THE JOURNAL OF SPORTS MEDICINE AND PHYSICAL FITNESS
EDIZIONI MINERVA MEDICA

Recommendations for Natural Bodybuilding Contest Preparation: Resistance and Cardiovascular Training

Eric HELMS, Peter J FITSCHEN, Alan ARAGON, John CRONIN, Brad J SCHOENFELD

J Sports Med Phys Fitness 2014 Jul 05 [Epub ahead of print]

THE JOURNAL OF SPORTS MEDICINE AND PHYSICAL FITNESS
Rivista di Medicina, Traumatologia e Psicologia dello Sport
pISSN 0022-4707 - eISSN 1827-1928
Article type: Review Article

The online version of this article is located at http://www.minervamedica.it

Recommendations for Natural Bodybuilding Contest Preparation: Resistance and Cardiovascular Training

Eric Helms[1], Peter J. Fitschen[2], Alan Aragon[3], John Cronin[1, 4,] Brad J. Schoenfeld[5]

[1]Sport Performance Research Institute New Zealand, AUT University, Auckland, New Zealand

[2]Division of Nutritional Sciences, University of Illinois, Urbana, Illinois, USA.

[3]California State University, Northridge, California, USA

[4]School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Australia

[5]Health Science Department, CUNY Lehman College, Bronx, NY

Congresses: none
Funding: none
Conflicts of interest: none
Acknowledgements: none

Corresponding Author
Eric Helms
Sports Performance Research Institute New Zealand
AUT University
17 Antares Place, Mairangi Bay, Auckland 0632, New Zealand
Tel: (64) 021638466
E-mail: eric.helms@aut.ac.nz

Abstract:

The anabolic effect of resistance training can mitigate muscle loss during contest preparation. In reviewing relevant literature, we recommend a periodized approach be utilized. Block and undulating models show promise. Muscle groups should be trained 2 times weekly or more, although high volume training may benefit from higher frequencies to keep volume at any one session from becoming excessive. Low to high (~3-15) repetitions can be utilized but most repetitions should occur in the 6-12 range using 70-80% of 1 repetition maximum. Roughly 40-70 reps per muscle group per session should be performed, however higher volume may be appropriate for advanced bodybuilders. Traditional rest intervals of 1-3 minutes are adequate, but longer intervals can be used. Tempo should allow muscular control of the load; 1- 2sec concentric and 2-3sec eccentric tempos. Training to failure should be limited when performing heavy loads on taxing exercises, and primarily relegated to single-joint exercises and higher repetitions. A core of multi-joint exercises with some single-joint exercises to address specific muscle groups as-needed should be used, emphasizing full range of motion and proper form.

Cardiovascular training can be used to enhance fat loss. Interference with strength training adaptations increases concomitantly with frequency and duration of cardiovascular training. Thus, the lowest frequency and duration possible while achieving sufficient fat loss should be used. Full-body modalities or cycling may reduce interference. High intensities may as well; however, require more recovery. Fasted cardiovascular training may not have benefits over fed-state and could be detrimental.

Key Words: caloric restriction, resistance training, aerobic exercise

Introduction:

In the United States, over 200 amateur natural (drug tested) bodybuilding contests occurred during 2013 and the number of contests is expected to increase in 2014 [1]. Preparation for bodybuilding competition involves drastic reductions in body fat. Typically, this is achieved through a decreased caloric intake, intense resistance training, and increased cardiovascular exercise. The goal is not only to decrease body fat levels, but to also maintain muscle mass.

Competitors partake in numerous dietary and exercise strategies to prepare for a contest. Some have a strong scientific basis; however, many do not. The purpose of this article is to review the scientific literature on training topics relevant to bodybuilding competition. In particular, recommendations will be made pertaining to resistance training and cardiovascular training for natural bodybuilders.

Methods:

An extensive literature search was performed using the PubMed, MEDLINE, SPORTDiscus and CINAHL databases. Searches were performed for ‘bodybuilders’, ‘hypertrophy’, ‘resistance training’, ‘exercise’, ‘bodybuilding’, ‘cardiovascular exercise’, ‘strength training’, ‘concurrent training’, ‘muscle’, ‘body fat’, ‘athletes’, and combinations of the aforementioned keywords. The publications obtained were carefully screened for studies that included healthy humans or humans in a caloric deficit. Studies on drug free bodybuilders were preferentially included. In their absence, long-term human studies focusing on hypertrophy and body fat loss were selected; however, studies examining strength, performance, and/or acute studies were selected in the absence of adequate long-term human studies. In addition, author names and reference lists were used for further search of the selected papers for related references. Due to a lack of studies specifically on natural bodybuilders during contest preparation and the broad nature of this review, a narrative style was chosen.

