

A BRIEF REVIEW: FACTORS AFFECTING THE LENGTH OF THE REST INTERVAL BETWEEN RESISTANCE EXERCISE SETS

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ABSTRACT. Willardson, J.M. A brief review: Factors affecting the length of the rest interval between resistance exercise sets. *J. Strength Cond. Res.* 20(4):978–984. 2006.—Research has indicated that multiple sets are superior to single sets for maximal strength development. However, whether maximal strength gains are achieved may depend on the ability to sustain a consistent number of repetitions over consecutive sets. A key factor that determines the ability to sustain repetitions is the length of rest interval between sets. The length of the rest interval is commonly prescribed based on the training goal, but may vary based on several other factors. The purpose of this review was to discuss these factors in the context of different training goals. When training for muscular strength, the magnitude of the load lifted is a key determinant of the rest interval prescribed between sets. For loads less than 90% of 1 repetition maximum, 3–5 minutes rest between sets allows for greater strength increases through the maintenance of training intensity. However, when testing for maximal strength, 1–2 minutes rest between sets might be sufficient between repeated attempts. When training for muscular power, a minimum of 3 minutes rest should be prescribed between sets of repeated maximal effort movements (e.g., plyometric jumps). When training for muscular hypertrophy, consecutive sets should be performed prior to when full recovery has taken place. Shorter rest intervals of 30–60 seconds between sets have been associated with higher acute increases in growth hormone, which may contribute to the hypertrophic effect. When training for muscular endurance, an ideal strategy might be to perform resistance exercises in a circuit, with shorter rest intervals (e.g., 30 seconds) between exercises that involve dissimilar muscle groups, and longer rest intervals (e.g., 3 minutes) between exercises that involve similar muscle groups. In summary, the length of the rest interval between sets is only 1 component of a resistance exercise program directed toward different training goals. Prescribing the appropriate rest interval does not ensure a desired outcome if other components such as intensity and volume are not prescribed appropriately.

KEY WORDS. recovery, fatigue, strength, power, hypertrophy, endurance

INTRODUCTION

Resistance training has been recognized as an essential component of a comprehensive fitness program for individuals with diverse fitness goals. Individuals may participate in resistance training for rehabilitative reasons or in preparation for strenuous jobs such as firefighting, law enforcement, or military service. Manipulation of training variables is dependent on the specific training goals of the individual and the physical demands encountered during daily life (2, 4).

A recent meta-analysis by Rhea et al. (20) demonstrated that when the training goal is maximal strength development, multiple sets per muscle group were superior

to single sets. However, the superiority of performing multiple sets per muscle group may depend on the ability to sustain consistent repetitions over consecutive sets (22). The ability to sustain consistent repetitions is largely dependent on the length of the rest interval between sets (12, 15, 21, 29, 30, 32–34). The length of rest interval must be sufficient to recover energy sources (e.g., adenosine triphosphate [ATP] and phosphocreatine [PCr]), clear fatigue producing substances (e.g., H⁺ ions), and restore force production (2, 4, 10, 23, 31).

Generally, the length of the rest interval between sets is prescribed based on the training goal. The recommended rest interval increases when programs are designed for strength or power (e.g., 2–5 minutes) and decreases when programs are designed for hypertrophy (e.g., 30–90 seconds) or muscular endurance (e.g., less than or equal to 30 seconds) (2, 4). Although these recommendations provide an important foundation for generalized exercise prescription, the length of the rest interval may vary based on several factors (see Figure 1). Therefore, the purpose of this review will be to discuss these factors and rest interval length in the context of different training goals.

MUSCULAR STRENGTH

Muscular strength-oriented programs place primary emphasis on the maintenance of training intensity through longer rest intervals of 2–5 minutes between sets (2, 4). Longer rest intervals make greater strength increases possible through greater consistency in the repetitions performed for each set (12, 21, 29, 32–34). Two studies to date have compared strength increases resulting from different rest intervals between sets.

