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1 **MUSCLE HYPERTROPHY: A NARRATIVE REVIEW ON TRAINING**

2 **PRINCIPLES FOR INCREASING MUSCLE MASS**

3 Louis P Howe, MSc., BSc, Dr Paul Read, Dr Mark Waldron

4

5 **ABSTRACT**

6 Developing muscle cross sectional area has the potential to enhance performance for
7 many athletes. As emerging evidence challenges traditional beliefs regarding the
8 prescription of hypertrophy focused training programs, this review provides an
9 overview of the current literature relating, specifically, to programming variables.
10 Evidence-based recommendations are provided for the design of effective resistance
11 training programs, with the goal of increasing an athlete’s skeletal muscle mass.

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1 INTRODUCTION

2 Within a strength and conditioning coach's practice, the development of physical
3 qualities that result in improvements in athletic performance are arguably at the heart
4 of the role. One such physical quality is maximal force development as it relates to
5 the constraints of each specific sport skill (86). Although neurological factors
6 primarily contribute to the development of force, structural adaptations following
7 long-term strength training may also influence force generation capacity (19), though
8 the role of muscle hypertrophy is likely to be exaggerated for increasing maximal
9 strength (50). Nonetheless, increases in muscle mass are typically desirable in
10 instances where athletes are required to produce large forces against their external
11 environment. Indeed, cross-sectional area of the limbs has been associated with both
12 horizontal and vertical power production in elite athletes (94). This concept provides
13 the rationale for developing the skeletal muscular system, prior to neural factors, as
14 part of a 'phase potentiation periodisation model' (86). Therefore, increases in muscle
15 mass can, in many circumstances, support athletic development to a point.

16

17 Alongside performance considerations, increasing muscle mass may also be required
18 following injury occurrence. During the rehabilitation process, muscle atrophy is a
19 key concern, secondary to unloading (40). In cases where muscle atrophy is
20 heightened due to immobilisation, the rehabilitation time has been suggested to be
21 extended (8). Therefore, recovery of lean muscle tissue may be a significant objective
22 that should be achieved in order to restore the athlete to full function following injury.

23

24 Three proposed primary mechanisms are responsible for training adaptations,
25 including: mechanical tension, metabolic stress and muscle damage (66). Mechanical

1 tension refers to the loading of muscle and is proposed to disrupt skeletal muscle
2 structures, compromising the integrity of individual muscle fibres and leading to
3 cellular responses via stimulation of the mTOR pathway (38). Local metabolic stress
4 involves the accumulation of metabolic by-products, such as blood lactate (B[La])
5 and hydrogen ions ($[H^+]$), caused by a cumulative demand on fast glycolysis (32, 90).
6 It is thought that this metabolic perturbation has the potential to stimulate anabolism
7 through mechanisms associated with increased local release of myokines, greater
8 reactive oxygen species production, cell swelling and acute hormonal responses (67).
9 Lastly, muscle damage is theorised to lead to hypertrophic responses (37), whereby
10 the inflammatory response and upregulation of muscle protein synthesis to exercise
11 induced muscle damage results in greater muscle size. For the interested reader
12 seeking further understanding of each mechanism and the underlying physiological
13 adaptations, please refer to Schoenfeld (66).

14

15 Traditional beliefs of the most effective strategies for the development of lean muscle
16 tissue have recently been challenged (17). This article reviews the current body of
17 literature related to training considerations for increasing muscle hypertrophy in
18 young healthy adults. Where appropriate, this review will indicate the training status
19 of the subjects used for each investigation. As such, this will allow coaches to
20 adequately interpret the discussion in order to suitably apply the findings in their own
21 strength and conditioning practice.

22 In particular, this article discusses the following foundational factors that should
23 influence a coach's decision-making when designing resistance training programs for
24 increasing muscle size:

- 25
- Training volume

- 1 • Load
- 2 • Training frequency
- 3 • Training to momentary muscular failure
- 4 • Exercise variation
- 5 • Contraction type
- 6 • Exercise order
- 7 • Repetition tempo
- 8 • Inter-set recovery

9 Evidence-based recommendations will be provided for the design of effective
10 resistance training programs, with the goal of increasing an athlete's skeletal muscle
11 mass.

