IMPROVING MUSCLE STRENGTH AND SIZE: THE IMPORTANCE OF TRAINING VOLUME, INTENSITY, AND STATUS

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Abstract:

Increases in muscle size and strength are influenced by the mechanical and metabolic stresses imposed by resistance training. Mechanical stress is induced by the use of high-intensity training and it is believed it activates a larger percentage of muscle fibers. Conversely, metabolic stress is generated by high training volumes with moderate intensities using short rest intervals. This training paradigm results in greater fatigue and potentially stimulates a greater anabolic hormone response to exercise. Although evidence exists for both strategies, it still remains inconclusive whether one training paradigm is more advantageous than the other regarding muscle hypertrophy development. In untrained adults, the novelty of most resistance training programs may be sufficient to promote hypertrophy and strength gains, whereas greater training intensity may be more beneficial for trained adults. However, the body of well-designed research in this advanced population is limited. Therefore, the purpose of this brief review is to discuss the merits and limitations of the current evidence.

Key words: *hypertrophy, endocrine response, resistance exercise*

Introduction

Manipulation of the acute program variables of resistance exercise (i.e. exercise selection and sequence, intensity, volume, frequency, and rest intervals) will affect the mechanical and metabolic stresses that are believed to influence muscle growth and strength development (Moritani, 1993; Ratamess, et al., 2009). Mechanical stress is defined by the tension created when activated muscle moves through a range of motion against an external force (Adams & Bamman, 2012). Within the context of resistance training, the severity of mechanical stress is related to the magnitude and/or duration of the applied tension (Nosaka, Sakamoto, Newton, & Sacco, 2001) and is therefore maximized by using heavy loads (1 – 6 repetition maximum [RM]) with long rest periods (3 – 5 minutes) (Ratamess, et al., 2009). In contrast, metabolic stress is defined by the use of anaerobic glycolysis resulting in an accumulation of metabolites (i.e. lactate, H+, Pi) from contractile-induced hypoxia. It is maximized through a variety of training variable combinations such as programs that employ high training volumes (8 – 12 RM) with short rest intervals (30 – 90 seconds) (Ratamess, et al., 2009). Considering the amount of variability (in program manipulation) encompassed by these two general training models (i.e. high intensity vs. high volume), determining the most useful combinations for imposing these stresses and maximizing gains in muscle size and strength appears to be an important endeavor.

Mechanical and metabolic stress on muscle adaptation

The manner in which increases in muscle size and strength are stimulated by the mechanical and metabolic stresses present during resistance exercise appears to be interrelated. Depending upon the nature of the applied tension (e.g. passive or active, muscle shortening or lengthening) sensed by a skeletal muscle, information regarding the mechanical stress is converted into a biochemical process (i.e. mechano-transduction) that results in either protein synthesis or protein breakdown (Hornberger, 2011; Martineau & Gardiner, 2001). Although this process is not well understood, mechanical tension (in some cases producing muscle damage) applied to skeletal muscle structures (i.e. lipid bilayer, spatial organization of non-contractile costameric proteins) are thought to stimulate the release of growth factors that result in protein synthesis (Hamill & Martinac, 2001; Wang, Butler, & Ingber, 1993). If sufficient tension is applied (i.e. greater than the amount to which the muscle is generally accustomed), strain to the activated structural and contractile proteins may also initiate an inflammatory response that results in the fusion of stem cells (i.e. satellite cells) to the damaged tissue (Tidball, 2005) for the purpose of improving muscular size, strength, and durability against future damage brought on by similar stimuli (Anderson & Kearney, 1982). Further, because muscle activation is proportional to the intensity of exercise (Henneman, Somjen, & Carpenter, 1965), increasing mechanical stress theoretically stimulates growth in a larger percentage of muscle fibers while also encouraging a faster and more coordinated response from the activated fibers (Brentano & Martins, 2011; Ratamess, et al., 2009). Thus, emphasizing mechanical stress can promote muscle growth across a larger percentage of muscle fibers and facilitate strength gains through improved neurological recruitment patterns.