Pincivero et al. (18) compared isokinetic strength increases in 2 groups assigned to either a 40-second or a 160-second rest interval between sets. Subjects in each group performed 4 sets of 10 maximal isokinetic knee extensions and knee flexions at 90 degrees per second 3 times per week for 4 weeks, using a randomly assigned leg. At the conclusion of the study, the 160-second rest group demonstrated greater peak torque in the quadriceps and hamstrings. The authors concluded that the 160-second rest interval led to greater strength increases because of a higher volume of work.

Robinson et al. (22) compared squat strength increases in 3 groups assigned to either a 3-minute, 90-second, or 30-second rest interval between sets. Subjects in each group performed 5 sets of 10 repetitions 2 times per week for 5 weeks. At the conclusion of the study, subjects in the 3-minute group demonstrated greater strength increases vs. the other 2 groups. The authors concluded

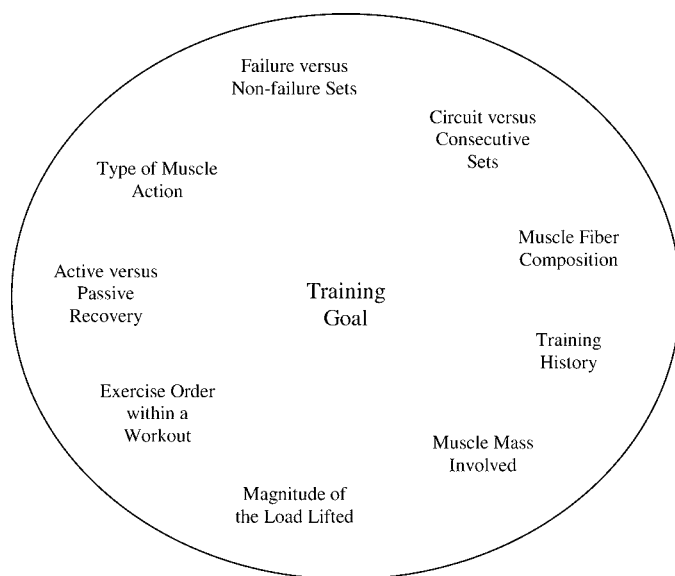


FIGURE 1. Factors affecting the length of the rest interval between sets.

that the 3-minute rest interval led to greater strength increases because of the ability to maintain a higher training intensity.

These studies demonstrated that greater muscular recovery via longer rest intervals between sets is the key to greater strength increases (18, 22). However, research has demonstrated that the length of the rest interval necessary to facilitate sufficient recovery can vary based on several factors (see Figure 1). **Two of the most frequently studied of these factors are the type of muscle action and the magnitude of the load lifted; these will be discussed below.**

Type of Muscle Action

Stull and Clarke (27) compared patterns of strength recovery for the wrist flexors following isotonic and isometric fatigue tasks conducted on separate days. Isotonic fatigue was induced as subjects performed repeated maximal contractions for 3 minutes. Isometric fatigue was induced as subjects sustained a maximal isometric muscle action until strength had deteriorated to the final strength level of the isotonic testing condition. Each subject then performed a maximal contraction at different time intervals following the fatigue task (see Table 1). The key finding was that for both the isotonic and isometric conditions, strength levels had returned to approximately 98% of initial values in less than 4 minutes. However, isotonic strength initially recovered more rapidly than isometric strength. The authors attributed this to slower reestablishment of intramuscular blood flow following the isometric condition.

Bilcheck et al. (5) examined the time necessary for strength recovery of the quadriceps following an isokinetic fatigue task. Subjects attended 4 testing sessions during which 3 sets of 30 maximal contractions at 120°·s⁻¹ were performed with 1-minute rest intervals between sets. Subjects were tested for strength at 2.5, 5, and 10 minutes into the recovery period. The results demonstrated no significant differences between the torque produced prior to the fatigue task and the torque produced at each test point during the recovery period. The authors concluded that isokinetic resistance exercise protocols could utilize 2.5 minutes between sets without fear of compromising force production.

