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ORIGINAL RESEARCH

Acute effects of different load intensities and rest intervals on muscle strength endurance in male college athletes

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Abstract

The purpose of this study was to compare the effects of different load intensities with rest intervals between sets on heart rate, rating of perceived exertion (RPE), power output, and blood lactate concentration during a squat strength endurance training protocol. A total of 4 sets of strength endurance tests were performed on 15 national Level 2 or above athletes with different load intensities (30% of 1 repetition maximum (1RM), 50% 1RM) and different rest intervals between sets (1 min, 2 min), 20 reps per set. Mean power (P-mean), mean heart-rate (HRmean) and RPE variations during the exercise were collected by using a linear position transducer, heart rate monitor, and Borg 6–20 scale. Besides, finger blood was collected before and after the exercise, and analyzed by using a blood lactate analyzer. HRmean, P-mean and RPE values were significantly higher at 50% 1RM load intensity than at 30% 1RM ($p < 0.01$), HRmean was significantly higher at 1 min rest interval than at 2 min between sets, while P-mean was significantly higher at 2 min rest interval than at 1 min between sets ($p < 0.05$); at 30% 1RM loading intensity, blood lactate concentrations were significantly higher at the completion of exercise for the 1 min rest interval between sets than for the 2 min ($p < 0.01$). However, at 50% 1RM loading intensity, blood lactate increased similarly at the completion of training in multiple sets, independent of the rest interval between sets. From a practical point of view, the results suggest that a 1 min rest interval between sets may be sufficient in a strength endurance training protocol when the load intensity is 30% 1RM. However, when the load intensity is 50% 1RM, we suggest that a 2 min rest interval between sets is required for optimal recovery and maintenance of power output.

Keywords

Male; Athlete; Strength endurance; Rest interval between sets; Load intensity; Blood lactate

1. Introduction

Strength training has become very popular and is now considered an essential component of every athlete's conditioning program [1]. For athletes, strength training has been shown to contribute to improvements in sports performance [2]. It is shown that different training programs can induce physiologically specific adaptations in the muscle, and stimulate various acute responses or long-term adaptations in the muscle, which can lead to the changes in the internal structure and internal environment of the muscle, thereby effectively promoting muscle hypertrophy, and the growth of explosive power and muscular endurance [3–5]. Among them, muscular endurance, also known as strength endurance, refers to the ability of the neuromuscular system to resist fatigue under larger loads (>30% of the maximal force) in the form of static or dynamic conditions [6]. According to the American College of Sports Medicine, the main methodological variables of strength endurance training are the intensity, number of sets and repetitions, rest intervals between sets, order of exercises, movement velocity, and training frequency [2, 7].

Due to the effect of the principle of specificity, muscles will adapt according to the type of training stimulus applied [8]. And regarding muscle adaptation, it can be maximized by the manipulation of resistance training variables [9]. One such variable is the time taken between sets, commonly known as the rest interval. To date, several studies have investigated the effects of different rest interval lengths on muscular adaptations. Some studies have shown that longer rest periods promote greater increases in muscle strength and hypertrophy in young resistance trained men [9]. In addition, Willardson and Burkett concluded that different rest intervals between sets significantly affected the number of repetitions during exercise when performing strength endurance training [8, 10].

In strength endurance training, the application of appropriate loads and timely recovery make training more effective [11].

When training for muscular endurance, lifting a relatively low amount of resistance and performing a relatively high number of repetitions per set have been recommended [2, 12, 13]. Because of the relatively low amount of resistance lifted, it has been theorized that short rest intervals of 1 min or less allow the muscles sufficient recovery between sets [2, 14]. However, previous studies have shown that the total number of repetitions completed during a workout decreases when consecutive sets of the bench press, leg press, and squat were performed with a 1 min rest interval between sets [15, 16]. Therefore, additional research is required concerning what rest periods are needed between sets of strength endurance training for optimal performance. When training for muscular endurance, the rest interval must be long enough to sustain a high number of repetitions over consecutive sets, but also short enough to stimulate increased mitochondrial and capillary density and buffering capacity, all important adaptations related to muscular endurance performance [13, 17, 18].

In regard to limitations in existing literature, we designed this present study to investigate the acute effects of different load intensities and rest intervals between sets on the lower limb strength endurance in male college athletes. It should be noted that the body requires rest in order for the muscles to recover and re-stock their enzymatic capacity to perform exercise [19], and longer rest intervals allow for lower levels of metabolic acids [20]. Our hypothesis was that a 2 min rest interval between sets would allow greater power output and lower metabolic impact (*i.e.*, lower lactate response) when compared to a 1 min rest interval between sets in a multi-set squat strength endurance training protocol.

2. Materials and methods

2.1 Participants

Fifteen male track and field athletes at national Level 2 or above were recruited from the College of Physical Education of Ningbo University according to the following criteria (Table 1). The sample size for this study was calculated based on G*Power software (G*Power 3.1.9.7 for Windows, Heinrich Heine University, Dusseldorf, Germany) [21]. The following design specifications were taken into account: α = 0.05; (1–β) = 0.9; effect size f = 0.25; test family = F test and statistical test = repeated measures analysis of variance (ANOVA), within-within interaction. Therefore, the sample size estimated according to these specifications was 11 subjects. At the same time, considering sample attrition, four additional athletes were recruited for this study, making a total of 15 subjects.

