The Effect of Different Rest Intervals Between Sets on Volume Components and Strength Gains

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Abstract

The purpose of this study was to compare squat strength gains and volume components when resting 2 minutes vs. 4 minutes between sets over multiple mesocycles. After the first squat 1 repetition maximum, 15 trained men were matched and randomly assigned to either a 2-minute (n = 7) or a 4-minute (n = 8) rest interval group. Each group performed the same training program, with the only difference being the length of the rest interval between sets. Subjects performed two squat workouts per week; one was labeled as Heavy and the other was labeled as Light. The squat workouts varied in the intensity, number of sets, and repetitions performed per set in a nonlinear periodized manner throughout each mesocycle. Differences in strength gains and volume components (the load utilized per set, the repetitions performed per set, the intensity per set, and the volume performed per workout) were compared between groups. Both groups demonstrated large strength gains; however, these differences were not significant between groups ($P = 0.47$). During all mesocycles, the 4-minute group demonstrated significantly higher total volumes for the Heavy workouts ($P < 0.05$). The findings of the present study indicate that large squat strength gains can be achieved with a minimum of 2 minutes' rest between sets, and little additional gains are derived from resting 4 minutes between sets. Therefore, athletes attempting to achieve specific volume goals may need longer rest intervals initially but may later adapt so that shorter rest intervals can be utilized without excessive fatigue, leaving additional time to focus on other conditioning priorities.

Key Words recovery, repetitions, fatigue, sets, intensity

Introduction

Over the last 20 years, resistance exercise research has focused on the intensity and repetition ranges that produce the greatest strength increases in different populations (2,3,14). However, one training variable that has received relatively little attention is the rest interval between sets (20). Including sufficient rest between sets is essential, particularly when the goal is maximal strength development (19). The muscles must be allowed a period of recovery to resynthesize intramuscular adenosine triphosphate and phosphocreatine and to clear fatigue-producing substances (8). This process allows for the restoration of force production, which is essential for maintenance of training intensity and repetitions within the range that allows for maximal strength development (4,6).

In the past, athletes may have used a subjective approach to determine the rest interval between sets, with the next set being performed when they felt ready. A general recommendation when training for maximal strength has been to rest 2 to 5 minutes between sets (2,3). However, prior research has demonstrated significant performance differences when utilizing longer versus shorter rest intervals during a workout (9,15,21–23). For example, Kraemer (9), Richmond and Godard (15), and Willardson and Burkett (21–23) demonstrated that when performing multiple sets with 50% to 90% of one repetition maximum (1RM), resting 3 or 5 minutes between sets allowed for significantly more repetitions versus resting 1 or 2 minutes. However, these studies were limited in design, and strength gains were not tracked to determine the significance of performing more repetitions.

Currently, few longitudinal studies exist that have compared strength gains with different rest intervals between sets. Robinson et al. (16) demonstrated that resting 3 minutes between sets resulted in greater squat strength increases versus resting 90 seconds or 30 seconds between sets in trained lifters. Pincivero, Lephart, and Karunakara (13) demonstrated that resting 160 seconds between sets resulted in greater peak torque in the quadriceps and hamstrings versus resting 40 seconds between sets in untrained lifters. These authors concluded that longer rest

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intervals resulted in greater strength gains as a result of higher training volumes.

However, the components that comprise training volume (i.e., sets, load, repetitions), were never fully broken down to determine the precise advantages. Furthermore, these interventions were relatively short, lasting 4 weeks (13) and 5 weeks (16). Clearly, an intervention is necessary to determine whether longer rest intervals are advantageous over longer time periods. Trained lifters may adapt so that volume goals and strength gains can be achieved with shorter rest intervals (12), which would allow more time to focus on other conditioning priorities. Therefore, the purpose of this study was to compare squat strength gains and volume components when resting 2 minutes versus 4 minutes between sets over multiple mesocycles.

Methods

Experimental Approach to the Problem

This study compared volume components and squat strength gains in two groups of trained lifters consequent to a training program that differed only in the amount of rest between sets. The squat was selected as the exercise to examine because of its extensive use for sports conditioning and functional relationship to sports skills (2,3). This study was split into three 4-week mesocycles. During week 1 of each mesocycle, 1RM squat testing was conducted to determine the load assignments for the succeeding 3 weeks (11). During each week, two squat workouts were performed, with one being labeled as Heavy and other being labeled as Light. This training program was based on an undulating or nonlinear periodized model used by Kraemer et al. (10), with the load and repetitions varying within each week (see Table 1).