12

13 This article does not describe, with any detail, the physiological mechanisms for
14 increasing in muscle mass, nor does it examine the evidence relating to specific
15 training techniques aimed at increasing muscle hypertrophy. Likewise, while a variety
16 of nutritional and lifestyle factors can be manipulated to augment the effects of
17 hypertrophy training (63), these will not be discussed herein.

18

19 **TRAINING VOLUME**

20 Resistance training volume, described as the amount of work completed for any given
21 unit of time, is a key variable for consideration in the pursuit of muscle hypertrophy.

22 Much like increases in maximal strength (44), muscle hypertrophy is enhanced
23 following high-volume longitudinal programs, particularly when multiple sets of
24 exercise are utilised, rather than single set routines (45). This evidence has been used
25 to support the current American College of Sports Medicine (ACSM)

1 recommendations, which suggest prescribing multiple sets for advanced lifters in
2 order to increase muscle hypertrophy (4). Acutely, significant increases in muscle
3 protein synthesis have been observed following high volume training in comparison
4 to low volume sessions (14), thus reinforcing this recommendation.

5

6 Although acute responses are not linearly accompanied by long-term increases in lean
7 muscle mass (53), numerous longitudinal studies have demonstrated that high volume
8 training facilitates muscle hypertrophy (20, 58, 59, 62). Using ultrasound to measure
9 elbow flexor and extensor muscle thickness, Radaelli et al. (59) showed that five sets
10 of exercises per training session resulted in significantly greater upper arm
11 development when compared to one and three set routines, across a six-month
12 training period. This increase in muscle mass was accompanied by significantly
13 superior gains in five repetition maximum (RM) loads for the bench press and lat pull
14 down following the high volume intervention (59).

15

16 While findings of higher volumes leading to superior gains in muscle growth are not
17 consistent throughout the literature (11, 51), a recent meta-analysis identified a dose-
18 response relationship between training volume and muscle hypertrophy (73). For
19 example, high weekly volumes (>10 total sets per body part, per week) were
20 associated with greater increases in muscle mass than lower volumes (< 5 sets, per
21 body part, per week), with an effect size of 0.241 (73). Schoenfeld et al. (73)
22 concluded that higher volume training produces greater gains in muscle mass than
23 lower volume training.

24

1 The mechanisms underlying the relationship between high training volume and
2 increased muscle mass are potentially linked to the prolonged metabolic stress (34). A
3 greater number of total sets per body part increases the total duration placed on the
4 relevant energy systems and variety of muscle fibres during training. However, if
5 prolonged metabolic stress is responsible for increases in muscle hypertrophy
6 following high volume routines, then coaches should carefully manage the types of
7 exercises that comprise their program, particularly if high-load exercises are included.
8 For example, utilisation of drop sets has the potential to heighten the accumulation of
9 metabolic by-products by placing greater demand on the fast glycolytic energy
10 systems (33). If a high number of sets of this type of training were to be prescribed
11 across sessions in order to increase volume, then an athlete may be taken beyond their
12 recovery threshold, resulting in a blunting of the hypertrophy response (28).

13

14 It is important to emphasise that the relationship between volume and muscle growth
15 is unlikely to be linear. That is; continual increases in training volume would
16 inevitably lead to a plateau in the development of muscle mass. This concept is
17 supported by the recent findings of Amirthalingham et al (3). In their investigation, no
18 significant difference in muscle hypertrophy was found between subjects who
19 performed either 5 sets of 10 repetitions or 10 sets of 10 repetitions over a six-week
20 period (3). Coaches should appreciate each individual athlete's recovery capacity
21 when prescribing training programs, with excessive volumes leading to extended
22 overreaching or, perhaps overtraining syndrome (83). The net effect of this would be
23 a reduction in the capacity for anabolic processes due to a heightened catabolic status
24 and increased protein metabolism (46). In this sense, the relationship between volume
25 and hypertrophy training is suggested to follow an inverted-U curve (71). As each

1 individual possesses their own capacity to recover from a given amount of work,
2 strength and conditioning coaches should use appropriate testing and monitoring tools
3 to identify thresholds which maximize increases in muscle mass, while maintaining
4 the athlete's health.