These studies suggest that regardless of the type of muscle action, approximately 75% of muscular strength is recovered within the first minute, with an additional 2–3 minutes needed to recover full strength (5, 27). Therefore, when performing workouts designed for mus-

TABLE 1. Summary recovery of muscular strength vs. muscular endurance.*

Authors	Muscles	Task	Measure	Time	Recovery (%)
Bilcheck et al. (5)	Knee extensors	3 sets of 30 maximal isokinetic contractions at 120°; s ⁻¹	Strength	2 min 30 s	100
Sahlin and Ren (23)	Knee extensors	Sustained isometric muscle action at 66% of MVC until force declined to 50% of MVC	Strength	2 min	100
			Endurance	40 min	100
Stull and Clarke (27)	Forearm flexors	30 isotonic maximal contractions per minute for 3 minutes	Strength	10 s	56
				35 s	84
				1 min 10 s	96
				1 min 55 s	98
	Sustained maximal isometric muscle action	Strength	10 s	36	
			35 s	49	
			1 min 10 s	68	
			1 min 55 s	80	
				2 min 55 s	89
				3 min 55 s	97
Yates et al. (36)	Elbow flexors	38 isotonic repetitions per minute at one-sixth MVC	Endurance	30 s	35
				2 min	50
				7 min	75
				20 min	90

* In the studies that assessed recovery of muscular strength, a single maximal voluntary contraction (MVC) was performed at different time intervals following the fatigue task. In the studies that assessed recovery of muscular endurance, the fatigue task was repeated at different recovery intervals and the fatigue time was compared with the fatigue time of the initial task.

TABLE 2. Rest interval length and bench press performance.*

Author	Load	Sets	Rest	Reps
Kraemer (12)	10RM	3	1	25
			3	30
Richmond and Godard (21)	75% 1RM	2	1	18
			3	20
			5	22
Todd et al. (29)	60% 1RM	3	1	11
			2	13
			3	15
			4	16
			5	17
	90% of 1RM	3	1	2
			2	3
			3	4
			4	4
			5	4
Willardson and Burkett (32)	8RM	4	1	17
			2	22
			5	26
Willardson and Burkett (33)	15RM	5	0.5	26
			1	30
			2	39
Willardson and Burkett (34)	50% of 1RM	5	1	59
			2	75
			3	88
	80% of 1RM	5	1	18
			2	23
			3	27

* In all studies, the load was held constant and all sets were performed to the point of muscular failure. Rest measured in minutes; Reps = total repetitions; 1RM = 1 repetition maximum.

cular strength, resting 3 or 4 minutes might be beneficial to allow for full recovery prior to the next set. Of course, the amount of muscle mass involved and the type of muscle action must also be considered. For example, movements such as the deadlift and squat, which involve both isotonic (e.g., hip extensors, knee extensors) and isometric (e.g., wrist flexors, abdominals) muscle actions, might require 3–4 minutes rest between sets. However, when training small muscle groups (e.g., wrist flexors) or large muscle groups (e.g., quadriceps) in isolation, 1-minute rest intervals might be sufficient.

Magnitude of the Load Lifted

Relatively few studies have been conducted that examined the effect of rest interval length on the sustainability of repetitions during traditional isoinertial resistance exercises. The studies that currently exist have almost exclusively examined the bench press exercise (see Table 2). The maintenance of repetitions during the bench press has been shown to be highly dependent on the magnitude of the load lifted.

Kraemer (12), Richmond and Godard (21), Todd et al. (29), and Willardson and Burkett (32–34) demonstrated that when training with submaximal loads between 50% and 90% of 1 repetition maximum (1RM), longer rest intervals of 3–5 minutes between sets allowed for more total repetitions to be completed during a workout. In contrast, Weir et al. (30) and Matuszak et al. (15) demonstrated that when assessing maximal bench press and squat strength, longer rest intervals were not as impor-

tant. These authors reported that a maximal squat and bench press were repeatable with a 1-minute rest interval between repeated attempts.