When the emphasis is directed towards the metabolic stress imposed by resistance training, a moderate degree of mechanical stress is still present. However, adaptations are believed to be maximized via other mechanisms. For instance, blood lactate concentrations are elevated when the demands of exercise target anaerobic glycolysis (Essen-Gustavsson & Tesch, 1990). The dissociated hydrogen ions lower intracellular pH, impair glycolytic enzyme activity and impair ATP production (Cairns, 2006). These impairments are exacerbated by repeated muscular contractions that limit blood flow and oxygen delivery to the exercising musculature (Tamaki, Uchiyama, Tamura, & Nakano, 1994). The ability to rephosphorylate ADP is impaired as muscle acidity increases resulting in an increase in free radical production (Goldfarb, et al., 2008). Several investigations have indicated that these conditions may be advantageous for muscle growth (Fry, et al., 2010; Takarada, et al., 2000). In attempts to exacerbate these metabolic conditions by occluding exercising musculature, studies have shown comparable muscle growth when using low training intensities (20 – 50% 1RM) in comparison to greater training intensities without occlusion (50 – 85% 1RM) (Barcelos, et al., 2015; Martín-Hernández, et al., 2013; Vechin, et al., 2014), and greater hypertrophy when occlusion is compared to the same intensity (i.e. 70% 1RM) under normal blood flow conditions (Nishimura, et al., 2010). Though it has been suggested that these observed changes are in part the consequence of increased intracellular hydration (Martín-Hernández, et al., 2013), these findings illustrate the effectiveness of stimulating hypoxic conditions to facilitate muscle hypertrophy. Further, the fatiguing nature of this process has been suggested to positively influence muscle fiber activation (Miller, Garland, Ivanova, & Ohtsuki, 1996; Takarada, et al., 2000), where high-intensity threshold fibers (i.e. type II fibers) begin to activate as low-intensity threshold fibers (i.e. type I fibers) fatigue. Though activation may not be comparable to the imposition of high-intensity mechanical stress (Henneman, et al., 1965; Suga, et al., 2009), adaptations across a larger percentage of fibers may be stimulated by increasing metabolic stress. Figure 1 depicts a theoretical model for stimulating muscle hypertrophy and strength improvements via emphasizing mechanical and/or metabolic stress during resistance training.

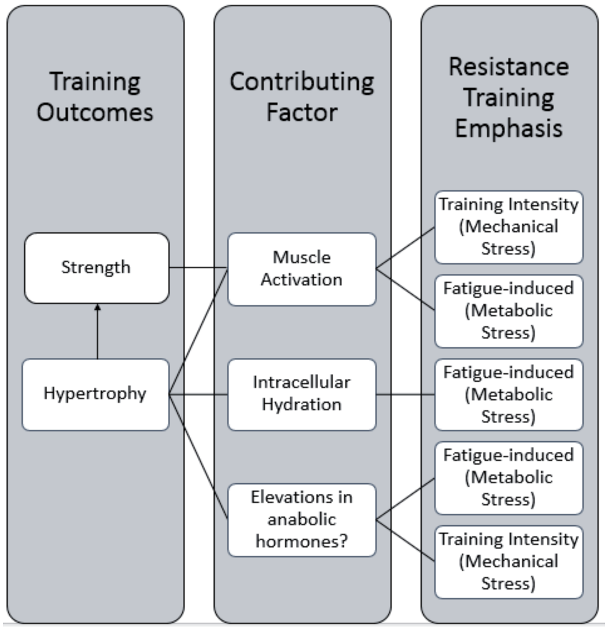


Figure 1. Theoretical model for stimulating muscle and strength improvements via resistance training.