Participants were excluded if they had any history of lower limb musculoskeletal injuries or immediate family members with cardiovascular and metabolic diseases and a family history of genetic predisposition to mental disorders. Participants were asked to maintain their normal dietary intake, to avoid any strenuous exercise in the 48 h before the experimental sessions, and avoid smoking, alcohol and caffeine consumption for 24 h before all tests.

2.2 Experimental approach to the problem

2.2.1 Experimental design

Weighted squat is the main training method for athletes to improve their leg strength, and in this experiment, the form of a 90° weighted squat at the knee joint was used. An elastic band was placed behind the participant throughout the experiment to keep the bar displacement and knee angle (~90) constant on each squat repetition. According to the previous studies on strength endurance training, it is believed that the load weight of 30%–70% of the maximal force, and the exercises of more than 20 times can be used as the main training method to develop the strength endurance of athletes [22, 23]. Studies have also shown that using low loads and multiple repetitions is more effective than high loads and fewer repetitions when performing strength endurance training [12]. Therefore, the experimental load was set to 30% 1RM and 50% 1RM, respectively, and the participants need to complete 4 sets of 20 weighted squats per set. According to the training theory of strength endurance, the optimal way to train strength endurance is to combine low resistance with high repetitions, supplemented by short intervals [24]. Studies have shown that multi-set training programs are very effective in improving local muscular endurance, with rest intervals of 1–2 min at high repetitions (15–20 or more) [12]. In this regard, in this experiment, 1 min and 2 min intervals were designated between sets, respectively. Finally, random drawing was arranged for all participants involved in the experiment, and a total of four tests (30% 1RM $\times$ 1 min, 30% 1RM $\times$ 2 min, 50% 1RM $\times$ 1 min, 50% 1RM $\times$ 2 min) were completed according to the order of draw. The time period between each of the four tests was 48–72 hours.

2.2.2 Performance assessments

The indicators selected for this study include mean heart-rate (HRmean), rating of perceived exertion (RPE), mean power (P-mean) and blood lactate. During exercise, the HRmean represents the magnitude of the exercise load, which is an objective indicator for monitoring and adjusting the intensity of training. The athlete's perceive exertion provides a method to measure exercise intensity, which is widely used in different fields, such as mass fitness and competitive sports to provide scientific guidance for strength endurance exercises [25]. For endurance events, the P-mean is closely related to sports performance [26]. Therefore, the P-mean can be used to reflect the body's exercise capacity and muscle work state. In addition, in strength endurance exercises, post-training blood lactate concentrations reflect the biochemical response of the organism to training intensity.

2.2.3 Procedures

First, each participant's one repetition maximum (1RM) strength during lower limb squat was assessed by using the Smith machine. The specific process of testing was consistent with the guidelines established by the National Strength and Conditioning Association [14]. In brief, participants performed a general warm-up before testing that consisted of light cardiovascular exercise lasting approximately 5–10 minutes. A specific warm-up set of the given exercise of 5 repetitions was performed at ~50% 1RM followed by 1 to two

TABLE 1. Basic information of athletes.

Age/(yr)	Height/(cm)	Weight/(kg)	BMI/(kg/m^2)	1RM/(kg)	Training years/(yr)
20.60 $\pm$ 0.73	180.80 $\pm$ 5.08	69.38 $\pm$ 6.04	21.23 $\pm$ 1.69	137.80 $\pm$ 16.48	7.93 $\pm$ 2.25

BMI: body mass index; 1RM: 1 repetition maximum strength for resistance training (squat).

sets of 2–3 repetitions at a load corresponding to ~60%–80% 1RM. Participants then performed sets of 1 repetition with increasing weight for 1RM determination. At the same time, provide 3 to 5 minutes of rest between each successive attempt. In addition, participants were required to reach parallel in the 1RM for the attempt to be considered successful as determined by the research team. All 1RM determinations were made within 5 attempts. The test procedure was performed by the same investigator, and 4 formal tests with different load intensities and rest intervals were performed after 48–72 hours of 1RM determination.

Subsequently, all participants' 4 formal tests were randomly assigned across the 30 testing days separated by at least 48–72 hours. Participants were paired based on random draws, and on the same day, some performed rest intervals of 1 min between sets at 30% 1RM, while others performed rest intervals of 2 min between sets at 50% 1RM, *etc*. Prior to the test, blood lactate quiet values and warm-up (5 min) values were collected. The warm-up of the participants consisted mainly of 5 minutes of low resistance cycling on a cycle ergometer (Monark 928E, Monark, Varberg, Sweden), followed by 3 minutes of stretching of the muscle groups. During the study, the participants wore a heart rate monitor (Polar H7, Polar Electro Oy, Kempele, Finland) to record their heart rate prior to warm-up as a resting heart rate value, and also that during each set of exercise. The power generated during the experiments was measured by a linear position transducer (GymAware PowerTool, Kinetic Performance Technologies, Canberra, Australia), mainly by attaching the device to a barbell bar in order to record time and the displacement at a frequency of 100 Hz. The configuration of the test assessment and calibration follows the manufacturer's specifications. In addition, the athletes' RPE of each set was recorded by using a session-rating of perceived exertion (Borg 6–20 scale, Sweden). The Borg 6–20 scale ratings of perceived exertion were performed once at the completion of each set of exercises.