Resistance Training

Bodybuilders perform resistance training with the goal of achieving proportional maximal hypertrophy across all muscle groups. During preparation before competition, typically 3-6 months [2-4], bodybuilders reduce body fat substantially and perform resistance training to prevent lean body mass (LBM) loss. During severe caloric restriction, resistance training does not always attenuate LBM loss [5,6], but with less restrictive dieting and properly designed exercise it can be reduced or prevented [3,4,7-11]. Hypertrophy may occur during weight loss; however, the overall magnitude is limited with greater gains seen in novices, the untrained, and those who are overweight/obese[12-15].

During contest preparation calories are restricted and thus more time is spent in an energy deficit resulting in a net catabolic state. To offset potential losses of LBM, resistance training is performed during contest preparation for the goal of stimulating muscle growth. Even though hypertrophy is unlikely during preparation, total muscle mass is a product of muscle protein balance; the combination of muscle protein breakdown and synthesis. Thus, a resistance training program designed to positively influence protein synthesis and increase muscle mass should be the goal during contest preparation. Logically, this would mean that at its core a contest preparation training plan should be very similar to that of an offseason training plan. That said recovery is impaired during this period, so a discussion of how to appropriately design resistance training in a state of caloric restriction and reduced recovery follows.

There are three primary factors theorized to contribute to hypertrophy: mechanical tension, metabolic stress, and muscle damage [16]. An important point is that without the act of performing resistance to create mechanical tension, metabolic stress and muscle damage cannot occur. So while it is theorized that these three factors can be emphasized in varying combinations and degrees to elicit an optimal stimulus, it should be noted that progressive mechanical tension overload is the primary driver for growth[17].

Individual adaptation to resistance training is highly variable [18]. Training experience has a large influence on the degree an individual can adapt to training and the more muscular adaptations that are made, the harder it becomes to adapt further[19]. Additionally, the majority of available research has been performed on untrained and novice populations [20] and while hypertrophy is typically seen in relatively short time periods in these populations, highly trained bodybuilders who achieve a great deal of muscularity may not make measurable improvements in muscle mass even over the course of a six month period[21]. Since progressive tension overload is the primary driver for muscle growth, this review will cover strength adaptations as a secondary measure of importance in addition to hypertrophy. Improvements in strength increase the load that can be used, both increasing mechanical tension and the amount volume performed and strength improvements that occur after the novice period are more likely to be due to morphological rather than neurological adaptations[22,23]. In a practical sense, it also may be easier to track and monitor strength gains rather than changes in muscle size in experienced bodybuilders nearing their "genetic ceiling".

Besides training experience, age, diet and other variables also alter the response to training. Men adapt in greater magnitudes to strength training compared to women but, the adaptations are fundamentally the same thus, no significant differences in training approach are needed when training either gender [24]. The nutritional approach that bodybuilders take to prepare for competition also varies and will alter the response to training[25]. Thus, results that some individuals achieve with certain regimens may not represent a norm. Therefore, the following should be seen as a guide to training while preparing for bodybuilding competition. However, training should be tailored to the characteristics of the individual and adjusted based on the response to training. For those seeking information on nutritional approaches to bodybuilding preparation, the recently published review by Helms et al[25] can be seen as a companion to this review.

Periodization

Periodization is the process of organizing training in periods of macrocycles (often six months to one or more years in length), mesocycles (often one to three months in length), and microcycles (often one week in length). Different training parameters are utilized in phases to produce adaptation without overtraining, stagnation or injury. This can be accomplished through many models such as: linear periodization (LP) -decreasing volume while concurrently increasing intensity; reverse linear periodization (RLP) - increasing volume while concurrently decreasing intensity; or with undulating periodization (UP) - process by which concurrent adaptations are sought by utilizing multiple training parameters on different days of the week, or in alternating microcycles. Block periodization (BP) is another more recently developed form of periodization. It uses three or four mesocycles that are truncated in comparison to the traditional LP models to theoretically avoid losses of adaptations from previous cycles.

It is important to note that approaches to periodization within each of these models can vary greatly and each should therefore be seen as a philosophy rather than a distinct system. Thus, the conclusions of studies on periodization models can only be confidently applied to the iteration that was researched in that study. Additionally, it should be noted that the traditional models of periodization are primarily intended to create a peak in athletic performance during competition. This is not the focus of bodybuilding as a "peak" is achieved via an aesthetic ideal largely influenced by diet rather than a maximized level of strength or power largely influenced by training. Thus, for utility in bodybuilding we will review periodization models in the context of which models seem to promote the most efficient muscular adaptations in trained populations. For a more in depth discussion and definition of periodization and its related terminology see the review by Anthony [26].

Several groups of researchers have compared the efficacy of various types of periodization. Prestes et al [27] investigated a comparison of LP and RLP and found a significant 7% increase in LBM in the LP group; while non-significant increases in LBM (4%) were reported in the RLP group over the course of training. Moreover, a significant 17% decrease in body fat mass was observed in the LP group while the RLP group showed non-significant decreases in body fat mass (11%) from start to finish. The authors noted that further study of LP should be undertaken with a comparison to the UP model.