5

6 **LOAD**

7 The manipulation of load during resistance training, which is typically presented as
8 the percentage of maximal load that can be used for any given movement, has been
9 proposed as a vital factor in maximising muscle hypertrophy (66). This is likely to
10 relate directly to the mechanism of 'mechanical tension', as increased load results in
11 an intensification of tension on the musculotendinous unit. However, loads exceeding
12 85 % 1RM, while maximising mechanical tension, fail to provide adequate stress to
13 the fast glycolytic system due to reduced time under tension (60). Therefore, as a
14 compromise in emphasising both mechanical tension and metabolic stress
15 simultaneously, moderate loads (70-85 % 1RM) are traditionally recommended (4).

16

17 It has been suggested that high-load training (>65 % 1RM) leads to superior gains in
18 muscle mass due to the recruitment and fatigue of higher threshold motor units (43,
19 57). This outcome might be desirable among athletes, as hypertrophy of fast-twitch
20 fibres is known to be much greater than slow-twitch muscle fibres (1, 89) and fast-
21 twitch fibres demonstrate higher velocity contractions (97). Fry (29) showed that
22 programs incorporating loads above 50 % 1RM led to greater fast-twitch fibre
23 hypertrophy compared to slow-twitch fibres. Furthermore, during short duration
24 isometric contractions with low-load (30-45 % 1RM), glycogen depletion is non-
25 existent in type IIX fibres but rises significantly with increased resistance (91).

1

2 Although these findings suggest that type II fibres are stimulated to a greater degree
3 when exposed to heavy loading, it has been suggested that low-load training also
4 recruits fast-twitch muscle fibres, providing that the working set is continued close to
5 volitional fatigue (15). When high-load training has been directly compared to low-
6 load, Mitchell et al. (52) found no significant difference in fibre-type specific
7 hypertrophy. However, this study has been suggested to be underpowered (57),
8 consequently lacking the sensitivity required to establish a difference in fibre type
9 hypertrophy between loading strategies. As this investigation did establish a non-
10 significant difference in type I hypertrophy between high- and low-load training (17
11 vs. 30%, respectively) (52), it may be that the lack of statistical power prevented the
12 identification of differences. Mitchell et al. (52) used a sample size of 12 participants
13 per group, which would achieve a poor statistical power of 0.17, based on our own
14 *post-hoc* analysis, assuming an alpha level of 0.05 and an effect size 0.3 (*d*). It is
15 important for coaches to note that this investigation demonstrated very little
16 difference between high- and low-load training for type II fibre hypertrophy (16 vs.
17 18%, respectively) (52). Further evidence is required to establish whether load
18 determines fibre-type hypertrophy. Of course, coaches shouldn't underestimate the
19 importance of recruiting a wide range of motor units through the prescription of high
20 and low loads. Indeed, in the development of muscle cross sectional area, which is
21 determined by the increase in myofibrillar proteins and thus muscle fibre diameter, a
22 reliance upon the hypertrophy of type I fibres also exists. Exercises that activate a
23 greater proportion of type I fibres would, therefore, be of equal use in maximising
24 hypertrophic adaptation.

25

1 When considering whole muscle hypertrophy, a meta-analysis by Schoenfeld et al.
2 (76) showed high-load training ($> 65\%$ 1RM) to be no more effective than low-load
3 training ($<60\%$ 1RM) for increasing skeletal muscle mass. However, there was a
4 non-significant trend in favour of high-load training ($p = 0.076$), which might be due
5 to the low number of studies investigating the effects of training load on muscle
6 hypertrophy. The use of low-load training strategies is supported by reports that
7 training at 30% 1RM resulted in greater acute muscle protein synthesis relative to
8 high-load training (90% 1RM), providing low load training is continued to failure
9 (15). Additionally, Mitchell et al. (52) showed that a low-load training (30% 1RM)
10 regime resulted in similar increases in whole muscle cross-sectional area when
11 compared to high-load training (80% 1RM) over a 10-week period. Furthermore,
12 using a moderate loading scheme (8-12RM) or a variety of training loads (2-4RM, 8-
13 12 RM and 20-30RM) across a training week has been shown to result in similar
14 increases in muscle mass following an eight-week intervention (72).