Finally, at the completion of the four training sets, blood lactate was collected at 1, 3, 5 and 7 min, respectively [27, 28], and analyzed by using the blood lactate analyzer (Biosen C-Line, EKF Diagnostics GmbH, Barleben, Germany). Blood samples were collected from the fingertip area of participants' fingers.

2.3 Statistical analysis

Descriptive statistics (Mean $\pm$ standard deviation (SD)) were used to summarize basic information about the athletes, HRmean, RPE, power output and blood lactate data. The distribution of each variable was examined by using the Shapiro-Wilk normality test, and all tests were performed with the SPSS 26 (IBM Corp., Released 2010. IBM SPSS Statistics for Windows, Version 26.0., Armonk, NY, USA). For the HRmean, RPE, P-mean and blood lactate three-way repeated measures ANOVA 2 load intensity (30% 1RM and 50% 1RM) versus 2 group intervals (1 min and 2 min) versus moments (HRmean: quiet, Set 1, Set 2, Set 3, Set 4; RPE and P-mean: Set 1, Set 2, Set 3, Set 4; blood lactate: warm-up before exercise, after exercise) was used. The statistically significant interaction and main effects were further examined for difference based on the Bonferroni assessment. The sphericity assumption was tested using the Mauchly's test, and the Greenhouse-Geisser correction was conducted when the sphericity assumption was violated. Similar to other studies [29, 30], partial eta-squared ($\eta^2{}_p$) was used as a measure of effect size on the repeated measures ANOVA analysis and classified using the following scale (small: 0.01; moderate: 0.09; large: 0.25). All analyses were conducted based on α = 5%.

3. Results

3.1 Comparative analysis of HRmean under different load intensities and rest intervals between sets

Regarding the HRmean of each set, there was a strong interaction between load intensity and moment (F = 44.520; p < 0.001; $\eta^2{}_p$ = 0.761 (large)) (Fig. 1A). Regardless of load intensity, these athletes experienced higher HRmean in the latter sets ($Set_4 > Set_3 > Set_2 > Set_1 > Set_{Quiet}$; $Set_3 > Set_2 > Set_1 > Set_{Quiet}$; $Set_2 > Set_1 > Set_{Quiet}$; $Set_1 > Set_{Quiet}$) (*ps* < 0.001, all comparisons). HRmean at 50% 1RM load intensity was significantly higher than that at 30% 1RM at all moments (*ps* < 0.001) except for the quiet state (p = 0.181). In addition, there was a strong interaction between group interval and moment (F = 28.697; $p < 0.001$; $\eta^2{}_p$ = 0.672 (large)) (Fig. 1B). Regardless of the rest interval between sets, these athletes also experienced higher HRmean in the latter sets ($Set_4 > Set_3 > Set_2 > Set_1 > Set_{Quiet}$; $Set_3 > Set_2 > Set_1 > Set_{Quiet}$; $Set_2 > Set_1 > Set_{Quiet}$; $Set_1 > Set_{Quiet}$) (*ps* < 0.001, all comparisons). Except for the quiet state (p = 0.181) and the first set (p = 0.292), HRmean was significantly higher at 1 min of rest between sets than that at 2 min of rest between sets at all other moments (*ps* < 0.05). No interactions between load intensity and group interval or load intensity, group interval and moment were observed (p > 0.05).

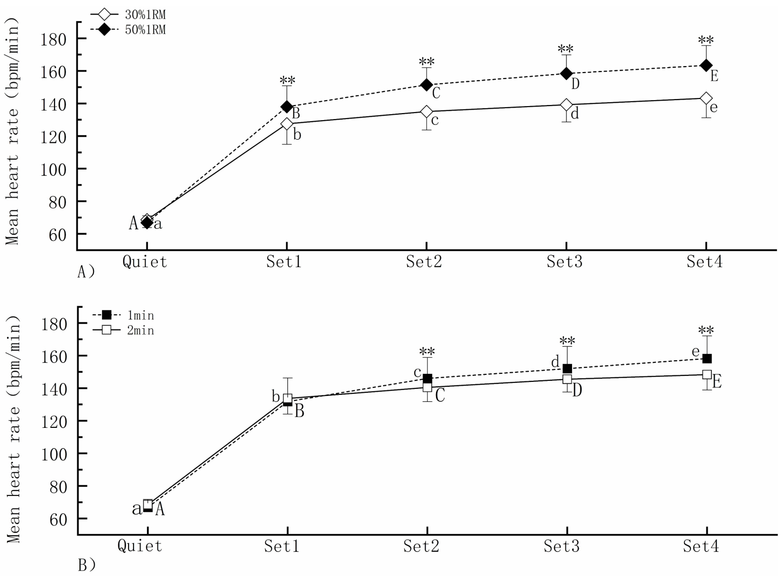

FIGURE 1. Variation of HRmean under different load intensities and rest intervals between sets. (A) Upper-case letters refer to the 50% 1RM intra-group comparisons and lower-case letters stands for the 30% 1RM intra-group comparisons; (B) Upper-case letters refer to the 2 min intra-group comparisons and lower-case letters stands for the 1 min intra-group comparisons; the presence of different letters between two comparisons represents the $p < 0.05$ and the same letter indicates $p > 0.05$; and "**" denotes a significant difference between load intensities (A) or rest intervals between sets (B) at each time point. 1RM: one repetition maximum.