In many of these comparisons, it would seem that the UP model is superior to LP in eliciting performance improvements[28,29]. However, the occasional study has found no significant differences between these two models[30] and one study has shown LP to be slightly more effective than UP[31]. Additionally, sometimes despite differences in performance significant differences in body composition have not been observed in studies comparing LP and UP[29-31]. However, these studies have looked primarily at recreationally trained and novice populations. Bodybuilders that have high degrees of training experience may not experience LBM gains in the short term [21]. Thus, it may be more valuable to examine studies of UP compared to LP in well trained subjects and to also consider strength gains made in these populations. When reviewing these studies, only one study found similar strength gains between

UP and LP [32], while the majority [33-35] indicate superior strength gains when utilizing an UP model. Disparities in program design between studies make it difficult to draw firm conclusions on the superiority of one model versus another, particularly given the virtually endless number of ways that program variables can be manipulated within the context of a periodized routine.

More recently, BP has been compared to both LP [36] and UP [37] in trained strength and power athletes. In one investigation, BP appeared to provide greater gains in bench press strength when compared to LP [36]. In another study by Painter et al.[37], BP was observed to produce similar gains in strength compared to UP even when less total volume was performed using the BP model. However, the model of daily UP used by Painter and colleagues[37] was one that was recently found to be a sub optimal design for strength development compared to an alternative UP model[38]. Zourdos found that when the UP model is changed from the traditional daily order of 'hypertrophy, strength, power' to an order in which power is placed before strength, greater strength development occurs in competitive power lifters[38]. Theoretically, this order allows additional time for muscle damage repair before the strength workout is performed which may allow for superior performance.

As a final note on the comparison of BP and UP by Painter et al.[37], more volume was performed by the group using the UP model. While the authors suggested that this indicated inefficiency of the UP model, it could be seen as a positive for bodybuilders given that strength is a secondary outcome indicative of progressive overload, while volume is a primary determinant of muscle growth[39-42]. Perhaps in support of this viewpoint, the UP group in this study increased body mass by 3.7% while the BP group increased body mass by 1%[37]. However, this difference was not statistically significant.

In the context of bodybuilding, the only firm conclusion that can be made is that a periodized approach to training is clearly more effective in achieving muscular adaptations than a non periodized approach[35,43-45]. However, BP and UP appear to be models which consistently produce strength improvement in well trained lifters faster than a LP model or allow for the performance of higher volume without overtraining and therefore may be of interest to bodybuilders.

Frequency of Training

Training frequency is a way to organize the work load in a given microcycle. Increasing frequency of training can substantially increase total volume if the volume per workout is kept static. However if the volume of a given microcyle is not altered, yet that volume is split up over more training sessions, this could potentially allow the same volume to be performed with less fatigue per session. In fact, a body of evidence in resistance trained subjects and strength athletes suggests that there is a threshold to how much volume can be done in a single session before the quality of that volume degrades; as it has been observed that neuromuscular adaptations [46,47] hormonal markers for recovery[46,48], strength improvement[46-50] and gains in LBM[47,49] are higher in some equated-volume programs with a higher frequency and less volume per session.

In a systematic review of 60 studies on hypertrophy by Wernbom et al[20], it was determined that rapid progress is made by novices performing very high frequency training (training each muscle group as much as four times per week), and intermediate trainees make optimal progress training each muscle group two to three times weekly. However, there was not enough data on very high frequency training in trained subjects to determine if frequencies higher than two to three times weekly could prove even more effective. The authors suggested that very high frequency training in advanced lifters requires more study [20]. Recently, Schoenfeld et al.[39] investigated muscular adaptations in a bodybuilding- versus a powerlifting-type resistance training program. The group performing bodybuilding-type training worked each muscle group once per week using a split-body routine while the powerlifting-type group worked each muscle group three times per week using a total-body routine. Total volume load was equated on a weekly basis. After 8 weeks, both groups showed significant increases in thickness of the biceps brachii with no significant differences noted between groups. Although this suggests that differences in training frequency are irrelevant to the hypertrophic response provided an equal volume load, it should be noted that the repetitions, sets, and inter-set rest intervals differed between groups, making it difficult to draw cause-effect conclusions on the topic. Moreover, recently completed research showed that professional bodybuilders performing a volume-equated four versus six day-a-week training program experienced similar increases in fat-free mass as measured by dual energy x-ray absorptiometry (Ribeiro et al. In Review). The subjects in this study were in a hypercaloric state, however, thus limiting generalizability to bodybuilders in the pre-competition phase.