Subjects

Fifteen trained men volunteered to participate in this study. All subjects were former high school and collegiate football players who had consistently performed the squat a minimum of 4 years for the purpose of gaining maximal strength and muscle mass. Therefore, the training programs of the subjects before the experimental training period were similar to the one used in the present study. The primary change to their training was the control of the rest interval between sets.

To qualify for inclusion, all subjects were initially screened using the Physical Activity Readiness Questionnaire (PAR-Q) and determined to be healthy. Before data collection, subjects were required to sign a consent form in accordance with human subject regulations. Subjects were permitted to continue with their usual upper body strength training throughout the intervention.

The lower body strength training, however, was strictly controlled so that subjects only performed the squat under the direct supervision of an experienced strength and conditioning professional. Subjects were not permitted to perform any other strength training exercises that involved the hip, knee, or trunk extensors (e.g., power clean, deadlift, leg press, lunge, leg extension, leg curl). Subjects were continuously monitored by phone calls and personal interviews to ensure compliance.

Procedures

Maximal squat testing was conducted before the study for the purpose of calculating work loads and matching subjects based on initial strength levels. All subjects had previously performed several squat 1RM tests and kept detailed workout logs for at least 6 months before the study. The most recently recorded squat 1RM was used to calculate warm-up sets for the pretest (11).

For the first warm-up set, 5–10 repetitions were performed at 40–60% of the most recently recorded squat 1RM. After a 1-minute rest and light stretching, three to five repetitions were performed at 60–80% of the most recently recorded squat 1RM. At this point, the resistance was increased to the same level or a level that was 5–10 pounds higher than the most recently recorded squat 1RM, and a maximal repetition was attempted. If that repetition was successful, 5–10 more pounds were added to the bar, and after a 5-minute rest, another maximal repetition was attempted (11).

This process was repeated until a failed attempt occurred. The 1RM was recorded as the last successfully completed attempt. Because the squat 1RM values after the first pretest were close to the squat 1RM values previously recorded in the workout logs, a second pretest was not deemed necessary before beginning the training. Subjects were matched based

Table 1. Squat study protocol (13 weeks).*

Week		
1	Squat 1RM test 1	
	Heavy workouts	Light workouts
2	8 sets; 70% 1RM; 11–15 repetitions	5 sets; 60% 1RM; 8 repetitions
3	7 sets; 80% 1RM; 6–10 repetitions	5 sets; 60% 1RM; 8 repetitions
4	6 sets; 90% 1RM; 3–5 repetitions	5 sets; 60% 1RM; 8 repetitions
5	Squat 1RM test 2	
6–8	Repeat mesocycle	
9	Squat 1RM test 3	
10–12	Repeat mesocycle	
13	Squat 1RM test 4	

*1RM = 1 repetition maximum.

on initial strength levels, then randomly assigned to either a 2-minute (n = 7) or a 4-minute (n = 8) rest interval group.

All squat 1RM tests and workouts were performed while standing inside a lifting cage. Subjects performed the squat with an Olympic bar that was supported across the upper portion of the trapezius muscle. The safety pins were adjusted in the lifting cage to allow each subject to descend to the point at which the tops of the thighs were parallel to the floor (3). If the subject was unable to complete a repetition, he was given assistance or instructed to set the weight on the safety pins.

For all Heavy and Light workouts, subjects reported to the university strength facility on a consistent day and time each week. The Heavy and Light workouts were separated by exactly 72 hours within each week (10,19,23). For the Heavy workouts, subjects were supervised individually, whereas for the Light workouts, subjects were supervised in groups. The rest interval between sets for the Heavy workouts was timed using a hand-held stopwatch (21–23). The stopwatch was started immediately after completion of each set. Subjects were given a verbal cue approximately 10 seconds before the next set was to begin. The rest interval between sets for the Light workouts was timed using a large clock mounted on the wall adjacent to the squat racks. Because supervision occurred in groups for the Light workouts, subjects were instructed to watch the clock to determine when the next set was supposed to be performed.