3.2 Comparative analysis of RPE values under different load intensities and rest intervals between sets

Regarding the RPE of each set, there was a strong interaction between load intensity and group interval (F = 7.848; p = 0.014; $\eta^2{}_p$ = 0.359 (large)) (Fig. 2A). The RPE values at 50% 1RM load intensity were significantly higher than that at 30% 1RM ($ps < 0.001$), regardless of whether the rest interval was 1 min or 2 min between sets. At the same time, there was a strong interaction between load intensity and moment (F = 16.247; $p < 0.001$; $\eta^2{}_p$ = 0.537 (large)) (Fig. 2B). The RPE values at 50% 1RM load intensity were significantly higher than that at 30% 1RM ($ps < 0.001$) regardless of the moment. Regardless of load intensity, these athletes experienced higher RPE values in the latter sets (50% 1RM: $Set_4 > Set_3 > Set_2 > Set_1$; $Set_3 > Set_2 > Set_1$; $Set_2 > Set_1$. 30% 1RM: $Set_4 > Set_3 > Set_2 > Set_1$; $Set_3 > Set_1$; $Set_2 > Set_1$) ($p < 0.001$, all comparisons). No interactions among group interval and moment or load intensity, group interval and moment were observed ($p > 0.05$).

3.3 Comparative analysis of P-mean under different load intensities and rest intervals between sets

Regarding the P-mean of each set, there was a strong interaction between load intensity and moment (F = 3.910; $p <$ 0.037; $\eta^2{}_p$ = 0.218 (moderate)) (Fig. 3A). Only at 30% 1RM load intensity, athletes showed lower P-mean in the first set ($Set_1 < Set_2 < Set_3 < Set_4$) ($p < 0.05$, all comparisons), with no significant differences at other moments or load intensities. Regardless of that moment, the P-mean output at 50% 1RM load intensity was significantly higher than that at 30% 1RM ($ps < 0.001$). In addition, there was a strong interaction between group interval and moment (F = 4.143; $p < 0.025$; $\eta^2{}_p$ = 0.228 (moderate)) (Fig. 3B). In the third and fourth sets, the P-mean output was significantly higher at 2 min rest between sets than that at 1 min rest ($ps < 0.001$). No interactions among load intensity and group interval or load intensity, group interval and moment were observed ($p > 0.05$).

3.4 Comparative analysis of blood lactate concentration under different load intensities and rest intervals between sets

Regarding the blood lactate concentration at the completion of exercise, there was a strong interaction among load intensity, group interval and moment (F = 6.021; p = 0.028; $\eta^2{}_p$ = 0.301 (large)) (Fig. 4). To be specific, firstly, at the same load intensity with different group intervals, there was a strong interaction between group intervals and moment at 30% 1RM load intensity (F = 5.101; p = 0.040; $\eta^2{}_p$ = 0.267 (large)). Peak post-exercise blood lactate concentrations were significantly higher than the pre-exercise one ($ps < 0.001$), regardless of whether the rest interval was 1 min or 2 min between sets. At the same time, the blood lactate concentration at the completion of the exercise was significantly higher at 1 min rest interval than that at 2 min one rest interval between sets ($ps < 0.05$). Finally, at the same group intervals with different load intensities, there was a strong interaction between load intensity and moment at 1 min (F = 50.507; $p < 0.001$; $\eta^2{}_p$ = 0.783 (large)) and 2 min (F = 45.984; $p < 0.001$; $\eta^2{}_p$ = 0.767 (large)) rest between sets, respectively. The 50% 1RM loading intensity was significantly higher than the 30% 1RM blood lactate concentration at the completion of the exercise ($ps < 0.05$), regardless of the group interval.

