Brief Review: Maximizing Hypertrophic Adaptation–Possible Contributions of Aerobic Exercise in the Interset Rest Period

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SUMMARY

TYPICAL RESISTANCE TRAINING SESSIONS INVOLVE A COMBINATION OF WORK AND REST PERIODS. MOST RESEARCH HAS FOCUSED ON MANIPULATING THE SETS, REPETITIONS, AND LOAD DURING THE WORK PERIOD IN MAXIMIZING SESSION'S MECHANICAL OUTPUT AND PHYSIOLOGICAL ADAPTATION, WITH LITTLE ATTENTION ON INTERSET REST PERIOD. HOWEVER, IT MAY BE POSSIBLE TO ENHANCE SET KINEMATICS AND KINETICS AND CONSEQUENTLY INCREASE THE ADAPTATIONAL EFFECT OF THE TRAINING SESSION BY PERFORMING LIGHT AEROBIC ACTIVITY DURING THE INTERSET REST PERIOD. THIS ARTICLE EXPLORES THIS CONTENTION, SUGGESTING THE POSITIVE BENEFITS OF THIS TYPE OF EXERCISE ON A MECHANICAL, METABOLIC, HORMONAL, AND NEURAL PROFILE OF A RESISTANCE TRAINING SESSION.

INTRODUCTION

Given that a resistance strength training session consists of work and rest periods in its simplest form, it would seem intuitive that to improve strength and power adaptation, optimizing work and rest for a given purpose is fundamental. A great deal of research has investigated the work period during resistance strength training with the intent of maximizing the mechanical stimuli (kinematics and kinetics). Improving our understanding of the training stresses that we impose on muscle is important because it is thought that strength and power adaptation is mediated by mechanical stimuli and their interaction with hormonal and metabolic factors. In terms of rest, however, apart from research that has investigated rest durations between sets (2,28,61,62,77), a paucity of research has investigated how the rest period may be optimized to enhance session kinematics and kinetics.

The research dealing with an active recovery (20,44) suggests that low-intensity activity during the rest period could enhance the ensuing set and workout kinematics and kinetics. The net result could be a session with-increased mechanical, hormonal, neural, and metabolic outputs and hence the opportunity for improved strength and power adaptation. For this to occur, the interset rest periods need to be viewed not as a period of passive rest but as recovery periods. With this in mind, current practice with reference to rest and hypertrophic training, in particular, is discussed. The discussion is not exhaustive but does review the possible benefits of adding an active interset routine (cycling at 50–70 rpm, for example) during the interset rest/recovery period that may optimize the total session training stimulus and hence adaptation.

KEY WORDS:
active recovery; hypertrophy; mechanical; metabolic; hormonal; neural; strength training

HYPERTROPHY LOADING PARAMETERS AND REST

Studies have shown that strength gains from resistance training are not only the result of improved neural functioning (e.g., increased motor unit activation and firing frequencies) but also because of increases in muscle cross-sectional area (17,40,45,85). Recommendations for increasing muscle hypertrophy include the use of moderate loading (70–85% of 1 repetition maximum [1RM]) for 8–12 repetitions per set for 1 to 3 sets per exercise, for novice and intermediate individuals (12,15,28,56, 73,84). For experienced athletes, it has been recommended that a loading range of 70–100% of 1RM be used for 1–12 repetitions per set for 3–6 sets per exercise in a periodized manner (51,54,58,76). With regard to the duration of rest period, 1–3 minutes have been suggested depending on the athlete's training status (76).

Providing longer rest periods allow more complete recovery of the energy and neuromuscular systems. However, short rest periods (1–2 minutes) coupled with moderate- to high-intensity loading and volume have elicited the greatest acute anabolic hormone and metabolic responses to resistance exercise in comparison with programs using very heavy loads with long rest periods (52,53). Toigo and Boutellier (90) highlight recovery time as an important mechanobiological factor for developing strength. Of interest, however, is not only the duration of the rest/recovery period but also the effects of activity, such as aerobic exercise on the metabolic, hormonal, neural, and mechanical profiles of a resistance strength training session. The next sections explore the possible benefits of such interset recovery activity.