For each Heavy workout, subjects performed two warm-up sets for 10 repetitions with 50% and 75% of the load that would be used for that workout (21). All sets were performed at 70–90% of 1RM to volitional exhaustion, and subjects were encouraged to maintain repetitions within a prescribed range for each workout (4,14) (see Table 1). If the repetitions dropped below the prescribed range on any set, the load was lowered approximately 5% (4,6,10,12). For each Light workout, subjects performed one warm-up set for 10 repetitions with 50% of the load that would be used for that workout. All sets were performed at 60% of 1RM for eight repetitions, which prevented subjects from reaching volitional exhaustion. The purpose of the Light workouts was to allow additional training volume but not interfere with the recovery process (10). All volume components (sets, load, and repetitions) were recorded for each subject with exactness after each workout. The total volume per workout was calculated by multiplying the total number of sets by the mean load utilized and the mean number of repetitions performed per set (1).

Statistical Analyses

Subjects were required to complete 90% of the workouts to be included in the analysis. Independent *t*-tests were conducted to compare differences in age, height, and body mass between groups. The intraclass correlation coefficient between the squat 1RMs previously recorded in the workout logs and the pretest squat 1RMs for this study demonstrated high reliability at 0.90. A two (groups) by four (squat 1RM tests) repeated analysis of variance (ANOVA) was conducted to compare strength scores within subjects (tests) and between subjects (groups). Effect sizes were calculated using Cohen's *d* statistic to assess the magnitude of the treatment effects (5).

A series of two (groups) by three (workouts per mesocycle) repeated ANOVAs were conducted to compare volume components for the Heavy and Light workouts. The load (kg) utilized per set, the repetitions performed per set, the intensity (percentage of 1RM) per set, and the total volume (kg) performed per workout were compared between subjects (groups) for each mesocycle. We used an α level of 0.05 to determine significance for all comparisons. In the case of significance, follow-up comparisons were made using the Bonferroni adjustment. Statistical analysis was completed using Microsoft Excel and SPSS version 14.0 (SPSS Inc., Chicago, IL).

Results

All subjects within each group completed 90% of the workouts and were included in the analysis. A total of three Light workouts and one Heavy workout were missed by the 2-minute group, and a total of three Light workouts and two Heavy workouts were missed by the 4-minute group. The independent *t*-tests indicated that the groups did not differ significantly in age, height, or body mass (see Table 2).

The two (groups) by four (squat 1RM tests) repeated ANOVA indicated a significant within-subjects (tests) comparison for strength gains ($P = 0.0001$; power = 1.0). The interaction between group and tests was not significant ($P = 0.39$). Follow-up comparisons indicated that strength scores were significantly different between all 1RM tests (see Table 3). However, the between-subjects comparison indicated that strength gains were not significantly different between groups ($P = 0.47$). Cohen's *d* statistics indicated large treatment effects for each group. However, the 4-minute group experienced a larger treatment effect than the 2-minute group (2.96 vs. 1.96).

Table 2. Comparison of demographical characteristics.*

	2-minute group	4-minute group	*P* value
Age (y)	20.71 ± 1.38	22.75 ± 4.56	0.26
Height (cm)	182.52 ± 6.46	180.66 ± 5.99	0.58
Body mass (kg)	82.27 ± 5.56	91.31 ± 10.44	0.06

*Values are mean ± SD.

Table 3. Comparison strength gains.*

Test	2-minute group	4-minute group	Post hoc test	*P* value
1	145.13 ± 24.17	150.00 ± 18.54	1 vs. 2	0.001†
2	156.82 ± 22.88	162.78 ± 19.28	1 vs. 3	0.0001†
3	162.34 ± 22.26	172.73 ± 18.42	1 vs. 4	0.0001†
4	171.43 ± 25.34	182.10 ± 21.44	2 vs. 3	0.0001†
			2 vs. 4	0.0001†
			3 vs. 4	0.0001†

*Values are mean ± SD. One repetition maximum loads are represented in kilograms.
†*P* value <0.05.

For the Heavy workouts, the series of two (groups) by three (workouts per mesocycle) repeated ANOVAs indicated significant between-subjects (groups) comparisons for the total volume performed per workout (see Table 4). However, when compared independently, none of the volume components were significantly different, but the 4-minute group demonstrated higher scores for the load utilized per set and the repetitions performed per set. For the Light workouts, there were no significant between-subjects (groups) comparisons, but the 4-minute group demonstrated higher scores for the load utilized per set and the volume performed per workout (see Table 5).