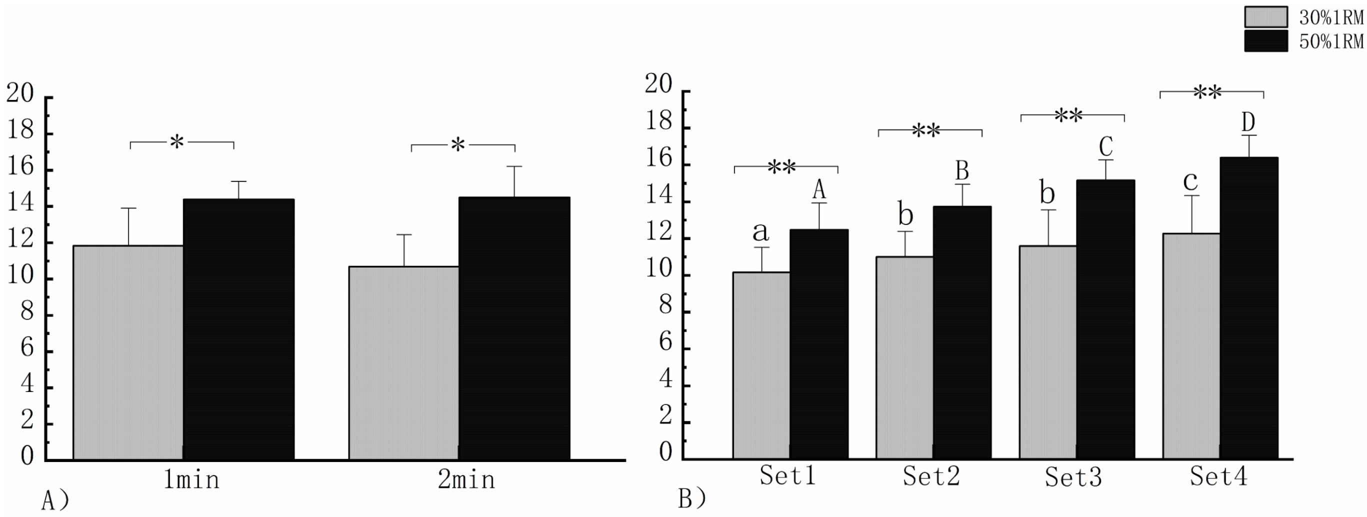

FIGURE 2. Variation of RPE values under different load intensities and rest intervals between sets. (A) "*" refers to the $p < 0.05$. (B) Upper-case letters stand for the 50% 1RM intra-group comparisons and lower-case letters indicates 30% 1RM intra-group comparisons; the presence of different letters between two comparisons represents the $p < 0.05$ and the same letter denotes $p > 0.05$; and "**" indicates a significant difference between load intensities at each time point. 1RM: one repetition maximum.