The endocrine response to resistance exercise and muscle adaptation

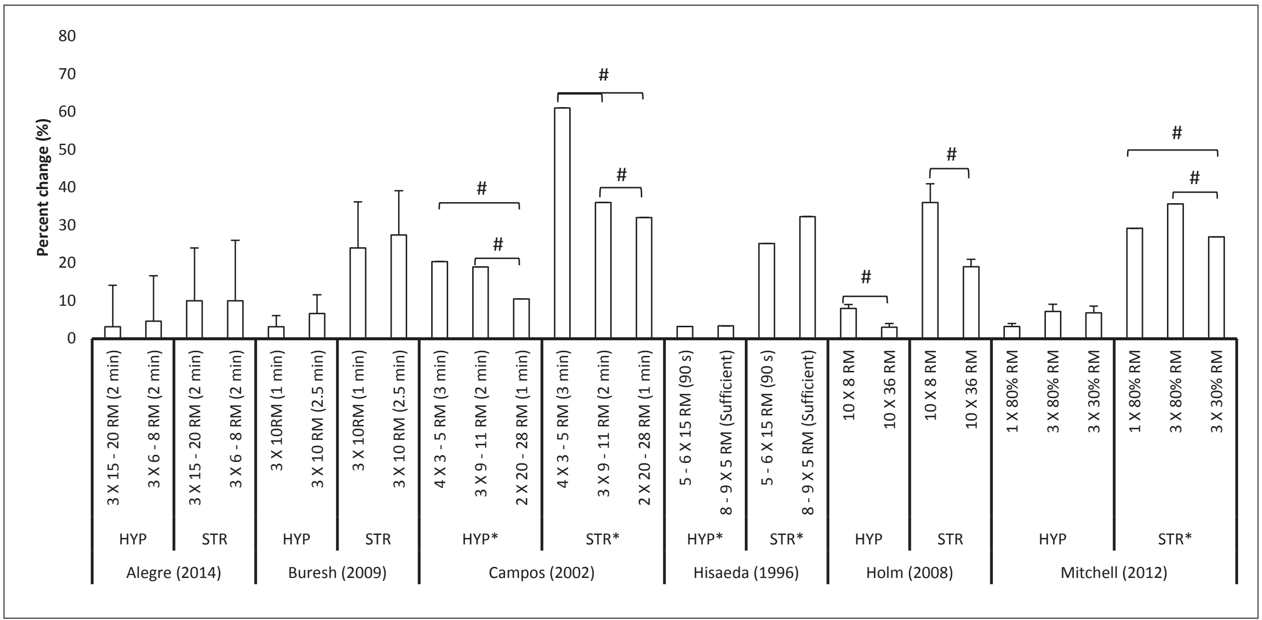
In addition to the aforementioned mechanisms, a prominent feature associated with high-volume, moderate-intensity resistance training is an elevation in the circulating concentrations of anabolic hormones (e.g. the growth hormone [GH] superfamily, testosterone, and insulin-like growth factor-1) (Kraemer & Ratamess, 2005). In a classic study, a greater GH response to resistance exercise was noted when using a higher volume and lower intensity protocol (3 × 10 RM) with short rest periods (1 min) compared to a higher intensity and lower volume (3 – 5 × 5 RM) protocol with longer rest periods (3 min) (Kraemer, et al., 1990). Subsequent investigations have reported similar results in regard to GH and high-volume resistance training, but also suggested that testosterone and insulin-like growth factor-1 (IGF-1) responses may also be augmented (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2003; Gregory, et al., 2013; Hansen, Kvorning, Kjaer, & Sjøgaard, 2001; McCaulley, et al., 2009; McKay, O'Reilly, Phillips, Tarnopolsky, & Parise, 2008; Schwab, Johnson, Housh, Kinder, & Weir, 1993; Smilios, Pilianidis, Karamouzis, & Tokmakidis, 2003; West, et al., 2010). Central to this line of research is the theory that by elevating concentrations of testosterone, GH, and IGF-1, the chances of initiating a cascade of intracellular reactions that lead to muscle growth would be improved (Mitchell, et al., 2013; Nader, 2005; Terzis, et al., 2008). However, evidence demonstrating this distinct relationship is limited.