Based on the results of the aforementioned studies, a recovery threshold appears to exist when training with loads greater than or equal to 90% of 1RM at which resting 1–2 minutes between sets is sufficient (15, 30). Conversely, when training with loads less than 90% of 1RM, resting 3–5 minutes between sets is necessary to sustain repetitions without large reductions in the training intensity (12, 21, 29, 32–34). Simply stated, recovery following maximal or near-maximal lifts appears to occur more rapidly relative to recovery following submaximal lifts performed to failure. This observation is consistent with previous studies, which demonstrated shorter recovery time of muscular strength vs. muscular endurance (see Table 1) (5, 23, 27, 36). **Sahlin and Ren (23) concluded,**

Thus there is an apparent paradox in that acidosis does not impair contractile force but appears to limit endurance during a sustained contraction. The explanation of this paradox could be that the link between H⁺ accumulation and muscle fatigue is indirect. **One possibility is that acidosis through H⁺-mediated inhibition of phosphofructokinase results in a reduced capacity to generate ATP through glycolysis.** During a sustained contraction PCr decreases to low levels and ATP generation from glycolysis will become essential for the ability to maintain a high rate of ADP rephosphorylation, and acidotic inhibition of glycolysis could then impair the contractility. However, during recovery when a partial resynthesis of PCr has occurred it is unlikely that a limitation of glycolysis can impair the capacity to generate ATP (and thus maximal force), because the breakdown of PCr is the most rapid process in ADP rephosphorylation (p. 653).

MUSCULAR POWER

Because training exercises designed to increase muscular power require maximal rates of force development, longer rest intervals of 2–5 minutes between sets have been recommended to allow for greater neurological recovery and consistency in movement mechanics (2, 4). However, little research exists regarding how much rest is needed between sets of single maximal-effort movements (e.g., 1RM power clean) vs. repeated-maximal effort-movements (e.g., plyometric jumps). Longer rest intervals of 2–5 minutes might be necessary between sets of repeated maximal effort movements, because of the primary involvement of the glycolytic energy system and the need to clear fatigue-producing substances (e.g., H⁺ ions) from the muscles (23, 31).

In contrast, shorter rest intervals of 1–2 minutes might be sufficient between sets of single maximal-effort movements, because of the primary involvement of the phosphagen energy system (15, 23, 30, 31). **According to Fleck and Kraemer (7), 90% of phosphagens can be recovered within 1 minute following a high-intensity resistance exercise set.** In the context of muscular power, all of the rest interval research to date is applicable to sets of repeated maximal-effort movements.

Pincivero et al. (19) compared quadriceps and hamstring peak torque, total work, and average power in 2 groups assigned to either a 40-second or a 160-second rest interval between sets. Both groups performed 4 sets of 10 reciprocal, concentric, maximal isokinetic knee extension and flexion repetitions at 90°·s⁻¹. Results demonstrated that from set 1 to set 4, the 40-second rest group had

significant reductions in peak torque (quadriceps 16%, hamstrings 12%), total work (quadriceps 19%, hamstrings 19%), and average power (quadriceps 19%, hamstrings 18%). Conversely, the 160-second rest group had no significant reductions in peak torque (quadriceps 2.2%, hamstrings 2.4%), total work (quadriceps 2.8%, hamstrings 5.7%), and average power (quadriceps 2.4%, hamstrings 5.7%).

In a follow-up study, Pincivero et al. (17) used the same experimental design, with the exception that 4 sets of 20 maximal isokinetic knee extensions were performed at $180^{\circ}\cdot\text{s}^{-1}$. Results demonstrated that from set 1 to set 4, the 40-second rest group had significant reductions in peak torque (29%), total work (47%), and peak power (46%). Conversely, the 160-second rest group had much less reduction in peak torque (11%), total work (25%), and average power (24%). The authors concluded that longer rest intervals allowed for maximal torque and power to be sustained, which may result in greater increases in strength and power when applied in a long-term training program.