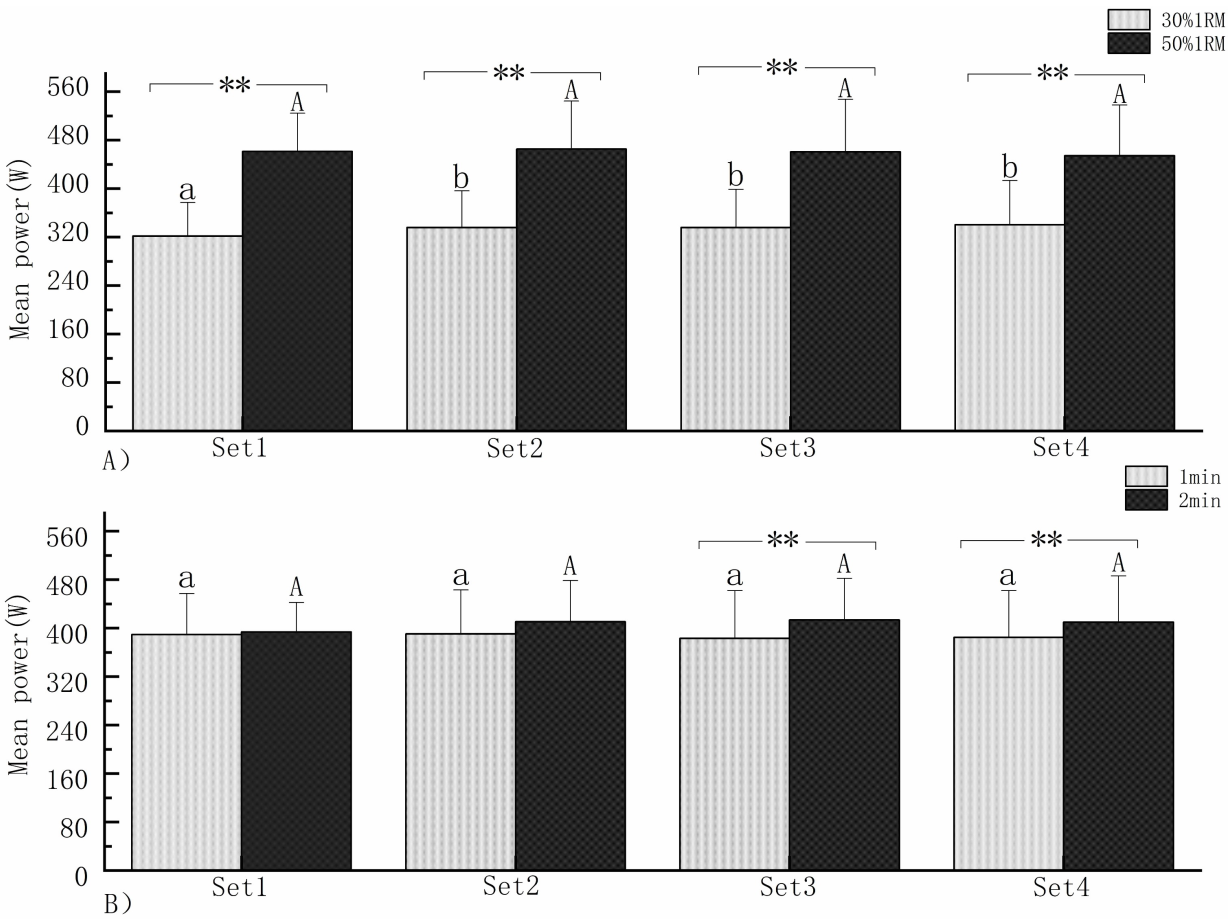

FIGURE 3. Variation of P-mean under different load intensities and rest intervals between sets. (A) Upper-case letters refer to the 50% 1RM intra-group comparisons and lower-case letters stands for the 30% 1RM intra-group comparisons; (B) Upper-case letters refer to the 2 min intra-group comparisons and lower-case letters stands for the 1 min intra-group comparisons; the presence of different letters between two comparisons represents the $p < 0.05$ and the same letter indicates $p > 0.05$; and "**" denotes a significant difference between load intensities (A) or rest intervals between sets (B) at each time point. 1RM: one repetition maximum.

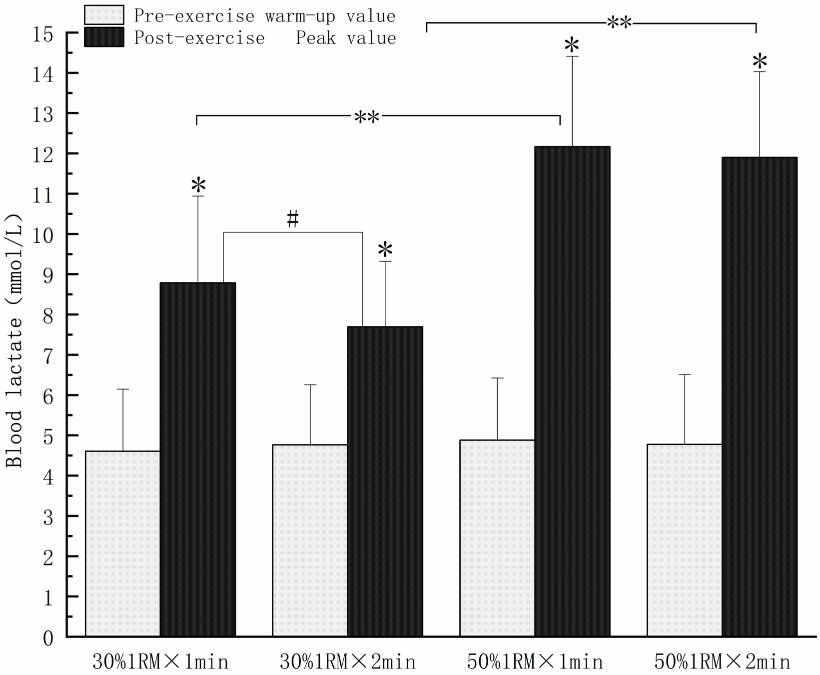

FIGURE 4. Variation of blood lactate concentration under different load intensities and rest intervals between sets. "*" refers to the significant difference between post-exercise peak and pre-exercise warm-up comparison ($p < 0.05$); "#" stands for the significant difference in the comparison between different rest intervals of the same load intensity ($p < 0.05$); and "**" represents the significant difference when comparing different load intensities at the same rest interval ($p < 0.05$). 1RM: one repetition maximum.

4. Discussion

Currently, the studies of rest intervals between sets in strength endurance training are both rare and controversial. On the other hand, few experimental studies have been reported on the effects of different load intensities combined with different rest intervals between sets on strength endurance training. Therefore, in this paper, the effect of different rest intervals (1 min *vs.* 2 min) between sets with different load intensities (30% 1RM *vs.* 50% 1RM) on strength endurance training by comparing the variations in HRmean, RPE and P-mean during exercise and the variations in blood lactate concentration at the completion of exercise was studied. We found that: (1) During exercise: load intensity affected HRmean, RPE and P-mean, while the rest interval between sets only affected HRmean and P-mean; (2) At the completion of exercise: lactate concentration in each experimental group was significantly higher than that before the exercise, and at the completion of low-load (30% 1RM) exercise, lactate concentration in the group with 1 min rest between sets was significantly higher than that with 2 min rest.

4.1 Influence of different load intensities and rest intervals between sets on HR and RPE values

It was found in this paper that the HRmean of each experimental group varied significantly when two-by-two comparisons were made at time points during exercise, and it was significantly increased at different load intensities and different rest intervals between sets, indicating that all the factors of load intensity and rest intervals between sets had certain effect on heart rate variation (Fig. 1). Similar studies have shown that at the constant load of 50% 1RM (1 min inter-set rest), a substantial increase in heart rate occurs after the first set of exercises, which maintains a steady upward trend in the subsequent exercises [23]. However, the results of this paper differed from some studies, which showed that load intensity (6RM versus 12RM) and number of sets had an independent effect on heart rate, respectively. In contrast, the rest interval factor between sets had no significant effect on heart rate [31]. The reason for the difference between the results of this paper and that of previous studies may lie in the fact that the load intensity and number of repetitions selected during exercise differed, allowing the rest interval factor between sets to have an effect on heart rate variation. One study showed that at the constant load of 70% 1RM (3 sets/8–10 reps), the heart rate of the group resting 1 min between sets was significantly higher than that of the group with the rest of 2 min between sets [32], while at the low load of 70%–10RM (3 sets/10 reps), there was no significant difference in heart rate at different rest intervals between sets (1/3 min) [33], showing that the rest intervals between sets had different effects on heart rate at different load intensities and repetitions. The previous focused more on the effects of load intensity, number of sets and repetitions on heart rate, rather than the effects of rest intervals between sets on heart rate [34–36].