The major limitation amongst many correlational studies is that they attempt to independently assess each hormone's relationship to muscle growth (Ahtiainen, et al., 2003; McCall, Byrnes, Fleck, Dickinson, & Kraemer, 1999; West & Phillips, 2012), thus ignoring the complex mechanisms that govern the muscle remodeling process. Further, the relationships that have been examined are based upon several unrealistic assumptions. For example, Ahtiainen and colleagues (2003) used change scores to analyze relationships, which assumes that the magnitude of the initial endocrine response (or starting muscle size) is irrelevant. When muscle growth has been related to the average hormone response (McCall, et al., 1999) or a response from a single-time point (McCall, et al., 1999; West & Phillips, 2012), the assumptions are that non-significant changes in the hormone response do not affect muscle growth or that they do not occur at all, respectively. Recently, Mangine and colleagues (2015b) have suggested that the use of structural equation modeling may overcome these limitations. Though preliminary, this procedure revealed a similar influence from elevations in testosterone on muscle growth when resistance training focused on either the mechanical (3 – 5 RM) or the metabolic (10 – 12 RM) stress (Mangine, et al., 2015b). Thus, designing a resistance training program specifically focusing on increasing the concentration of a specific hormone may not be necessary.

Role of training experience on muscle strength and size gains

Training experience is known to significantly affect training outcomes (Ratamess, et al., 2009). During the initial weeks of a new training regimen, novice lifters experience several neurological adaptations that help improve exercise technique, muscular recruitment, activation efficiency, and ultimately maximal strength (Moritani, 1993; Moritani & deVries, 1979). The beginning stages of muscle hypertrophy also take place during this time, but phenotypic changes in muscle size will not be apparent for several weeks (Moritani & deVries, 1979; Phillips, 2000). Though using greater training intensity may be theoretically more advantageous, the lack of experience in the novice lifter allows for the rapid development of muscle from a wide variety of training schemes. For example, similar hypertrophy has been observed following studies that have compared: lower (3 – 8 RM) and higher (9 – 20 RM) training volumes (Alegre, et al., 2014; Campos, et al., 2002; Hisaeda, Miyagawa, Kuno, Fukunaga, & Muraoka, 1996), shorter (60 seconds) and longer (150 seconds) rest periods (Buresh, Berg, & French, 2009), as well as single and multiple sets (Mitchell, et al., 2012). Only low (20 – 28 RM) and very low (36 RM) loads appear to be less effective in comparison to moderate (8 – 11 RM) and high (3 – 5 RM) loads (Holm, et al., 2008). Similarly, the evidence supporting the use of heavier loads (Campos, et al., 2002; Holm, et al., 2008; Mitchell, et al., 2012) and multiple sets (Mitchell, et al., 2012) for developing strength is not without contrast (Alegre, et al., 2014; Buresh, et al., 2009; Hisaeda, et al., 1996; Tanimoto & Ishii, 2006; Tanimoto, et al., 2008). Comparable strength gains have been noted following investigations comparing: heavy (5 – 8 RM, 80% 1RM) and moderate (15 – 20 RM, 50% 1RM) loads (Alegre, et al., 2014; Hisaeda, et al., 1996; Tanimoto & Ishii, 2006), shorter (60 seconds) and longer (150 seconds) rest periods (Buresh, et al., 2009), and slower (4 – 6 seconds) versus normally (2 – 3 seconds) paced repetitions (Tanimoto & Ishii, 2006; Tanimoto, et al., 2008). Thus it appears that several options exist for designing effective resistance training programs for healthy, untrained adults. Figure 2 illustrates the percent changes in lower-body muscle size and strength in untrained individuals across several investigations involving a wide variety of training intensities, volumes, and rest intervals.

Individuals with several years of resistance training experience appear to be limited in their capacity to stimulate muscle adaptations from non-specific training designs (Ratamess, et al., 2009). Numerous studies have compared differences in intensity and volume of training on changes in strength and size in resistance-trained adults (Brandenburg & Docherty, 2002; Mangine, et al., 2015a; Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015; Schoenfeld, et al., 2014). These studies indicate that training intensity is more advantageous for stimulating strength gains, but are less conclusive about promoting muscle growth. In answer to this question, only one study has reported that a higher training intensity (3 – 5 RM) is more effective for simulating hypertrophy than a higher training volume (10 – 12 RM) (Mangine, et al., 2015a). The remaining studies did not observe any differences between high-intensity and high-volume training protocols for stimulating hypertrophy