METABOLIC STIMULUS

The energetic contribution to resistance strength training will, in its most simplest form, depend on the intensity and duration of the work-rest (set) periods, the total number of work-rest periods within a session (i.e., session duration), and repletion kinematics. In terms of the work period, typical hypertrophic loading as described previously consists of 10 repetitions of approximately 3- to 4-second coupled eccentric-concentric contractions per repetition. This equates to an approximate work period of 40 seconds per set, the metabolic cost of which is obviously influenced by variables such as the size of the muscle mass involved and the emphasis on the eccentric phase. Given the recommended loading stated previously and that typical hypertrophic training is suggested to be high in volume and include at least 6–8 exercises per session, the total sets per session could be between 24 and 32 sets per session (23,25,56,68,71,76). This combined with interset rest periods of approximately 60–90 seconds results in total session duration of at least 60 minutes and total session recovery of approximately 20–40 minutes.

Given this information regarding work-rest ratios and session duration, all energy systems would be mobilized during a session aimed at increasing muscle mass. This contention is supported by a previous study that found bodybuilding type of training being associated with a high rate of energy utilization through phosphagen breakdown and activation of glycogenolysis (89). Marked increases in blood lactate and intramuscular lactate, indicative of a high rate of anaerobic glycolysis, have also been reported after intense and prolonged heavy-resistance exercise comprising 5 sets of front squats, back squats, leg presses, and knee extensions (89). Even though anaerobic nonglycolytic and glycolytic energy sources were used, lipolysis (utilization of lipids/fats) has also been found to provide energy during resistance exercise, as shown by the reduced triglyceride content observed in muscle after training (29). However, based on the evidence given, anaerobic metabolism provides the majority of energy for hypertrophic training.

With anaerobic energy systems identified as the main contributor to energy production during hypertrophic training, the rate of energy repletion that occurs in the 60- to 90-second rest periods could influence the amount of work completed in ensuing exercise bouts. The rate of repletion is closely related to the efficiency of the energetic and cardiovascular systems (44,68,76,78,80). However, given the nature of the hypertrophic training stimulus and the short rest period, there is not enough time for complete repletion of energy stores and there is an increase in metabolic byproducts, such as lactate, H^+ ions, and inorganic phosphate (83). The regeneration of ATP during hypertrophy training using anaerobic pathways (i.e., for the most part without the presence of oxygen) increases lactic acid levels (79,81). The increase in lactic acid will affect session kinematics and kinetics, resulting in decreased force production (70). For example, hypertrophy-type resistance training has been shown to elicit greater lactate accumulation compared with other types of resistance training (50). Accumulation of lactic acid in the skeletal muscle cell can be buffered or resolved by the presence of oxygen; this process would be less likely to occur during the work component of a hypertrophic resistance training session (46,72).

Typically, most interset rest periods are relatively passive in nature. Given that there are increases in lactate in the muscle during hypertrophy-type loading, engaging in interset active recovery may enhance lactate clearance, without adversely affecting session kinematics and kinetics. Light aerobic exercise, such as low-intensity cycling, would increase blood flow, which in turn could assist with: (a) the oxygenation of lactate to pyruvate, which is subsequently used as fuel in the Krebs cycle; and/or (b) conversion to glucose via gluconeogenesis in the liver and then released back into the circulation (Cori circulation). Both outcomes may facilitate an increase in workload. For example, active recovery consisting of low-intensity cycling at 25% onset of blood lactate accumulation between sets of parallel squats was shown to be the most effective means of significantly reducing blood lactate concentration during recovery and increasing performance by an additional 5 parallel squats as compared with a passive recovery (20). Similarly, 2 minutes on a bicycle ergometer at 45% $\dot{V}O_2$max during the interset rest period of 4 sets of maximum repetition bench presses at 65% 1RM was found to be more effective in clearing lactate (10%) and producing greater (10%) isometric force as compared with passive rest (44). Although the effectiveness of active recovery after moderate-duration exercise is well documented (4,27,60,66), few investigations (10,86,93) have determined the impact of short-duration active recovery (<10 minutes) on high-intensity exercise, and most of these studies are not specific to resistance strength training nor have investigated active recovery specific to the 60- to 90-second interset duration common to hypertrophy training. To our knowledge, the studies of Corder et al. (20) and Hannie et al. (44) were the only research that investigated active recovery in relation to resistance strength training, so further research is needed in this area.