Although training muscle groups more than once per week may be beneficial under normal conditions, there is a paucity of research that has investigated advanced lifters in a caloric deficit whilst also performing cardiovascular training, as is commonly seen in bodybuilding contest preparation. During preparation, bodybuilders commonly increase volume [51], but since hypertrophy under these conditions is limited [3,4,52], it may also be beneficial to determine what frequency is needed to maintain or perhaps slightly increase muscle mass while avoiding overtraining.

We propose training each muscle group 2 to 3 times weekly[20] for most bodybuilders, but we also acknowledge that very limited study of advanced lifters has been performed. Additionally, optimal frequency is integrally linked with volume per session. Thus, performing higher volumes per session would likely necessitate a lower frequency per week, and vice versa. However in the context of the volume found to be optimal in the meta analysis performed by Wernbom and colleagues (~40-70 reps per muscle group per session)[20], it is suggested that training each muscle group 2 to 3 times per week may be appropriate for the majority of bodybuilders. Or at the very least, this frequency and volume of training can be seen as a starting point from which to adjust based on individual response. A case can be made for periodizing frequency over the course of a pre-contest phase, altering the number the number of times a muscle group is trained weekly in accordance with individual response. This hypothesis warrants further study.

Number of Sets and Volume

Total volume is determined as the product of sets, repetitions and load. While an increase in training frequency can create the largest increase in volume in a microcycle if volume per session is kept static, an increase in the number of sets performed (and thus total repetitions) can also substantially increase volume. A recent meta analysis by Krieger reported 40% greater hypertrophy when multiple sets were compared to single sets [53]. Furthermore, effect sizes for hypertrophy tended to increase as sets increased (0.24 for 1 set, 0.34 for 2–3 sets, and 0.44 for 4–6 sets). It seems that while there may be a linear increase in hypertrophy along with a concomitant increase in the number of sets performed, there is also evidence that doing too much volume in a single session can actually be detrimental to hypertrophy beyond a certain point [20,46-50]. This suggests an inverted U response to volume, whereby there is a "sweet-spot" that maximizes the hypertrophic response to resistance training. Based on the inter-individual response to training, the exact threshold would vary between bodybuilders based on training age, genetic- and lifestyle-related factors.

In Wernbom and colleagues' systematic analysis of hypertrophy studies in the elbow flexors and the quadriceps[20], it was found that rate of increase in cross sectional area (CSA) of the elbow flexors increased from 0.15% per day when 7-38 repetitions per session were performed, to 0.26% per day when 42-66 repetitions per session were performed, but then fell to 0.18% per day when 74-120 repetitions per session were performed. In the quadriceps, a similar trend was found with the highest rate of gain (0.13% per day) occurring in the moderate repetition range (40-60 repetitions per session). However, in the quadriceps the reduction in rate of CSA increase was smaller compared to the elbow flexors when more repetitions were performed. A CSA increase rate of 0.8% occurred when 66-90 repetitions per session were performed and 0.12% when 100 or more repetitions per session were performed[20]. It should be noted that the vast majority of these studies were carried out in untrained subjects, limiting generalizability to a bodybuilding population.

Observing a similar trend, Ronnestad et al [54] found no significant differences in hypertrophy between single and multiple sets in the upper body while the lower body responded significantly more to multiple (11%) sets versus single (7%) sets in a sample of untrained subjects. Thus, it appears that the lower body may be more resilient to higher volumes than the upper body. These regional differences in the hypertrophic response to training may reflect the "training age" of different muscle groups of the subjects. Possibly due to our ambulatory nature, the lower body tends to respond in a slower fashion in terms of hypertrophy than that of the upper body in response to a similar number of repetitions per workout, and seems to be more resilient to higher volume training. However, in well trained bodybuilders who have trained their entire body for years, these regional differences may not exist or may be substantially reduced.

As previously stated, volume is a primary determinant of muscle growth[39-42] and continued adaptation requires progressive overload[55]. Thus, volume should likely be increased as the training age and workload capacity of the individual advances [56]. That being said, in a study of seventy untrained adults, both young and old, it was found that muscle size can be maintained with as low as one third the training volume that initially produced adaptation [57]. Thus, while the goal may be to increase training volume globally over the career of a bodybuilder to accommodate advancement towards his or her genetic potential, it can be potentially lowered to a degree during contest preparation to accommodate fatigue and reduced recuperative abilities without necessarily compromising muscle size. Therefore, intermittent periods of lower volume training could be used as a recovery strategy between training cycles to help to prevent overtraining during contest preparation.

To conclude, ~40-70 repetitions per muscle group per session with the appropriate combination of intensity and frequency of training appears to be the optimal balance for creating a hypertrophic stimulus in beginner and intermediate trainees. Some advanced bodybuilders may require higher volumes of training for continued adaptation. Furthermore, volume should be scaled according to work load capacity, experience and differences in the response of specific muscle groups. Lastly, planned periods of reduced volume (i.e. deloads) may allow recovery between cycles of training. This may be an especially useful approach during contest preparation as recovery will likely be impaired.