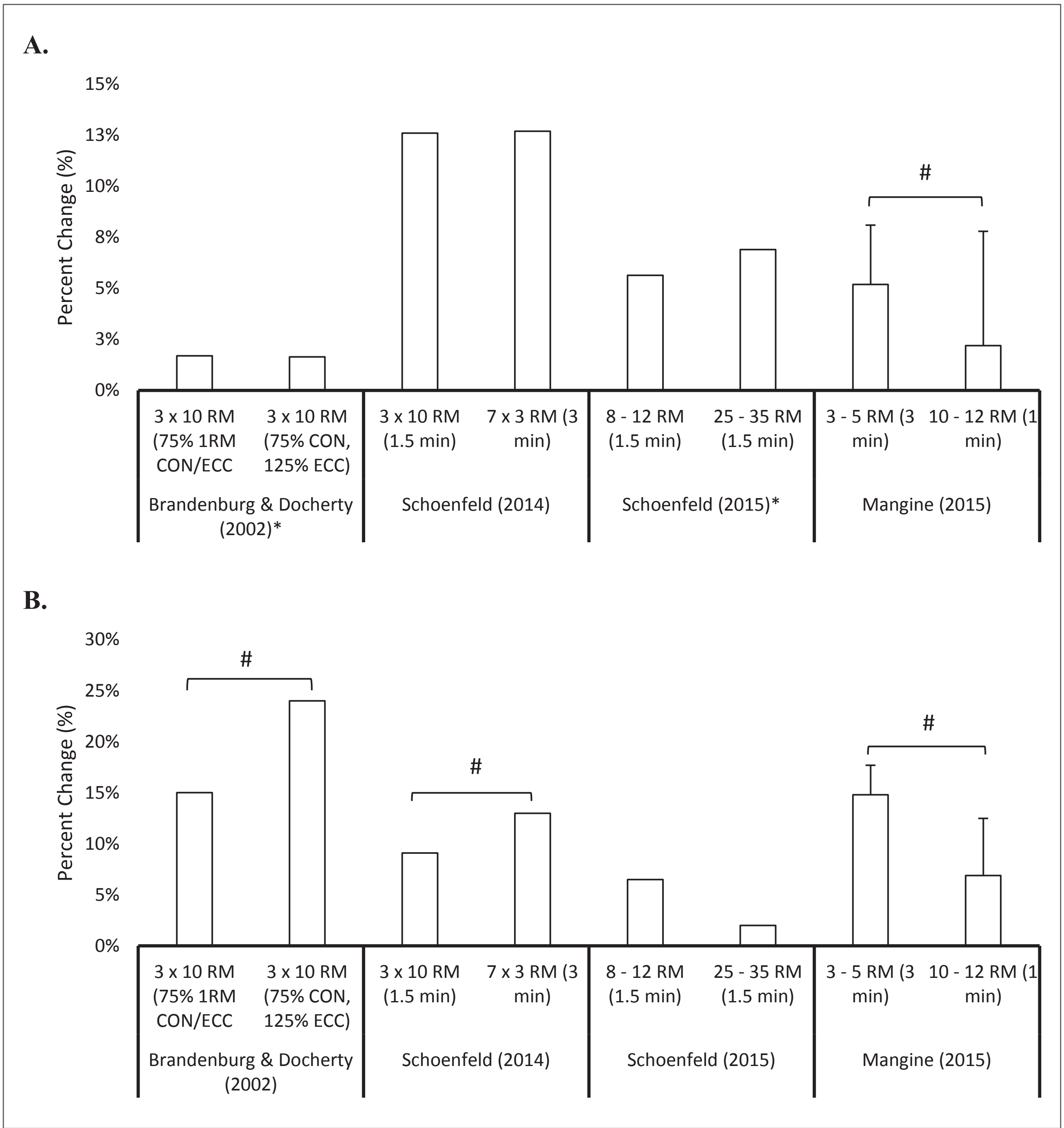
Note. HYP – denotes percent changes in muscle size. STR – denotes percent changes in muscle strength.
* Estimated percent change from reported mean changes.
# Significant difference reported between groups.

Figure 2. Percent changes in lower-body muscle size and strength in untrained individuals.