Abdessemed et al. (1) demonstrated comparable results when recovery duration was examined on muscular power and blood lactate during the bench press exercise. Subjects performed 10 sets of 6 maximal effort repetitions at 70% of their 1RM, and with a 1-, 3-, or 5-minute rest interval between sets. The results demonstrated that from set 1 to set 10, the mean power did not decrease significantly for the 3- or 5-minute rest conditions (4.8% and 2%, respectively), but did decrease significantly for the 1-minute rest condition (27%). Decreases in mean power with the 1-minute rest condition were negatively and highly correlated to increases in blood lactate (individual correlations ranged from 0.64 to 0.99). The authors concluded that resting 1 minute between sets was not sufficient for lactate to buffer the fatigue producing effects of H^{+} ions.

Overall, the aforementioned studies indicate that when performing sets of repeated maximal effort movements, 3 minutes of rest is sufficient between consecutive sets (1, 17, 19). A limitation of the aforementioned studies was the assessment of only isokinetic movements and the free weight bench press, which may have limited application to the movements encountered during sports competition. Therefore, future research should be conducted to determine how different rest intervals affect the maintenance of power during standing upper- and lower-body explosive resistance exercises. For resistance exercises that involve single maximal effort movements (e.g., 1RM power clean), future research should examine whether 1–2 minutes is sufficient to maintain power and movement mechanics between repeated attempts.

MUSCULAR HYPERTROPHY

In strength-type regimens, the recommended rest interval of 2–5 minutes between sets has been shown to allow for consistent repetitions, without lowering the training intensity (12, 21, 22, 29, 32, 34). Conversely, in hypertrophy-type regimens, the recommended rest interval of 30–90 seconds is not sufficient to sustain the training intensity over consecutive sets (8, 13, 14, 16). Therefore, performing the next set prior to when full recovery has taken place is considered more important. However, consistent training with short rest intervals may result in adaptations that allow for training intensity to be sustained.

Kraemer et al. (14) found that specific training practices can reduce the amount of rest needed between sets. In this study, 9 male bodybuilders and 8 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 a 10RM load that was progressively lowered to allow for 10 repetitions in 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 percentage of 1RM during performance of the bench press and leg press sets. Kraemer et al. (14) 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 H^{+} ions out of the muscles.

Few studies have compared differences in hypertrophy consequent to workout protocols that involve relatively short vs. long rest intervals between sets. The general recommendation for short rest intervals was derived from research that examined acute anabolic hormonal secretions. Kraemer et al. (13) demonstrated that a hypertrophy-type regimen, consisting of 3 sets of 8 exercises performed with a 10RM load and 1-minute rest intervals between sets, produced greater acute increases in growth hormone (GH) vs. a strength-type regimen, consisting of 5 sets of 5 exercises performed with a 5RM load and a 3-minute rest intervals between sets. McCall et al. (16) used a similar hypertrophy-type regimen in a 12-week training study that demonstrated significant correlations between acute GH increases and the relative degree of type I ($r = 0.74$) and type II ($r = 0.71$) muscle fiber hypertrophy in the biceps brachii.

Although these studies provided probable evidence that moderate-intensity resistance exercises combined with short rest intervals are superior for hypertrophy training, there were limitations. For example, Kraemer et al. (13) did not conduct a training program, and consequently hypertrophy was not assessed. Kraemer et al. concluded, “The link between the concomitant in vivo changes of endogenous anabolic hormones and tissue growth has not been specifically determined, and increased concentrations of circulating anabolic hormones may not reflect anabolism at the tissue level” (p. 1447). Although McCall et al. (16) did conduct a training program and hypertrophy was assessed, only 1 type of workout regimen was examined.

Goto et al. (8) addressed these limitations by comparing differences in acute growth hormone secretion and quadriceps muscle cross-sectional area consequent to a 10-week periodized resistance program for the lower body. Subjects were assigned to either a hypertrophy/composition (HC) group ($n = 8$) or a hypertrophy/strength (HS) group ($n = 9$). During the first 6 weeks of the study, the HC and HS groups performed a hypertrophy-type regimen 2 days per week, which consisted of 3 sets each of leg extension and leg press with 30 seconds rest between sets and 3–5 minutes rest between exercises. For each exercise, the resistance was progressively adjusted to allow for 10–15 repetitions on each set.