Repetition Range and Intensity

When volume is equated, intensity may be the overriding factor in determining the magnitude of hypertrophy[58-60]. Thus, many researchers have sought to examine the ideal repetition range and intensity for hypertrophy. Campos et al. [59] examined the effects of using loads in the 3-5, 9-11, or 20-28 repetition ranges and found that the 3-5 and 9-11 repetition ranges resulted in a 12.5%, 19.5%, and 26% increases in CSA for type I, type IIA, and type IIB fibers, respectively. However, no significant differences in CSA were observed in the 20-28 repetition range group. Similarly, Schuenke et al. [60] randomized untrained women to perform multiple sets of the squat, leg press, and leg extension at either a moderate intensity (80-85% RM) or a low intensity (~40-60% RM) for 6 weeks. Results of muscle biopsy showed significant increases in both type I and type II fiber CSA for the traditional group whereas the low-load group saw no significant increases in fiber-type hypertrophy. On the other hand, several studies have shown similar hypertrophic increases when comparing very low- (≤50% 1RM) versus high-load training[61-63]. When taking the body of literature into account, it is clear that training with low-loads can promote substantial hypertrophy, sometimes reaching levels similar to that of heavier loads. Additionally, it has been speculated that combining low- with high-load training can be synergistic for enhancing gains in muscle mass[64]. Studies on well-trained subjects are lacking on the topic and thus further investigation is needed to establish proof of principle.

Although low to moderate repetition range resistance training may be beneficial for increasing muscle size, exclusively low repetition, low volume, heavy weight training, even at loads of 90% 1RM may not produce significant changes in CSA if insufficient volume is performed[65]. Thus, while optimal loads should be used, sufficiently high volumes must be utilized to maximize the hypertrophic response. In support of this, Goto et al [41] showed a trend ($p=0.08$) for increased hypertrophy when high repetition, low intensity training (one set at 25-35 RM) was added after low repetition, high intensity training (5 sets at 3-5 RM) versus when low repetition, high intensity training was performed alone. Despite the low load utilized, its addition effectively increased the total work performed and thus augmented hypertrophy.

Researchers have examined the effects of numerous training repetition ranges, and the ACSM has concluded that repetition ranges of 1 to12 with intensities of 1 to 12RM can be utilized in the context of a periodized program to elicit hypertrophy [56]. Fine tuning these recommendations further, authors of a recent systematic review concluded that to produce optimal changes in CSA, a repetition range of 6 to12 using 70-80% of 1RM should be the primary training intensity utilized [20].

To put it into context, a higher percentage of 1RM will create more recruitment of muscle upon initiation of a set and “train” muscle at an earlier point than when performing higher repetition training. However, high loads necessitate low repetitions, create high fatigue, require longer rest periods and make the performance of adequate work for hypertrophy difficult. In fact, a recent study by Schoenfeld and colleagues found that equated volume performed with 3RM sets and three minute rest periods versus 10RM sets and 90 second rest periods took nearly four times as long to complete[39]. Thus while the “hypertrophy repetition range” may not necessarily be mechanistically superior for eliciting muscle growth, it may be practically superior as it provides enough mechanical tension and allows for enough volume to be completed in a time-efficient manner.

However, it should be noted that the participants in Schoenfeld and colleagues recent study performing heavier load training experienced greater increases in strength than the moderate load group[39]. High-repetition low-load training emphasizes metabolic fatigue and aids in the development of muscular endurance, while low-repetition high-load training emphasizes mechanical tension and aids in the ability to handle heavier loads through neurological adaptation. Thus, the authors suggested that both high-repetition low-load and low-repetition high-load training should be included to some degree alongside moderate-load moderate-repetition training to maximize all possible avenues of hypertrophy[39];

which has been previously theorized as a method to augment hypertrophy perhaps by enhancing type I muscle fiber size[64].

Exercise Order

The order of exercise impacts adaptation to resistance training. Greater volumes are accomplished with the first exercise performed[66,67] which may result in greater hypertrophy in muscles trained by the initial movements. Thus, compound movements that train multiple muscle groups at one time in an efficient manner, should normally be placed first within a workout. The common practice by bodybuilders of “pre fatiguing” a muscle by training it in isolation first followed by training it with a compound lift, might not be effective at improving recruitment of the target muscle [66]. More likely this practice augments the recruitment of synergists to make up for the fatigued prime mover. Exercise order could also be prioritized based on the needs of the competitor, as greater hypertrophy may be observed in muscle groups trained with the initial lift[66]. Therefore, muscle groups that are lagging in the development of a proportional physique could be prioritized early in an exercise session. Prioritizing “weak points” by achieving higher volumes on these muscle groups during contest preparation early in the exercise session may help to minimize muscle loss in these areas which could worsen proportionality.