15

16 Therefore, when coaches are prescribing a training stimulus for muscle hypertrophy,
17 high- or low-loads may be selected. Traditionally, loads $> 65\%$ 1RM have been
18 prescribed for hypertrophy programs, which might not be necessary. This information
19 might also be useful for injury rehabilitation, where low-load training can be an
20 effective method to increase muscle mass without the augmented forces associated
21 with high-load training, leading to reduced joint loads.

22

23 While low-load training might be equally as effective for muscle hypertrophy,
24 coaches should not overlook the superior strength adaptations that high-load training
25 provides in comparison to low-load training (10, 65, 55, 68). These differences are

1 explained by the principle of training specificity, whereby the all-out efforts required
2 during high-load training produces maximal force, whereas low-load training requires
3 only low-to-moderate forces in a fatigued state (18). As such, high-load training that
4 results in the accumulation of considerable training volume may allow for increased
5 muscle strength alongside substantial increases in muscle mass. Such adaptations
6 have been defined as *functional hypertrophy*, where increases in muscle mass and
7 maximal strength occur simultaneously (64).

8

9 **TRAINING FREQUENCY**

10 Training frequency is defined as the number of training sessions per unit of time.
11 From the perspective of increasing an athlete's muscle mass, training frequency
12 relates directly to training volume. During a single training session, the capacity to
13 recover from the work performed is limited. Therefore, for high levels of training
14 volume to be achieved, multiple sessions are likely to be required. As training volume
15 is a key factor in muscle growth (73), optimising training frequency will allow for
16 volume to be maximized without excessive fatigue being incurred.

17

18 In establishing the optimal training frequency for muscle hypertrophy, Wernborn et
19 al. (95) showed that two-to-three training sessions per week was optimal. This is
20 supported by a recent meta-analysis, identifying that two weekly training sessions for
21 the same muscle group led to significantly greater increases in muscle mass compared
22 to one or three sessions per week (74). These findings are in contrast to the traditional
23 practices of some bodybuilders, who are reported to train a single muscle group once
24 per week (36). However, it should be noted that both Schoenfeld et al. (74) and

1 Wernborn et al. (95) included both untrained and trained subjects in their analysis,
2 potentially impacting the application for athletic populations.

3

4 For the majority of resistance-trained athletes, it is inevitable that the training volume
5 per session and training frequency are inversely related, such that an increase in
6 training frequency leads to a reduction in volume per session. In the case of a high
7 frequency training program, where a muscle group is trained on multiple occasions,
8 the training volume for each session should be lower in order to prevent excessive
9 weekly training volumes. High training frequency should be periodized strategically
10 so that adequate recovery is provided between sessions. Indeed, training the same
11 muscle group before protein synthesis has returned to homeostasis may impair the
12 muscle hypertrophy process (49); thus, 48 to 72 hours' rest between training sessions
13 for the same muscle group may be required in order to optimise the training response
14 (74).

15

16 Although this general recommendation is likely to be appropriate for many athletes, it
17 has been recently suggested that higher training frequencies may be more beneficial
18 for trained individuals in stimulating greater muscle hypertrophy (23). As trained
19 individuals adapt to resistance training in the long-term by reducing the muscle
20 protein synthesis response (22), distributing training volume across a higher
21 frequency has the potential to increase the total time spent in a positive protein
22 balance by an athlete (23). Such approach would require a large reduction in training
23 volume per session in order to avoid the accumulation of excessive fatigue. Dankel et
24 al. (23) suggests strategies of high training frequency may be less than optimal for
25 untrained individuals, as the subsequent bouts of resistance training would likely

1 interfere with the increase protein synthesis response for the preceding training
2 session. While this hypothesis is supported mechanistically, at present little evidence
3 exists to confirm this theoretical model and future investigations are required.