During weeks 7 through 10, the HS groups performed a strength-type regimen 2 days per week, which consisted of 5 sets each of leg extension and leg press with 3 minutes rest between sets and 3–5 minutes rest between exercises. For each exercise, the resistance was progressively adjusted to allow for 3–5 repetitions in each set. The HC group performed a combination-type regimen, which was the same as the strength-type regimen, with the exception that an additional set was performed 30 seconds following the fifth set of each exercise with a resistance that allowed for 25–35 repetitions.

Goto et al. (8) demonstrated that acute increases in growth hormone were highest after the hypertrophy-type regimen, followed by the combination-type regimen, and then the strength-type regimen. During the hypertrophy phase (first 6 weeks), the HS and HC groups increased quadriceps cross-sectional area equally. However, during the subsequent strength phase (weeks 7 through 10), only the HC group continued to increase cross-sectional area. The authors concluded that moderate-intensity loads combined with short rest intervals (e.g., 10–15RM with 30 seconds to 1 minute rest between sets) were superior to high-intensity loads with long rest intervals (3–5RM with 3 minutes rest between sets) for hypertrophy.

Further, after transition to a strength-type regimen, a light “burnout” set performed 30 seconds following the last heavy set was effective for continued hypertrophy. However, as the name implies, the hypertrophy-type regimen was most effective; this may have been in part because of repeated exposure to greater acute growth hormone secretions. Overall, short rest intervals between sets are only 1 component of a program designed for hypertrophy and appear to be most effective when utilized in conjunction with moderate intensity sets performed to muscular failure.

MUSCULAR ENDURANCE

Very little research has been conducted on the effect of different rest intervals between sets on muscular endurance adaptations. Because muscular endurance is defined as the ability to sustain submaximal contractions over extended periods of time, the current recommendation is for rest intervals of less than or equal to 30 seconds between sets (2, 4). Studies that validated the strength/endurance continuum demonstrated that resistance programs involving low resistance and high repetitions were superior to programs involving high resistance and low repetitions for increasing muscular endurance (3, 6, 26). However, no studies have examined changes in muscular endurance when low-resistance and high-repetition programs are compared with different rest intervals between sets.

Willardson and Burkett (33) compared the sustainability of squat and bench press repetitions with different rest intervals between sets. Five consecutive sets were performed with a 15RM load and a 30-second, 1-minute, or 2-minute rest interval between sets. The load was kept constant over all 5 sets and the percentage decline in repetitions was compared between rest conditions. The results demonstrated that for all rest conditions, significant declines in repetitions occurred between the first set and the fifth set for both exercises. However, the 2-minute rest condition afforded greater sustainability of repetitions, with more total repetitions completed vs. the 30-second and 1-minute rest conditions (see Table 2). The authors concluded that muscular endurance training pro-

grams that involve 30 seconds rest between sets should lower the training intensity over consecutive sets in order to sustain repetitions within the range conducive to this training goal.

The optimal program for muscular endurance training likely includes a combination of low resistance, high repetitions, and short rest intervals between sets (2, 4). For this reason, a circuit strategy has been hypothesized to be ideal for muscular endurance training (35). Using this strategy, shorter rest intervals (e.g., 30 seconds) are prescribed between resistance exercises that involve dissimilar muscle groups, while longer rest intervals (e.g., 3 minutes) are prescribed between resistance exercises that involve similar muscle groups. Because sets for the same muscle group are not performed consecutively, high repetitions can be sustained.

PRACTICAL APPLICATIONS

In summary, the length of the rest interval between sets is only 1 component of a resistance exercise program directed toward different training goals. Prescribing the appropriate rest interval does not ensure a desired outcome if other components such as intensity and volume are not prescribed appropriately. Although recommendations exist regarding the appropriate rest interval based on the training goal, several factors may shorten or lengthen these generalizations (see Figure 1). Therefore, strength coaches should consider individual differences and the type of workout being performed when prescribing the rest interval between sets.