Discussion

The primary finding of this study was that squat strength gains were not significantly different between groups that rested 2 minutes or 4 minutes between sets. Cohen's *d* statistics indicated that the 4-minute group experienced a larger treatment effect than the 2-minute group. Cohen defined a large effect size as $d > 0.8$, indicating a mean difference greater than 0.8 of a standard deviation. Thus, the treatment effects for the 4-minute group (i.e., 2.96) and the 2-minute group (i.e., 1.96) were considered large and 1 standard deviation apart. However, quantitatively, this difference in effect sizes ($d = 2.96$ vs. 1.96) was actually quite small

Table 4. Comparison of heavy workouts.*

	2-minute group	4-minute group	*P* value
Load per set (kg)			
Mesocycle			
1	109.48 ± 7.04	113.63 ± 6.59	0.67
2	118.70 ± 6.75	123.87 ± 6.32	0.59
3	126.93 ± 6.10	132.45 ± 5.71	0.52
Repetitions per set			
Mesocycle			
1	8.12 ± 0.80	9.55 ± 0.75	0.21
2	7.47 ± 0.56	8.75 ± 0.53	0.12
3	6.88 ± 0.39	7.75 ± 0.36	0.13
Intensity per set (%1RM)			
Mesocycle			
1	75 ± 0.01	76 ± 0.01	0.69
2	76 ± 0.01	76 ± 0.01	0.63
3	78 ± 0.01	77 ± 0.01	0.76
Volume per workout (kg)			
Mesocycle			
1	5892.32 ± 376.71	7302.84 ± 352.38	0.02†
2	5723.70 ± 369.52	7452.37 ± 345.65	0.01†
3	5606.67 ± 394.10	6866.40 ± 368.65	0.04†

*Values are mean ± SE. Comparisons are between subjects (groups) for each mesocycle.
†$P < 0.05$.

Table 5. Comparison of light workouts.*

	2-minute group	4-minute group	*P* value
Load per set (kg)			
Mesocycle			
1	86.70 ± 4.94	90.34 ± 4.62	0.60
2	95.28 ± 4.48	97.94 ± 4.19	0.67
3	98.14 ± 4.29	102.87 ± 4.01	0.44
Volume per workout (kg)			
Mesocycle			
1	3467.53 ± 197.70	3613.64 ± 184.93	0.60
2	3810.97 ± 179.28	3917.75 ± 167.70	0.67
3	3925.69 ± 171.64	4114.72 ± 160.55	0.44

*Values are mean ± SE. Comparisons are between subjects (groups) for each mesocycle. The repetitions performed per set and the intensity utilized per set did not vary for all Light workouts. Each group performed eight repetitions at a constant intensity of 60% of 1 repetition maximum.

because Cohen's *d* statistic is not normally distributed (5). Therefore, from a practical standpoint, there was little added benefit derived from resting 4 minutes between sets.

An analysis of the Heavy workout data demonstrated that the squat mean intensity levels for the 2-minute group (i.e., 75%, 76%, and 78% 1RM) and the 4-minute group (i.e., 76%, 76%, and 77% 1RM) were nearly equal for each of the three 4-week mesocycles (see Table 4). These mean intensity levels are comparable to those reported by Häkkinen et al. (7) for elite weightlifters who performed the squat during three 4-month mesocycles (77%, 77%, and 79% 1RM). Similar to the present study, Robinson et al. (16) compared squat mean intensity levels in groups that trained with different rest intervals between sets.

The group that rested 3 minutes between sets maintained higher intensity levels vs. two other groups that rested 90 or 30 seconds between sets (16). For example, during week 5 of that study, the 3-minute group maintained a mean squat intensity of 80% 1RM, whereas the 90-second and 30-second groups were much lower (72% and 66% 1RM, respectively). Based on the results of the present study and those of Robinson et al. (16), resting a minimum of 2 minutes between sets might be ideal to prevent intensity levels from dropping and thus allow greater gains in strength.