4

5 **TRAINING TO MOMENTARY MUSCULAR FAILURE**

6 Training to momentary muscular failure results in the inability to produce the
7 necessary force to lift a load through the concentric phase (66). When training to
8 failure, it is hypothesised that maximal motor unit recruitment is achieved resulting in
9 the fatigue of a greater number of muscle fibres (16, 98), in turn leading to a greater
10 hypertrophic response. Performing repeated muscle contractions of a fixed load (i.e. a
11 set) to failure is associated with progressive increases in both the perception of effort
12 (5) and muscle activation levels (obtained from surface EMG) (87). These findings
13 infer an increase in the recruitment of high-threshold motor units (87). In support of
14 this, Burd et al. (14) reported no differences in muscle adaptation in low- or high-load
15 training strategies, providing that each set was completed to failure. However, it is
16 difficult to come to such conclusions where training volume is not equated.

17

18 Goto et al. (34) investigated the effects of training to failure on muscle hypertrophy in
19 a twelve-week study, where participants were volume-matched and assigned to either
20 a group that trained to failure or a group that incorporated an intra-set rest preventing
21 failure from occurring. With volume equated, the “no-rest” group using repetition
22 maximums achieved significantly greater muscle hypertrophy in the quadriceps, along
23 with higher levels of maximal strength (34). This is similar to the findings of Schott
24 (78), who also identified training to failure induced superior hypertrophy adaptations
25 compared to finishing a set prior to failure.

1

2 Although these findings indicate the positive effects of training to failure, caution
3 should be taken with routinely prescribing this approach. Sundstrup et al. (87)
4 reported that complete concentric failure was not required in order to achieve full
5 muscle activation using EMG analysis, with a plateau occurring during the final 3-5
6 repetitions with a 15 RM load. This is an important consideration, as routinely
7 performing resistance training to failure may produce symptoms of overtraining, and
8 subsequent threats to the anabolic status of athletes (39). As many of the studies
9 evaluating the benefits of training to failure are of relatively short duration, the long-
10 term implications are yet to be elucidated. Such findings have been identified in
11 training programs for maximal strength (25). Therefore, it is recommended that
12 practitioners strategically expose their athletes to training that induces failure to
13 prevent the occurrence of overtraining.

14

15 **EXERCISE VARIATION**

16 Traditionally, bodybuilders tend to subscribe to the notion that broad exercise
17 variation is required in order to maximize muscle hypertrophy (36). A proposed
18 rationale is that muscles such as the pectoralis major (47) and trapezius (7) perform
19 different movements of the same joint segment via the functional subdivisions of each
20 muscle (6). As such, manipulating exercises has the potential to target large sections
21 of the muscle. For example, in the case of the pectoralis major, utilising a 15° decline
22 during the bench press results in greater EMG activity of the sternal fibres relative to
23 the clavicular fibres (47). Therefore, in order to overload specific portions of different
24 muscles, a wider variety of exercises is essential to recruit and fatigue all muscle
25 subdivisions.

1

2 The above concept may be extended to muscles that possess numerous fibres
3 orientated at a variety of angles between the origin and insertion. For example, both
4 the long head and short head of the biceps brachii musculature are architecturally
5 classified as fusiform (31); the biceps brachii is not functionally compartmentalised
6 like the pectoralis major muscle. By manipulating shoulder and elbow positioning, the
7 biceps brachii demonstrates a region-specific muscle activation strategy during
8 supination (12). Furthermore, during elbow flexion, the biceps brachii does not
9 uniformly shorten, suggesting that separate muscle fascicles contract concentrically at
10 varying rates thus manipulating the range in the work produced for each muscle fibre
11 (31).