Inter-Set Rest interval

Increasing or decreasing inter-set rest intervals has a significant impact on the performance of subsequent sets as well as the hormonal response to exercise. Thirty to sixty second rest intervals increase acute growth hormone response and for this reason are frequently recommended for hypertrophy [68,69]. However, West et al. [70] observed that acute increases in anabolic hormones, such as free testosterone, growth hormone, and insulin-like growth factor 1, during training did not show a significant relationship with hypertrophy. De Souza [71] found no significant difference in muscle CSA, maximal strength or isokinetic peak torque ~~to~~ when rest intervals of 2 minutes were incrementally decreased from 2 minutes to 30 seconds. In addition, Buresh et al [72] observed no significant differences in strength or hypertrophy with 2.5 min rest intervals compared to 1 min rest intervals, despite greater acute anabolic hormonal responses during the shorter rest period training. Extending rest periods even further, Ahtiainen et al. [73] compared 2 minute rest periods to 5 minute rest periods in protocols of matched volume, with differing intensities. No significant differences in muscle size or strength were found.

It seems clear that restricting rest intervals for hypertrophy training may not be necessary. As previously stated, the guideline for restricting rest intervals has been proposed in part to augment increases in hormone levels, often growth hormone. However growth hormone, even when taken exogenously at levels comparable to doping programs for a full month, does not appear to have a significant impact on hypertrophy[74]. Thus, it is not surprising that variations in the natural hormonal responses to training which are small in magnitude and short in duration lack a significant relationship with muscle growth[70]. Restricted rest periods have also been recommended to augment metabolic fatigue to enhance hypertrophy[75]. While this theory is sound, no investigation to date has yet found variations in rest periods between 1 to 5 minutes to alter the hypertrophic response.

The commonly recommended rest periods of one to two minutes for hypertrophy are likely acceptable. While traditional rest periods for hypertrophy training appear not to hamper performance, longer rest intervals should be taken as needed to maintain volume and load, especially during contest preparation where recovery is potentially hindered.

Repetition Tempo

Changes in repetition tempo and speed alter the acute physiological response to resistance training [16,76,77]. With little exception [78], normal tempo, full contraction spectrum, traditional resistance training results in superior adaptations when compared to slow tempo training which necessitates lighter loads [79-83]. Thus, a tempo that maintains muscular tension during the concentric and eccentric phases without sacrificing the magnitude of load may be optimal. However, with concern to minute alterations in tempo that do not alter the load the subject is able to use, it is unclear if tempo has a significant impact on hypertrophy[84-86].

Often, conclusions about the importance of repetition tempo during the concentric and eccentric phases of lifts are made based upon studies examining concentric-only and eccentric-only training. When comparing eccentric training to concentric training, eccentric training elicits a greater hypertrophic response[20,87]. This could be caused by increased total volume as greater loads can be used in eccentric training [20,77,87], or by increased muscle damage which may impact muscle growth [88,89]. That being said, eccentric or concentric-only studies may not provide appropriate data to inform contraction tempo for traditional resistance training which is neither eccentric nor concentric only.

When emphasizing different tempos for the eccentric and concentric portions of each repetition, the results are mixed with regards to hypertrophy[78,84-86,90]. Authors of a systematic review of training variables that influence hypertrophy [20] and the most recent ACSM position stand on resistance training [56] advise 1-2 second concentric and eccentric contractions during traditional resistance training for hypertrophy. However, in a review on the mechanisms of hypertrophy, Schoenfeld [16] advises 2-4 second eccentric contractions.

Some researchers have concluded that contraction mode may not be the primary determinant of muscle architectural adaptations [84] and training with slow speed concentric versus eccentric contractions does not significantly alter rate of force production [85]. In a study comparing moderate speed eccentric contractions (2 seconds) to slower eccentric contractions (4 seconds), heavier loads, greater work, and greater responses in IGF-1 occurred with moderate speed eccentric contractions[76]. Notably, metabolic stress, muscle damage and other factors that are effected by tempo which influence hypertrophy [16] were not measured in this study. Thus, highly specific guidelines for lifting tempo, especially for the eccentric portion, cannot yet be made based on the limited extent of current research.

What can be concluded is that extremes on either end of the lifting tempo spectrum are likely sub optimal for hypertrophy. Most importantly it must be understood that “time under tension” is not the only variable that matters for hypertrophy. The magnitude of tension must also be considered[39,58-60]. Higher relative loads require slower tempos because the lifter has only enough strength to overcome the mass of the load to move it. Likewise, lighter loads can be moved with greater speeds if more contractile force is applied. Thus, even if a moderate load is lifted quickly and time under tension is decreased, this can result in more work performed[76]. However, regardless of tempo of lifting muscle should control the weight during the concentric phase and muscle, not gravity, should lower the weight during the eccentric portion. Thus, 2-3s eccentric tempos should be performed and the concentric phase should be performed with maximal intentional force, which will likely result in 1-2s concentric contractions if using appropriate loads for hypertrophy training[20,56,76]. Moreover, when novices are given expert instruction on how to perform a movement, this can enhance activation of the given muscle[91]. Thus, repetition tempo should therefore also take into account the time it takes an individual to properly perform a movement and contract the target muscle throughout its full range of motion.