Furthermore, we found that heart rate should gradually increase with the increase of the number of test sets (external load). However, due to the combined effect of load intensity and rest intervals between sets, the experimental groups showed higher heart rates in the first test set, and their group means failed to differ significantly. It should be noted that some studies have shown that the cardiovascular system responds more significantly to strength training than other training modalities [37]. Therefore, it was hypothesized in this paper that the heart rate of the subjects in each experimental group reached a plateau phase from the pre-excitation phase by rapidly crossing the ascending phase (rapid and short increase in heart rate) during the first set of training, and the average fluctuation of heart rate stabilized when the superimposed effect of load intensity and rest interval between sets were accompanied by an increase of the number of sets tested.

Regarding the RPE values, it was found in this paper that the RPE values at 50% 1RM were significantly higher than those at 30% 1RM, while there was no significant difference in RPE values at different rest intervals between sets, indicating that load intensity exerts certain influence on the variations of RPE values (Fig. 2). The results of this paper are similar to those of previous studies, indicating that RPE values are positively correlated with load intensity (percentage of maximal repetitions: % 1RM) when the total training volume (number of sets $\times$ repetitions $\times$ load) and rest interval between sets are kept constant [38]. However, the rest intervals in this paper were not constant, but the lack of significant differences in ratings of perceived exercise suggests that the accumulation of fatigue-inducing substances (H+ ions) may have been similar at high repetitions of relatively low intensity loading. It is possible that significant differences in relation to the RPE occur only when submaximal repetitions are performed with a predetermined percentage of 1RM. In this case, the higher absolute load may be reflected in a higher RPE which is due to greater neural recruitment [39].

4.2 Influence of different load intensities and rest intervals between sets on P-mean

This paper showed that the P-mean of the experimental groups exhibited no significant difference when two-by-two comparisons of time points were made during exercise, indicating that the P-mean during strength endurance training generally tended to be stable (Fig. 3). The results of previous studies showed similar conclusions, showing almost no decrease in power during exercise when performing 40% 1RM (5 sets/16 reps) squat tests on men with a training background [40]. However, in one study, it was found that at the constant load of 75% 1RM, the maximal P-mean output occurred during the first set of the test, and continued to decrease with the number of sets [41]. This further suggests that the variation in power fluctuations may be related to the load intensity.

In addition, it was found in this paper that the P-mean of 50% 1RM was significantly higher than that of 30% 1RM at all time points, indicating that load intensity has an impact on power output. The results of this paper are in agreement with those of the previous studies. Based on Meta-analysis, Guo Chenggen from China found that in squat training, moderate load intensity (30%–70% 1RM) was beneficial for power output compared with low intensity ($\leq$30% 1RM) [42]. In other studies, squat testing was conducted on a force platform, showing that 50% 1RM was beneficial for optimal power output [43]. It was also found in this paper that the P-mean of the group resting for 2 min between sets was significantly higher in the third and fourth sets than that of the group resting for 1 min between sets, which indicates that in addition to load intensity, the rest interval factor also had certain influence on the P-mean output, especially in the latter stage of strength endurance training. Besides, the long rest interval between sets was beneficial to power output. The results of this paper are in agreement with those of some studies showing a significant decrease in mean power in the group with 40 s of rest between sets compared with the group with 160 s of rest between sets in a 4 sets/10 repetitions knee flexion/extension test using isometric dynamometry [44, 45]. And it was found in other studies that there was a significantly higher training effect in the group with 80 s of rest between sets compared with the group with 20 s of rest between sets in strength endurance training with a higher number of repetitions [46]. However, some studies also showed that a short rest interval of 40 s between sets is sufficient to maintain the strength endurance training effect at the constant load of 40% 1RM [47]. This further suggests that short rest intervals are suitable for training at lighter loads, and long rest intervals are beneficial for stabilizing power output during the later stages of strength endurance training.