12

13 Non-uniform muscle fibre recruitment has also been shown to occur in the hamstrings
14 musculature, with EMG activity varying between the lower and upper fibres,
15 depending on whether the hamstrings were required to flex the knee or extend the hip
16 against resistance (69). This finding was supported by the work of Mendez-
17 Villanueva et al. (54), who used functional magnetic resonance imaging to
18 demonstrate regional differences in muscle activation of each head of the hamstrings
19 during a variety of posterior chain exercises. Likewise, during resisted elbow
20 extensions, multi-joint and single joint exercises have been shown to elicit regional
21 differences in muscle activation. For example, single-joint elbow extension exercise
22 has been shown to increase activation of the distal portion of the triceps brachii (92).
23 Chronic adaptations to these exercises led to greater increases in cross-sectional area
24 in the distal region of the muscle after a 12-week overloaded intervention program
25 (92). Similarly, Wakahara et al. (93) showed that a multi-joint elbow extension

1 exercise (dumbbell bench press) increased muscle activation levels of the middle and
2 proximal region of the triceps brachii, leading to greater growth in these areas. This
3 suggests that in order to maximize hypertrophic adaptation, it is necessary to stress
4 the muscle across its different portions (proximal-distal) using a variety of exercises.

5

6 Fonseca et al. (26) showed that changing exercises within a 12-week period was more
7 effective for increasing muscle strength and hypertrophy compared to solely
8 manipulations in training load. Within this investigation, hypertrophy of the vastus
9 medialis and rectus femoris was more for subjects who varied exercises over three-
10 week cycles, compared to subjects who used the same exercise throughout (26). This
11 evidence supports the concept of utilising numerous exercises in order to fully exploit
12 adaptations of muscle hypertrophy.

13

14 One potential mechanism for the regional differences in hypertrophy may be the
15 compartmentalisation of skeletal muscle (6). Within the neuromuscular system,
16 sections of the muscle are innervated by specific motor units that are responsible for
17 orchestrating the contraction of their respective fibres (6). Indeed, even fusiform
18 muscle fibres terminate intrafascicularly (31, 96), meaning that there is potential for
19 various neuromuscular compartments to exist within a given muscle. As fibre-type
20 distribution inside muscles is also region specific (47, 84), intramuscular differences
21 are likely to exist relative to function. Therefore, resistance training targeting
22 preferential hypertrophy of fast-twitch fibres with strategies such as eccentric-only
23 training, may also lead to non-uniform hypertrophy (discussed in the following
24 section). It is likely that each muscle contains multiple neuromuscular compartments
25 that can be selectively overloaded through varying exercise selection.

1

2 **CONTRACTION TYPE**

3 Eccentric muscle contractions increase the amount of mechanical stress on the
4 musculotendinous units (7). While EMG amplitude is lower during eccentric
5 contractions, fast-twitch fibres are preferentially recruited over their slow-twitch
6 counterparts, leading to greater tension per muscle fibre and a bias toward type II
7 fibre damage (79). The greater muscle damage incurred promotes an adaptive
8 response in the fast-twitch fibres, which possess greater potential for growth (1).

9

10 Traditional methods to determine loads during a program typically use the concentric
11 strength of the athlete (i.e. percentage of 1 RM). However, because eccentric strength
12 can be as much as 45 % greater than concentric strength (41), it is likely that eccentric
13 training is rarely exploited to its full potential. Since, submaximal eccentric training
14 does not acutely raise muscle protein synthesis when compared to concentric training,
15 the downstream effects on muscle hypertrophy are likely to be limited if traditional
16 approaches to quantify load are used (21). However, when eccentric training is
17 performed with maximal resistance, muscle protein synthesis is significantly greater
18 than load-matched concentric training (56). When eccentric training is applied over a
19 number of weeks, muscle hypertrophy adaptations are shown to be superior to that of
20 concentric training (61). Therefore, supra-maximal eccentric training is likely to
21 induce greater hypertrophic adaptations, assuming that the necessary recovery is
22 provided. However, this is not consistent within the literature, with some studies
23 identifying no difference between modes of contraction (28). This is potentially due to
24 difficulties in matching volume-load between conditions, with eccentric training
25 requiring higher loads.

1

2 In a recent meta-analysis, Schoenfeld et al. (77) identified a non-significant trend that
3 eccentric-only training induced greater hypertrophic adaptations than concentric-only
4 concentric training for inducing hypertrophic gains ($p=0.076$). Mean effect sizes for
5 muscle growth following eccentric-only and concentric-only training were 1.02 and
6 0.77 respectively, with an effect size difference of 0.27. The authors propose that due
7 to many of the studies included for analysis matching the total repetitions performed
8 and not total work, the higher amount of work completed was likely to be a major
9 influence on these findings (77).