(Brandenburg & Docherty, 2002; Schoenfeld, et al., 2015; Schoenfeld, et al., 2014). The hypertrophy and strength outcomes from studies investigating the effect of training intensity in resistance-trained men are presented in Figures 3A and 3B, respectively.

Study design or methodological differences may have confounded the results of the three studies which were unable to observe significant group differences in hypertrophy. For example, two of the investigations (Brandenburg & Docherty, 2002; Schoenfeld, et al., 2014) utilized resistance training protocols that were not typical for resistance-trained adults (Hackett, Johnson, & Chow, 2013; Swinton, Lloyd, Agouris, & Stewart, 2009). Brandenburg and Docherty (2002) only incorporated two single-joint (i.e. preacher curl and supine elbow extension) exercises into training, while a typical workout for the high volume group in the Schoenfeld et al. (2014) study only lasted ~17 minutes; a likely consequence of participants only being required to complete three exercises (1 × upper-body push, 1 × upper-body pull, and 1 × lower-body) per workout session. Another consideration not taken into account was the novelty of the training stimulus. Although the participants in each study (Brandenburg & Docherty, 2002; Schoenfeld, et al., 2015; Schoenfeld, et al., 2014) were considered to be "trained", it is unknown whether their regular training habits were comparable to those introduced during the investigations. Finally, only one of the three studies used a criterion-related method (i.e. magnetic resonance imaging) for tracking changes in muscle size (Brandenburg & Docherty, 2002). The other two investigations utilized ultrasound (Schoenfeld, et al., 2015; Schoenfeld, et al., 2014), which is dependent upon the skill of the technician for accuracy. Given the size of their reported changes (< 1 cm), it would have been advisable to demonstrate that these changes exceeded the measurement error for their specific ultrasound measures (Weir, 2005).

To account for these limitations, all of the resistance-trained participants involved in the study by Mangine et al. (2015a) were required to complete the same two-week preparatory training phase prior to the actual investigation. Upon entering the investigation in a similarly trained state, the participants then completed 8 weeks of either a high intensity + long rest (3 – 5 RM, 3 min), or high volume + short rest (10 – 12 RM, 1 min) resistance training protocol using 3 – 5 multi-joint exercises along with 1 – 3 assistance exercises for a total of six exercises per workout session (Mangine, et al., 2015a). Following training, the significantly greater changes in lean arm mass (as measured by dual energy x-ray absorptiometry) observed in the high intensity group were supported by the observation that 93.3% of those participants experienced changes that exceeded the measurement error for lean arm mass (0.23 kg), while only 64.3% of the participants did so in the high volume group. Although no other group differences were observed, the percentage of participants exceeding the measurement error for assessing lean body mass (1.53kg; 60.0% vs. 35.7%), lean leg mass (0.91 kg; 46.7% vs. 21.4%), and *m. vastus lateralis* cross-sectional area (3.05cm^2; 50.0% vs. 21.4%; as measured by ultrasound) all favored high intensity



Note. A. Changes in muscle size; B. Changes in muscle strength
* Estimated percent change from reported mean changes.
# Significant difference reported between groups.

Figure 3. Percent changes in upper-body muscle size and strength in resistance trained individuals.

resistance training, whereas the high volume protocol did not provide an advantage in any of the collected measures.

Conclusion

The mechanical and metabolic stresses imposed by resistance training are important for stimulating increases in muscle strength and hypertrophy. For novice lifters, the evidence supports the use of a wide variety of training paradigms to achieve these goals, though it would appear that lower training intensities (> 20 RM) are less beneficial. For the advanced resistance training, the current recommendations include the use of both high and moderate loads for low to high volumes using an array of rest interval lengths to target the mechanical and metabolic mechanisms of muscle hypertrophy. Recent evidence suggests that emphasizing mechanical stress via heavy loads (3 – 5 RM) with sufficient rest intervals (~3 min) will stimulate changes across a larger percentage of muscle fibers and result in greater gains in both muscle strength and hypertrophy in resistance-trained individual. Nevertheless, the research in this population is limited and warrants further study into the role of training intensity and volume on strength and hypertrophic gains in skeletal muscle.

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