When training for muscular strength, longer rest intervals are generally prescribed to allow for greater recovery and maintenance of training intensity. However, the length of the rest interval can vary, depending on the magnitude of the load lifted. For submaximal lifts, less than 90% of 1RM, 3–5 minutes rest should be prescribed between sets to allow for consistency in repetitions without large reductions in the training intensity. Conversely, when testing for maximal strength, 1–2 minutes rest might be sufficient between repeated attempts. Another important factor to consider with regard to submaximal-intensity lifts is whether sets are performed to failure; if sets are not performed to failure, then 1–2 minutes rest might be sufficient because of reduced metabolic demand.

When training for muscular power, longer rest intervals are generally prescribed to allow for greater neurological recovery and consistency in movement mechanics. The applicable research conducted to date indicates that when performing repeated maximal-effort movements (e.g., plyometric jumps), a minimum of 3 minutes rest should be prescribed between sets to maintain power. Conversely, when performing single maximal-effort movements, such as those used to test for power (e.g., 1RM power clean), 1–2 minutes rest might be sufficient between repeated attempts, because of rapid resynthesis of intramuscular phosphagens.

When training for muscular hypertrophy, maintaining training intensity is not the primary focus, and consecutive sets should be performed prior to when full recovery has taken place. A combination of moderate-intensity sets with short rest intervals has been demonstrated to be superior for hypertrophy training. This might be because of repeated acute exposure to high levels of growth hormone. Keogh et al. (11) advocated the “breakdown” approach when training for hypertrophy. With this ap-

proach, the first set is performed at a relatively high intensity (e.g., 85% of 1RM), and then the intensity is gradually reduced over subsequent sets to sustain consistent repetitions, with 30–60 seconds rest between sets.

When training for muscular endurance, the extremely short rest intervals between sets necessitate lowering the training intensity over consecutive sets to sustain repetitions within the range conducive to this training goal. Therefore, achieving a high training volume is more important than sustaining training intensity. However, consistent training with short rest intervals may result in adaptations that allow training intensity to be sustained. The ideal strategy for increasing muscular endurance might be to perform exercises in a circuit, while alternating exercises for the upper and lower body. Using this strategy, shorter rest intervals (e.g., 30 seconds) are prescribed between consecutive exercises that involve muscles in different regions of the body, and longer rest intervals (e.g., 3 minutes) are prescribed between exercises that involve muscles in the same regions of the body.

RECOMMENDATIONS FOR FUTURE RESEARCH

Some key factors that have not been examined regarding rest interval length include exercise order within a workout, muscle fiber composition, and an active vs. a passive recovery between sets. Prior studies demonstrated reductions in total repetitions and training intensity when resistance exercises were performed last vs. first in a workout (24, 25). Therefore, future research should be conducted to determine whether longer rest intervals are advantageous for exercises performed last in a workout to increase total repetitions and maintain training intensity.

A prior study demonstrated that fast-twitch muscle fibers were more susceptible to fatigue vs. slow-twitch muscle fibers, possibly because of faster turnover of Ca^{2+} and ATP in connection with muscular contraction, and ATP production via anaerobic processes. Individuals with a higher proportion of fast-twitch muscle fibers were capable of greater force production, but were less capable of sustaining force production over extended periods of time (28). Therefore, future research should be conducted to determine whether individuals with a higher proportion of fast-twitch muscle fibers require longer rest intervals between sets when training for maximal strength.

Finally, a prior study demonstrated less reduction in repetitions with an active recovery (stationary cycling 45% peak $\dot{V}\text{O}_2$) vs. a passive recovery between sets (9). However, this study examined consecutive sets performed at a single training intensity (e.g., 65% of 1RM) and subjects consisted of untrained men. Therefore, future research should be conducted at higher training intensities with trained men, and long-term strength gains resulting from workouts that involve either an active or a passive recovery between sets should be compared.

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