10

11 A further consideration with eccentric training is the identification of region-specific
12 hypertrophy. Franchi et al. (27) showed that although muscle hypertrophy of the
13 vastus lateralis was equal between concentric and eccentric training, mid portion
14 hypertrophy was higher in the concentric group, whereas the eccentric group
15 experienced greater growth in the distal division. This may be due to the change in
16 muscle architecture, secondary to the activation of altered molecular responses,
17 following a concentric or eccentric-only training intervention (27). Eccentric-only
18 resistance training leads to increases in fascicle length, while concentric-only training
19 promotes greater pennation angles, indicating a higher number of sarcomere's in
20 parallel (27). This has the potential to alter the force-velocity relationship of any
21 given muscle, with an increased fascicle length (sarcomere's in series) resulting in
22 superior shortening velocities (19). Conversely, a muscle with a larger pennation
23 angles has the capacity to create higher levels of force due to an increased number of
24 sarcomeres in parallel (19).

25

1 **EXERCISE ORDER**

2 It is generally recommended that multi-joint exercises, relying on work being
3 produced by large muscle groups, should be performed in the initial stages of a
4 training session (2). As more repetitions can be completed with any given load earlier
5 in the training session (82), greater long-term accumulation of training volumes will
6 occur in response to exercises that are performed during these periods (81). While this
7 is dependent upon the design of the training session, it is, therefore, possible that
8 using multi-joint exercises at the start of a training session will result greater
9 hypertrophic adaptations in larger muscle groups.

10

11 Although this provides one reason to include multi-joint exercises earlier in the
12 training session, little evidence exists to support this hypothesis. This is mostly due to
13 limited amount of studies investigating the relationship between chronic structural
14 adaptations and exercise order (81). Of the research that does exist, Simão et al. (80)
15 and Spinetti et al. (85) both showed that ordering training sessions such that single-
16 joint elbow extension and flexion exercises were performed before the bench press
17 and lat pull-down, resulted in increased triceps muscle volume when compared to the
18 reverse order (effect size = 2.07 and 1.08 vs. 0.75 and 0.40). It should be noted that no
19 difference was seen for the biceps musculature between conditions in either
20 investigation (80, 85). However, neither study attempted to establish whether
21 structural changes occurred in the pectoralis major and latissimus dorsi muscles,
22 limiting the scope of their conclusions. It is likely that muscles trained and fatigued in
23 the early stages of a training session will accumulate higher training volumes and
24 therefore, adapt to a greater extent. As such, practitioners should prioritize exercises

1 for completion in the initial stages of the training session, based on the individual
2 needs of the athlete (81).

3

4 One issue with performing single-joint exercises prior to multi-joint exercises is that
5 the pre-fatigued muscle may alter the muscle activation patterns during the multi-joint
6 exercise. In both the lower extremity (9) and upper extremity (30), pre-fatiguing a
7 muscle with a single-joint exercise has been shown to decrease the recruitment of the
8 muscle during a multi-joint exercise. This occurs alongside an increased recruitment
9 of the synergistic muscles during the compound movement (30). However, activating
10 a muscle with a single-joint exercise but not to the point of fatigue may increase its
11 activation in the subsequent multi-joint exercise (42). Therefore, coaches may order
12 exercises to strategically manipulate the recruitment patterns of prime movers during
13 exercises in order to alter muscle activation patterns.

14

15 **REPETITION TEMPO**

16 Explosive strength training demonstrates a clear advantage over slow concentric
17 training for strength development (13). This is likely to be due to the higher forces
18 that are required to increase acceleration during the concentric phase of an
19 appropriately loaded lift. However, when attempting to develop muscle mass, this
20 relationship is not evident (70). This potentially occurs due to the reduced lifting
21 speed requiring less force, prolonging the duration of the set leading to increased
22 metabolic stress. When loads are lifted with the intention of achieving a high velocity,
23 the forces will be higher, increasing the tension of the muscle. In such instances
24 where the repetition duration increases, loading must be reduced due to the time
25 component placing increased demands on the involved energy systems (88).

