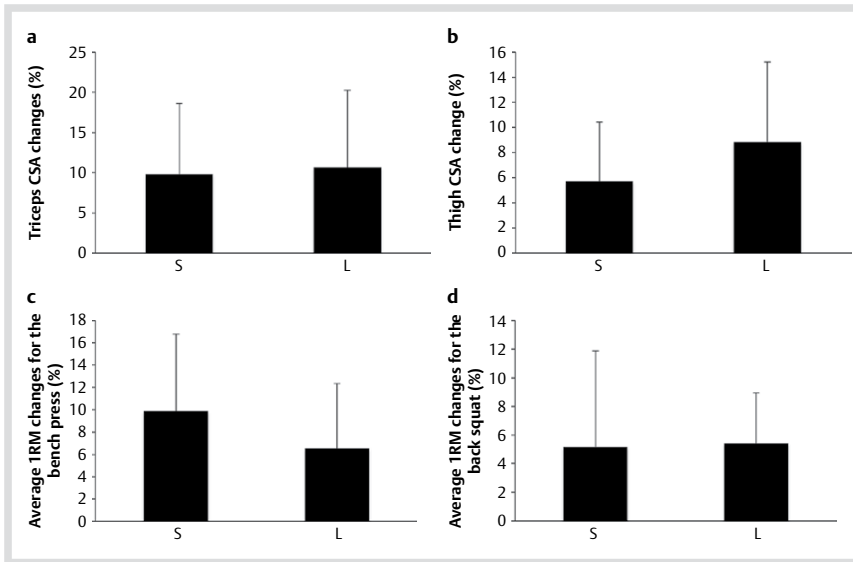
Fig. 2 Average cross-sectional area (CSA) changes (±SD) for the triceps **a** and thigh **b** muscles and average 1 RM changes (±SD) for the bench press **c** and back squat **d** after 8 weeks of short rest (S) or long rest (L) RT. * p<0.05 vs. pre.

Table 2   Average CSA increases.

	L group (*n* = 10)		ES	S group (*n* = 11)		ES
	Pre-	Post-		Pre-	Post-	
Triceps CSA (cm²)	5.3 ± 1.2	5.8 ± 1.1 *	0.43	6.6 ± 1.1	7.2 ± 1.2 *	0.52
Thigh CSA (cm²)	37.5 ± 3.7	40.7 ± 3.2 *	0.93	41.0 ± 3.4	43.3 ± 4.4 *	0.58

Mean cross-sectional area (CSA) ± SD. ES = Effect size. * p<0.05 significant change compared to pre-value

Table 3   Average 1RM increases

	L group (*n* = 10)		ES	S group (*n* = 11)		ES
	Pre-	Post-		Pre-	Post-	
Bench press 1RM	64.4 ± 10.7	69.5 ± 11.2 *	0.47	69.1 ± 12.0	76.1 ± 12.3 *	0.58
Back squat 1RM	113.2 ± 16.6	118.9 ± 17.3 *	0.34	119.1 ± 19.2	125.5 ± 17.0 *	0.35

Mean one repetition maximum (1RM) ± SD. ES = Effect size. * p<0.05 significant change compared to pre-value

Previous research indicates a positive association between training volume and muscle hypertrophy in moderate- to high-load RT. In a recent meta-analysis, Krieger [17, 18] found a clear dose-response relationship whereby multiple set training was associated with a 40% greater hypertrophy-related ESs compared to one set in both trained and untrained subjects. On the surface, the results from our study would seem to indicate that this dose-response relationship between training volume and muscle hypertrophy does not exist with low-load RT. However, it remains possible that because of the large number of repetitions performed in each condition, the volume of training reached a threshold whereby further increases were unnecessary to maximize the hypertrophic response. Further, comparable hormonal responses indicating similar metabolic stress in both groups were recorded. In this regard, both groups seem to have achieved enough volume under similar metabolic stress conditions, leading to similar muscle gains. Moreover, the greater ES values seen in L vs. S with respect to quadriceps CSA suggests that reductions in volume from short rest periods may have had a negative effect on lower body hypertrophy. This hypothesis warrants further investigation.