Active recovery during hypertrophy resistance training may have a positive influence on rate of energetic repletion and lactate clearance; however, it needs to be established whether metabolic stress is an important mediator of increased muscle mass or not. Scientific studies have suggested that acute metabolite buildup may increase the secretion of various anabolic hormones or lead to greater motor unit activation at a given load (34,57,87,88) and longitudinally may contribute to hypertrophic adaptation (34). Therefore, if metabolite accumulation is an important mediator for hypertrophy by promoting better anabolic hormonal responses, faster lactate clearance may have a negative influence. Conversely, a greater mechanical stimulus (higher forces or greater time under tension) may result from faster lactate clearance and provide a better hypertrophic stimulus. More research is needed to determine the exact interaction of mechanical and metabolic responses.

HORMONAL STIMULUS

Hormones, especially the growth-related hormones, have been known to be important in initiating/stimulating the skeletal muscle growth process (34). It is well documented that physical exercise triggers the production of growth hormones, testosterone, and insulin-like growth factor-1, along with epinephrine and norepinephrine, which support the muscle growth adaptational process (1,30,32,33,35,55). Hypertrophy-type loading schemes have been found to cause greater acute endogenous hormone responses as compared with heavy or explosive-type loading schemes (63). The hormonal responses differ in magnitude, depending on the type and/or volume of the stress of the exercise protocol used (22,36,41). These hormone responses can remain elevated for up to 30 minutes posttraining (42,55), along with elevated metabolic by-products, such as lactic acid (55).

Although the magnitude of the mechanical stimulus imposed (volume load, time under tension, etc.) seems to be responsible for greater hormonal secretion during hypertrophic loading schemes (23–25), the length of the interset rest period seems to be less important. Interset rest periods less than 5 minutes have been shown to have no influence on the magnitude of acute hormonal and neuromuscular responses or long-term training adaptations in muscle strength and mass in previously strength-trained men (2).

It is well documented that aerobic/anaerobic exercise can cause an increase in acute hormonal responses, with repeated bouts of exercise elevating human growth hormone (HGH) (21) and that exercise intensity has been shown to influence HGH output (49). A study involving 6 well-trained cyclists and 6 untrained subjects found that after 4 successive 7 minutes of cycling exercise at 30, 45, 60, and 75% of maximal work capacity, plasma HGH rose to a greater extent during exercise and remained elevated after the end of exercise in the untrained group but not in the trained group (9).

It has also been reported that concentrations of anabolic hormones, such as growth hormones, are augmented with repeated bouts of exercise, such as cycling (19,48). Intermittent cycling for 1 minute at 285 W followed by 2 minutes of rest repeated 7 times (total session of approximately 21 minutes) was found to elicit greater growth hormone levels than continuous cycling at 100 W for 20 minutes (92). These findings support the contention that aerobic exercise can have an influential effect on the hormonal milieu of the muscle.