Training to Failure

While not required to produce hypertrophy [92], training to failure causes increased stimulation of motor units and muscle fibers. Therefore, it may have potential as a method of achieving hypertrophy. However, because of the demand of training to failure it should be planned for, cycled into training and used sparingly during contest preparation to avoid injury or negative performance effects [16,92]. If improperly implemented, training to failure can alter the ability of the lifter to train with the optimal frequency, volume or intensity if the fatigue generated is too high [20]. Despite potential benefits, if fatigue reduces the number of repetitions or loads used in subsequent sets, exercises or training sessions (and therefore total training volume), it could negatively impact hypertrophy over time. There also is evidence that continually training to failure negatively alters chronic hormonal balance in a manner that is indicative of overtraining syndrome [93].Thus, training to failure should be used in a focused, planned manner and considered an advanced training technique [94], rather than utilized haphazardly, especially during contest preparation.

Although previous discussion seems to not necessarily support regular training to failure, there are potential uses for regular failure training in the context of bodybuilding. Compared to multi-joint exercises, lifts for isolated muscle groups cause lower levels of perceived exertion [95], neural recruitment [96] and hormonal response [97] and as a result, recovery from these exercises is quicker and they are therefore considered less demanding [98]. Also, lower repetitions with heavier loads emphasize mechanical tension and high levels of neurological recruitment, while higher repetition sets with lighter loads produce more metabolic fatigue [99]. Thus, the recovery period from higher repetition, isolated muscle-group training may be less than that needed for heavy, multi-joint training. Therefore, one might optimize the benefits and minimize the downsides of training to failure during contest preparation by utilizing this technique primarily with single-joint exercises in higher repetition ranges.

Exercise Selection and Form

While the quantitative variables listed thus far largely determine the adaptations that training produces, the quality of the training should not be ignored. Targeted hypertrophy can only be achieved if the intended muscle is activated and overloaded. Snyder et al. [91] found activation of the latissimus dorsi was increased by 17.6% when lat pull-downs were performed after expert instruction compared to performance without prior instruction. Furthermore, a full range of motion was shown to be superior in terms of increasing muscle girth compared to a partial range of motion in the elbow flexors (9.6% vs. 7.8% increase) [100] and deep squatting produced more complete muscular development of thigh musculature compared to squatting performed in a limited-range[101]. Thus, it may be best for bodybuilders to use proper form and full range of motion to enhance hypertrophy. Furthermore, bodybuilders sometimes exhibit limited joint range of motion [102], therefore full range of motion training and a balance of strength across muscle groups may help to prevent injury during training.

Skeletal muscles are often compartmentalized [103], and different compartments are preferentially activated based on joint position and angle [104]. Thus, reviewers of hypertrophy training have recommended a wide exercise variety and frequent exercise rotation based on the fact that variations in angle, plane of motion and grip position can change muscle activation patterns and may therefore maximize hypertrophy [16,105]. A recent study by Fonseca et al.[106] seems to support this contention, showing that a volume-equated combination of the smith machine squat, leg press, lunge, and deadlift produced more uniform muscle hypertrophy of all four quadriceps muscles compared to performing the smith machine squat alone despite a similar change in CSA. Given this data, it is tempting to a broadly recommend the use of a wide variety of exercises to maximize muscle development; however such a recommendation could potentially be detrimental if taken to extremes.

The initial strength gains seen when performing new exercises are predominantly attributed to neuromuscular adaptation [23]. As the movement skill is acquired and becomes more fine-tuned over time, the muscle can be exposed to increased loading, aiding morphological adaptations as training continues [22]. Therefore, while training with greater exercise variety may theoretically increase hypertrophy more than training with a limited exercise selection, if the frequency of exercise rotation is taken too far, a bodybuilder may spend more time developing motor skills with sub optimal loads than eliciting a hypertrophic response.

A middle of the road approach might be the optimal strategy to maximize hypertrophy. Multi-joint movements recruit large amounts of muscle mass via prime movers, synergists and stabilizers, and single joint movements can be used to address specific lagging muscle groups or asymmetries [16]. An approach utilizing a core group of multi-joint movements for the majority of training with some adjunct single-joint movements to reach the target volume for any given muscle group is suggested. Rotation of the core group of multi-joint exercises should occur infrequently and only to vary the frequency of their appearance in training rather than to completely remove them at any time point. This will allow a bodybuilder to maintain movement proficiency on these more complex lifts. Secondary single-joint exercises can be rotated on a more regular basis, but not to the point where they are altered every microcycle. This may make training more efficient, which could be crucial during contest preparation when recuperation is more difficult. Since muscle symmetry is paramount to success in bodybuilding competition, there should be a focus on exercises specific to bringing up weak muscle groups and a de-emphasis on those that are strong points.