It has been previously observed that low-load RT (25–35RM) increases endurance more as compared to high load RT (8–12RM) with the same rest interval length (90s) for both groups [29].

However rest interval length (1 vs. 3 min) did not affect endurance improvements with high-load RT (8–12RM) [30]. During the 8 weeks of RT, both groups showed a trend for increased fatigue resistance; however, the elevations were more pronounced in the L group, especially for the squat exercise. We cannot speculate as to why the trend for endurance was higher in the L group, although our data supports previous results showing that low-load RT enhances local muscular endurance.

Strength increases have been shown to be load dependent [24,29]. The relationship between strength increases and rest interval during high-load RT is controversial. Some studies found no relationship between rest interval length and strength gains [1,4], while some others found a positive association [30]. Our results (bench press: 9.9% (S), 6.5% (L); back squat: 5.2% (S), 5.4% (L)) showed similar results to previous low-load training protocols for the bench press (2%, 90s rest – 8.6%, 180s rest) and back squat 1RM increases (8.8%, 180s rest) [24,29] without significant between-group differences. These results confirm that compared to high-load RT, in which increases of 21% [24] for the bench press and 19.6% [29] for the squat have been reported, low-load RT produces suboptimal albeit significant strength increases in both the upper and lower body. Consistent with previous research for high-load RT [1,4], our results showed that the length of rest intervals does not affect strength gains in low-load RT.
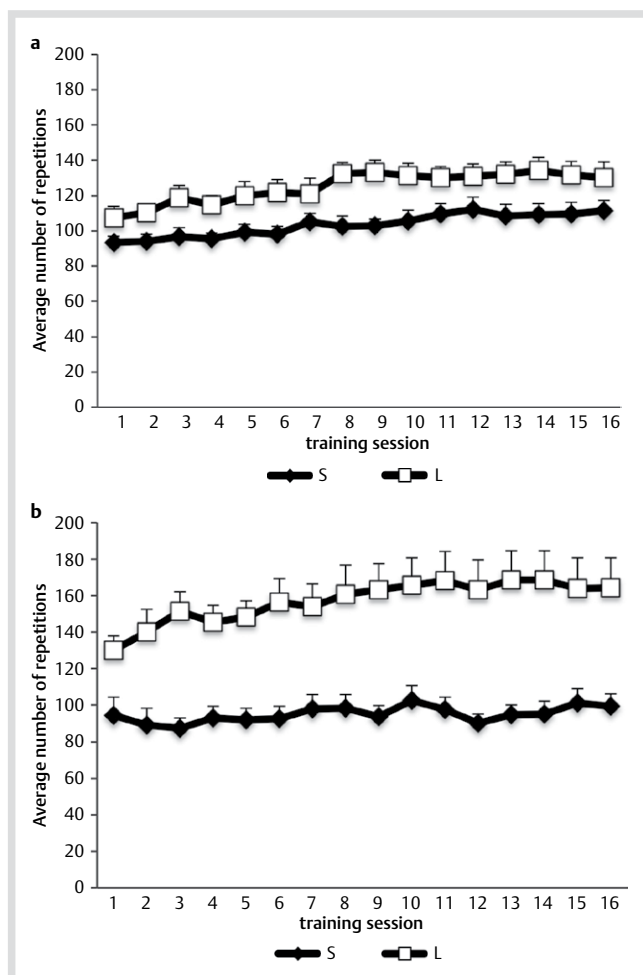
Fig. 3 Average number of repetitions (sum of 4 sets) (± SD) for the bench press **a** and back squat **b** exercises for each resistance session for the period of 8 weeks (total of 16 RT sessions).

In conclusion, the results of our study demonstrate that different rest interval lengths in low-load RT lead to similar muscle hypertrophy, strength and acute hormonal responses (GH, IGF-1). Marked gains in muscle mass can be achieved with short duration low-load RT as long as each set is performed to failure. Further, even though strength gains are suboptimal compared to high-load RT, low-load RT to failure can improve strength regardless of the length of the rest intervals.

Conflict of interest: The author have no conflict of interrest to declare.

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