From this brief treatise of some of the literature around the elevation of growth hormones with aerobic/anaerobic cycling, evidence for use of such activity in the interset rest period to magnify the total hormonal responses for the entire session do exist. Engaging in activity in the work period (resistance strength training) and rest period (cycling) may result in greater total anabolic hormone production within a session and subsequent hypertrophy. Much research is needed to determine the thresholds of aerobic intensity needed to increase the hormonal response to a practically significant level during the rest/recovery periods. However, it should be remembered that the net available time for aerobic (cycling) activity within a session is quite substantial (i.e., approximately 18–34 minutes) and may be somewhere between 30 and 40 interset rest periods of approximately 60- to 90-second duration within a training session. Research is also needed to determine the thresholds of aerobic activity needed to stimulate greater hormonal responses but at the same time do not negatively affect the kinematics and kinetics of ensuing sets. In other words, interset rest/recovery with aerobic exercise could also potentially lead to greater hormonal responses by reducing available hormone levels in the blood because of increased uptake into the tissue or it might also increase clearance (as with lactate) which might negatively affect the ensuing kinematics and kinetics.

NEURAL STIMULUS

Scientific evidence indicates that strenuous heavy resistance loading results in considerable acute fatigue in the neuromuscular system leading not only to decreased force production capacity of the muscles but also to a decrease in the voluntary neural activation of the exercised muscles (38,39). Integrated electromyography (EMG) recordings have been found to decrease by 10 and 32% after 3 sets of either 100% 10RM to failure or 10 repetitions for the first 2 sets using a 90% 10RM load using 3-minute rest periods (7). Another study found that mean neuromuscular efficiency (measured by EMG) decreased linearly with repetitions and sets (−41.1, −33.9, and −24.4% for sets 1, 2, and 3, respectively) during knee extensions using a loading of 3 sets of 8 repetitions with 2 minutes interset rest period, at 80% of maximum voluntary contraction (78).

Regarding the interset rest period, the working muscle typically is rested so neural drive to the muscle recovers. Thus, the inclusion of aerobic exercise, such as, cycling in the interset rest periods may have positive benefits to neural functioning and subsequent hypertrophic adaptation. Given that dynamic movement processes dependent on contractile rates are temperature dependent (6,80), increasing muscle temperature to normal physiological levels (37°C) can increase the speed of neural transmission and nerve receptor sensitivity, which may positively affect the kinematics and kinetics during the work period (37) and therefore might affect longitudinal adaptation. It should be noted, however, that temperatures above and below certain thresholds have inhibitory effects on muscle function. For example, maximal dynamic strength, power output, jumping, and sprinting performance were positively related to T_m (T_m ranged from 30.0 to 39°C). The changes were in the same order of magnitude for all the parameters (4–6%$\times$ C^{-1}) Maximal isometric strength decreased by 2% $\times$ C^{-1} with decreasing T_m, and the force-velocity relationship was shifted to the left at subnormal T_m (8).

An example of the benefits of active recovery is found in a study by Mika et al. (65), who reported that active recovery of low-intensity cycling for 30 seconds increased motor unit activation during 3 sets of leg extensions performed at 50% of maximal voluntary contraction (MVC), with no increase observed with passive recovery and stretching-type recovery. However, whether resistance exercise alone or resistance exercise coupled with interset aerobic exercise optimizes muscle temperature and neural functioning and thereafter hypertrophic adaptation needs investigation.

MECHANICAL STIMULUS

Studies have shown that manipulating certain loading parameters will have a direct impact on the mechanical stimulus associated with various resistance strength training loading schemes (e.g., hypertrophic loading schemes) (26,31,47,91). As mentioned previously, the mechanical stimuli associated with typical hypertrophic loading schemes influence both the metabolic and/or the hormonal responses. Therefore, finding methods to maintain or maximize the kinematics and kinetics of a session is important if hypertrophic adaptation is to be optimized. The methods available to achieve these ends are many, ranging from nutrition and supplementation to electrical stimulation and technology that allows accentuated eccentric loading.