4.3 Influence of different load intensities and rest intervals between sets on blood lactate

In this paper, it was found that the blood lactate concentration at the completion of exercise was significantly higher than that before the exercise in all experimental groups, and the lactate concentration at the completion of the exercise reached above 6.0 mmol/L (Fig. 4), which exceeded the “anaerobic threshold” (4 mmol/L) level, indicating a certain effect on the phosphagen system (ATP-CP) and the anaerobic glycolytic system. Besides, the anaerobic glycolytic system exerted a major effect. In addition, there was a significant enhancement of the athletes’ energy metabolism capacity, especially on lactate energy supply. It was found in similar studies that in a squat test at constant load intensity 50% 1RM (5 sets/20 reps), blood lactate increased significantly to above the “anaerobic threshold” after the second set, reaching over 6.0 mmol/L after 5 sets of exercises [23]. It also showed that the intensity and duration of exercise training affects the accumulation of blood lactate production [48]. The effect of load intensity combined with rest intervals between sets on blood lactate in this paper was similar to that of different strength endurance training modalities, with a significant difference in blood lactate at the completion of exercise in the interval set (4 sets/25 reps, 4 min set interval) compared with the continuous set (1 set/100 reps, no interval) [49]. Therefore, we found that different load intensities combined with different rest intervals between sets during strength endurance training may have an influence on blood lactate.

It was found in this paper that at 30% 1RM, the lactate concentration at the completion of exercise was significantly higher in the group with 1 min rest between sets than in the group with 2 min rest (Fig. 4), indicating that at low loads, shorter rest intervals between sets are more likely to promote the involvement of the anaerobic glycolytic system, and contribute to the development of local strength endurance in athletes, while longer rest intervals between sets may create the conditions for higher training volumes and muscle hypertrophy. It was shown in similar studies that in the bench press test at the constant load of 60% 1RM (2/4/6 min rest between sets), blood lactate was significantly higher in the group with a 2 min rest interval after exercise, promoting the development of local muscular endurance [50]. And it was found that in the bench press test at the constant load of 70% 1RM (1/3/5 min rest between sets), lactate concentrations were significantly higher in the group with a 1 min rest interval than that in the group with a 3/5 min rest interval [19]. However, in this regard, the results of this paper also differ from that of the previous studies, in addition to the test movements, the intensity of the selected loads is different, no acute physiological responses have yet been found to be caused by arranging rest intervals between sets at low loads. In this paper, an experimental study of strength endurance training with low loads, multiple repetitions and the arrangement of different rest intervals between sets was included.

In addition, it was found in this paper that at the completion of exercise, the lactate concentration in the group with 1 min rest between sets was significantly higher than that in the group with 2 min rest at 30% 1RM. However, at 50% 1RM, there was no significant difference in blood lactate concentration at different rest intervals, indicating that the rest intervals between sets factor had the most significant effect on blood lactate at low loads. With the increase of the resistance, the effect on lactate concentration shifted from the rest interval between sets factor to the load intensity, and as the load intensity increased, the need for rest intervals between sets increased to some extent. It can be seen from studies that insufficient rest intervals between sets at high loads increase the reliance on the glycolytic system, resulting in the accumulation of metabolites and decreased blood pH [51]. Shorter rest intervals between sets affect the ability of muscles to sustain repetitive contractions and the total number of repetitions per set [52, 53], which further suggests that long rest intervals are required at high loads (50% 1RM) to ensure the completion of the training volume and training goals.

In summary, the rest interval between sets is one of the most important variables in strength endurance training. As for the rest interval between sets, Tudor-Bompa from Canada believes that the appropriate rest interval between sets is 0.5–1.5 min in the 40–50% 1RM/(20–30) repetitions × (3–5) set [54], while Professor Guo Jiaxing from China proposes that the appropriate rest interval between sets is 1–1.5 min in the <40% 1RM/(>12) repetitions × (3–5) set [55]. It can be seen that at the load intensity around 40%, the rest interval between sets is generally not more than 2 min. However, it this paper, it was found that the need for rest intervals between sets was reduced only for light loads (30% 1RM). At 50% 1RM and a high number of repetitions, long rest intervals between sets were arranged to ensure the ability to repeat the exercise for subsequent training. And short rest intervals between sets may lead to some discomfort, especially when performing squatting multi-joint exercises [56]. Therefore, affected by a variety of factors, the scientific arrangement of the rest interval between sets in strength endurance training can be used to improve the effectiveness and safety of training.

4.4 Limitations and future research

This study had some limitations. Firstly, we did not measure the time to complete each set of 20 reps at each load, so it was not possible to determine the work to rest ratio in the study. Another limitation was that the participants were homogeneous college male athletes, hence the results might not be applicable to females, non-athletes or more experienced athletes. Lastly, the present study focused only on the strength endurance of the lower limbs with the exercise of squats. In view of this, the upper limbs can be used as the research object in the future, using the exercise of bench press.

5. Conclusions

In strength endurance training, the load intensity and the rest interval between sets will have a certain effect on the cardiovascular and muscle function, and short (1 min) rest intervals between sets are more significant at a light load of 30% 1RM. In addition, from a practical point of view, the results suggest that a 1 min rest interval between sets may be sufficient in a strength endurance training protocol when the load intensity is 30% 1RM. However, when the load intensity is 50% 1RM, we suggest that a 2 min rest interval between sets is required for optimal recovery and maintenance of power output.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and analyzed in the current study are available upon reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

YMC and JJM—designed the research study. QW and RX—performed the research; wrote the manuscript. YZW and DXL—analyzed the data. ZXZ and XPC—provided help and advice on the rowing ergometer test design. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Ethics Committee of Ningbo University (approval number: TY2022024). All study participants provided informed consent.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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