1 Therefore, manipulating repetition tempo is just another example of the inverse-
2 relationship between volume and load.

3

4 The available evidence shows equivocal differences between short and long repetition
5 tempos for muscle hypertrophy development. Tanimoto and Ishii (88) determined that
6 as long as subjects trained to failure, there was no significant difference in quadriceps
7 hypertrophy following high-load normal tempo training (1-second concentric: 1-
8 second eccentric: 1-second relaxation) when compared to a low-load, slow training
9 group (3-seconds concentric: 3-seconds eccentric: 1-second relaxation). Furthermore,
10 a recent meta-analysis showed no significant difference in muscle growth when
11 comparing regimes consisting of 0.5-seconds to 8-seconds for completion of the
12 concentric phase of a lift (70). Thus, manipulating repetition tempo between blocks of
13 training provides coaches with another strategy that may provide a novel form of
14 overload through increasing training volume (via long repetition duration) or load (via
15 short repetition durations).

16

17 **INTER-SET RECOVERY**

18 Much like repetition duration, coaches may also change inter-set recovery periods to
19 alter the balance of the training volume-load relationship. With short duration
20 recovery periods (< 30-seconds), training volume may be increased as training density
21 rises. However, if insufficient recovery is provided to fully replenish the anaerobic
22 energy stores (34), the load must be reduced. Likewise, with higher inter-set recovery
23 periods, greater loads may be used for each set at the expense of maintaining high
24 training density, coupled with additional rest time (24).

25

1 Research investigating inter-set recovery periods suggests that short rest intervals (\leq
2 60-seconds) potentially compromises volume load due to drastic reductions in the
3 load used, when compared to longer recoveries (3-minutes) (75). This is supported by
4 Buresh et al. (17), who showed greater increases in quadriceps cross-sectional area
5 when utilising longer (2.5 minutes), compared to shorter (60 seconds) inter-set
6 recoveries. However, caution should be applied when interpreting these results, as in
7 each of these studies volume was equated. Such control may remove the benefits of
8 utilising short recoveries, as training density cannot be increased. Whether shorter rest
9 periods permit tolerable increases in training volume has not yet been studied.
10 Therefore, further evidence is required in order to make clearer recommendations
11 regarding the manipulation of inter-set rest periods for increasing muscle hypertrophy
12 (35).

13

14 **CONCLUSION**

15 Certain aspects of traditional hypertrophy training have been recently challenged. A
16 more detailed understanding of key programming variables is therefore required to
17 maximize training effectiveness. Using the training principles outlined in this review,
18 coaches can design and deliver evidence-based hypertrophy training that has the
19 potential to increase athletic performance or expedite recovery from injury.

20

21 The current body of evidence suggests that there is no ideal load prescription to
22 maximize muscle hypertrophy. In fact, from a loading perspective, there appears to be
23 very few constraints, providing that the intensity of effort is high. However, an
24 important variable that must be considered is training volume. High training volumes
25 are necessary for maximising muscle growth. This may be accomplished through a

1 variety of approaches; one being increased training frequency. The current literature
2 indicates between 2-3 training sessions per muscle group per week are most effective,
3 although there may be potential for superior gains in muscle hypertrophy with the
4 prescription of higher frequencies (>3) in trained individuals.

5

6 Exercise variation is also important to access all ‘functional compartments’ of
7 individual muscles. This may be accomplished by including variations of basic
8 exercises that place stress on specific muscle divisions. By incorporating a variety of
9 exercises for a single muscle in the training program of an athlete, the hypertrophic
10 response has the potential to be enhanced. Such adaptations may also be obtained
11 with varying the type of contraction, as concentric-only and eccentric-only loading
12 strategies have been shown to provide hypertrophic adaptations in different sections
13 of a muscle. Furthermore, it seems that eccentric-only training has the potential to
14 increase muscle mass beyond that of concentric-only training through the increase in
15 total work performed.

16

17 Finally, exercise order, repetition tempo and inter-set recovery periods may all be
18 manipulated at the program level in order to present the athlete with a novel stimulus.
19 These variables should be considered in relation to the individual athlete goals and the
20 desired outcome.

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