In the present study, the 4-minute group demonstrated significantly higher total volumes for the Heavy workouts (Table 4). As stated previously, the total volume per workout was calculated by multiplying the total number of sets by the mean load utilized and the mean number of repetitions performed per set. When compared independently, the mean load utilized and the mean repetitions performed per set were not significantly different between groups (the total number of sets performed per workout was equal). However, the 4-minute group demonstrated higher scores for both of these variables. Consequently, when these variables were multiplied, the result was a significantly higher total volume per workout for the 4-minute group, but this did not produce statistically greater strength gains.

Previous studies have hypothesized that longer rest intervals may result in significantly greater strength gains as a result of a lifter's ability to perform a higher training volume (13,16). In support of this hypothesis, Robinson et al. (16) demonstrated that squat strength gains were significantly greater in trained men who rested 3 minutes vs. 90 or 30 seconds between sets. Likewise, Pincivero, Lephart, and Karunakara (13) demonstrated that resting 160 seconds between sets resulted in significantly greater peak torque in the quadriceps and hamstrings versus resting 40 seconds between sets for untrained lifters. The authors in both studies suggested that the greater strength gains in the longer rest groups were the result of a higher training volume.

Similar to the present study, Ahtiainen et al. (1) did not find significant differences in maximal isometric leg extension force, 1RM dynamic right leg extension, and quadriceps cross-sectional area in groups that rested 2 or 5 minutes between sets. Training volume (sets × load × repetitions) was equalized so that the 2-minute group performed more sets at a lower intensity, whereas the 5-minute group performed fewer sets at a higher intensity. The authors hypothesized that after a certain threshold volume, the length of the rest period between sets does not make a systematic contribution to the neuromuscular response.

Both groups in the current study may have reached the threshold volume necessary to gain a certain amount of strength (based on training age), which reduced the importance of including longer rest intervals between sets. Kraemer et al. (12) found that specific training practices may reduce the amount of rest needed between sets. In this study, nine male bodybuilders and eight male power lifters performed a 10-station circuit that included resistance exercises for the

entire body. Each exercise was performed with load and rest intervals conducive to the training practices of competitive bodybuilders. Three consecutive sets for each exercise were performed with 10-RM load that was progressively lowered to allow for 10 repetitions on each set. Subjects rested 10 seconds between sets and 30–60 seconds between exercises.

The key finding was that the bodybuilders were able to sustain a significantly higher mean intensity during performance of the bench press and leg press sets (12). Kraemer et al. (12) concluded that the bodybuilders were able to resist the effects of fatigue because of adaptations associated with the bodybuilding style of training (e.g., high volume with short rest intervals). These adaptations might include increases in capillary and mitochondrial density and in the ability to buffer and transport hydrogen ions out of the muscles.

For continued gains in maximal strength, advanced lifters must perform increasingly higher volumes of training (2,3,14). The rest interval between sets can be varied based on the training age of the individual. To achieve a given volume goal, longer rest intervals (e.g., 4–5 minutes) might be necessary initially, until an individual has adapted psychologically and physiologically and is able to perform the same volume with shorter rest intervals between sets (2–3 minutes).

The length of the rest interval may also depend on whether an exercise is performed at the beginning or end of a workout. Sforzo and Touey (17) demonstrated a 22% decline in total work (resistance × repetitions) on the first set of squats when preceded by leg curls and leg extensions. Similarly, Spreuwenberg et al. (18) demonstrated a 32% decline in total repetitions on the first set of squats when preceded by a total body circuit that included the lunge, stiff-leg deadlift, and hang pull. These studies suggest that including longer rest intervals at the end of a workout might be advantageous to maintain the repetitions performed for each set as fatigue accumulates.

Practical Applications

Including sufficient rest between sets is essential when training for maximal strength. The findings of the present study indicate that large gains in squat strength can be achieved with a minimum of 2 minutes' rest between sets and that little additional gains are derived from resting 4 minutes between sets. A limitation of this study is that the results may not apply to other exercises, especially those for the upper body, and additional research is necessary. Furthermore, several factors may lengthen or shorten the rest interval, such as the training age or whether the squat is performed at the beginning or end of a workout. Athletes attempting to achieve specific volume goals may need longer rest intervals (e.g., 4 minutes) initially but may later adapt so that shorter rest intervals (e.g., 2 minutes) can be utilized without excessive fatigue, leaving additional time to focus on other conditioning priorities.

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