Similar to the theme of previous sections, it may be that performing light aerobic exercise during the interset rest periods may provide a mean to optimize session kinematics and kinetics, especially because of the temperature-regulating properties of such exercise. For example, different muscle temperatures have been shown to influence the force-velocity relationship and muscle tension of fast and slow rat muscles (74,75). Mechanical isometric force for both slow and fast rat muscle decreased by 35–42%, velocity (muscle fiber length per second) decreased by 83–89%, and maximal power decreased by 63–64% when muscle temperature decreased from 35 to 30, 25, 20, 15, and 10°C (75).

The mechanical behavior of muscle depends on the stiffness-compliance of the musculotendinous unit, which determines the elasticity and extensibility of muscle (18). Increasing muscle temperature can affect both active stiffness (e.g., neural mechanisms discussed previously) and passive stiffness by increasing the elasticity of the muscle-tendon unit (82), which may have positive benefits to the work (force $\times$ distance) performed by a muscle and/or muscle tensile behavior (69). For example, 10 minutes of aerobic

Table 1
Proposed benefits of light aerobic activity during the interset rest period of resistance training for hypertrophy*

Mechanical	Optimize muscle temperature for greater force and velocity output, increase elasticity of muscle for increased work output (force $\times$ distance), and improve mechanical efficiency (ratio of energy turnover and mechanical output)
Metabolic	Improves lactate clearance rate and rate of energetic repletion
Hormonal	Greater total anabolic hormone production
Neural	Increase motor unit recruitment, firing frequency, synchronization and reflex potentiation, synergistic contribution, and co-contraction of antagonist

*Overall health benefits may include additional calorie expenditure and cardiovascular training effects similar to circuit training regimes.

Table 2
Proposed exercises for interset activity that may promote recovery and adaptation during resistance training regime

Body parts	Type of exercise	Suggested intensity
Lower limb	Cycling on cycle ergometer	Heart rate response of 50–60% of maximum heart rate or scale 6–11 of 15 scales based on Borg's rate of perceived exertion scale (13)
	Treadmill walking	
	Stair Stepper climbing	
Upper limb	Rowing	
	Grinder on arm-ergometer	
Combination	Skiing on ski-elliptical	

Finding aerobic thresholds that positively influence the hormonal, metabolic, neural and mechanical stimuli discussed previously certainly needs a great deal more research. In the first instance, it needs to be determined whether such interset aerobic activity negatively influences the kinematics and kinetics of ensuing sets and total session kinematics and kinetics. If there is no significant decrease in session kinematics and kinetics, then the acute effects of interset aerobic activity on the variables of interest discussed in this brief treatise need investigation. Finally, longitudinal studies are needed to quantify the change in CSA of muscle using such rest/recovery periods during hypertrophic loading programs.

CSA = cross-sectional area.

exercise (jogging) at 60% of the subject's maximum age–predicted heart rate has been found to effectively decrease (7%; $p < 0.05$) series elastic muscle stiffness (64) and thus increase muscle compliance. Furthermore, a more compliant muscle might be able to resist mechanical fatigue better because the passive components (i.e., connective tissues like tendons) may compensate for fatigue of the active component (i.e., contractile elements) in generating the prerequisite force output (11,59).

Elevating muscle temperature toward optimum working level has also been shown to increase mechanical efficiency (ratio of energy turnover and mechanical power out) from 32 to 34% (5). However, it is unknown how muscle temperature is affected across a resisted strength training session and if aerobic exercise would influence this in any manner.

PRACTICAL APPLICATIONS

Currently, most typical resistance loading schemes use passive recovery in between sets with shorter rest periods for hypertrophic loading and longer rest periods for neuronal loading schemes. It is important to note that active recovery using low-intensity aerobic exercises may have beneficial effects to hypertrophic adaptation. Some of the proposed benefits of including light aerobic activity in the interset rest period are summarized in Table 1. However, whether such adaptations occur is likely dependent on the intensity and duration of the aerobic activity used in the interset rest period, some basic examples of which are detailed in Table 2.

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