Cardiovascular Training

Weight loss is achieved when energy expenditure exceeds energy intake[107]. This can be achieved through reduction in caloric intake; however, an adequate caloric intake must be provided in order to preserve physical and mental health and to maintain LBM. Caloric restriction alone may not be enough for competitors to achieve extreme levels of body fat loss required for competition. Therefore, cardiovascular training or "cardio" is often performed to increase energy expenditure and further weight loss. This section will review the published studies on endurance training as applied to bodybuilding. Issues of interference of endurance and strength training, intensity of cardiovascular training, and fed versus fasted cardiovascular training will be discussed.

Interference

Interference in the context of this article refers to a reduction in strength, power, and/or hypertrophy when endurance training is added to a strength training protocol[108]. Interference is thought to occur as a result of conflicting responses to strength or endurance training such as differences in fiber type transformations and changes in motor recruitment. Additionally, endurance training may result in reduced muscle glycogen content or may impair recovery, both of which may inhibit performance during strength/hypertrophy training [109,110]. Numerous studies have found that endurance training results in significant decrements in muscle strength and/or hypertrophy when added to strength training [111-114]; however, not all studies have observed such findings [115,116]. The discrepancies in these studies may be due to the quantity, intensity, and/or modality of the endurance exercise protocol added to a strength training program. A recent meta-analysis of 21 studies examining the effects of concurrent training on muscle strength and hypertrophy found a significant negative correlation between hypertrophy, strength, and power and the number ($r = -0.26$, $r = -0.31$, $r = -0.35$, respectively) and length ($r = -0.75$, $r = -0.34$, $r = -0.29$, respectively) of cardiovascular training sessions performed weekly [108]. Interestingly, interference was body part-specific. For example, when running or cycling was performed, significant decrements in muscle strength and hypertrophy were only observed in the lower body. In addition, modality of cardiovascular training was shown to play a role in interference. Running resulted in significant decrements in both strength and hypertrophy; however, cycling did not, possibly due a lesser eccentric component in cycling which may have resulted in less muscle damage. Overall, it appears that interference can be minimized by performing the lowest number and duration of cardio sessions per week. However, some cardio may need to be performed in order to achieve minimal body fat levels. Thus, when cardio is performed, utilizing full-body exercises (e.g. light weight cleans or kettle bells) or cycling may be more preferable to running to prevent interference. Temporally separating cardio from strength training sessions and separating body parts trained during cardio and strength training workouts (e.g. upper body cardio, lower body strength training) may further reduce interference.

Intensity

The ideal intensity of cardio for fat loss during contest preparation is highly debated. High intensity cardio provides many benefits including similar adaptations to low-intensity cardio such as skeletal muscle mitochondrial biogenesis, muscle oxidative capacity and buffering capacity, but in less exercise time [117,118]. Moreover, high intensity cardio may result in reduced interference with strength training [108,119], and significantly increased post-exercise oxygen consumption (EPOC) [120] when compared to low intensity cardio. However, it is unknown if EPOC is additive when performing both resistance training and high intensity cardio in a single session or if a ceiling for EPOC exists following a single workout. In addition to the aforementioned benefits, high intensity cardio burns primarily carbohydrate during exercise. It has been suggested that if more carbohydrates are burned during exercise, more fat is burned throughout the rest of the day and vice-versa [121]. Indeed, a study comparing 20 weeks of high intensity interval exercise to low intensity exercise found significantly increased activities of many enzymes involved in fat oxidation and significantly increased fat loss with high-intensity interval training compared with low-intensity endurance training (-14 mm vs. -5 mm on a 6 site skin-fold test, respectively) [122]. However, it should be noted that the body composition measurements were performed with skin-fold calipers and a description of the researchers skill or reliability when performing the measurements was not given, thus, the results of this study need to be replicated using more precise body composition measurements. Although high intensity cardio provides many benefits to dieting bodybuilders, it may be more difficult to recover from high intensity cardio and it may not be appropriate for everyone due to individual recovery rates. Therefore, high intensity cardio should be performed if possible; however, the selection of cardio intensity should be based on individual recovery rates.

Fasted Cardiovascular Exercise

Many bodybuilders perform cardio in the fasted state in an attempt to increase fat oxidation and lose additional body fat; however, the scientific literature does not support additional benefits of fasted cardio. In fact, increased nitrogen loss, equivalent to nearly 14 gm of amino acids per hour has been observed during 60 minutes of fasted cardio [123]. However, it should be noted that the authors could not identify the source of the nitrogen nor is it known if the increase in amino acid oxidation has a long-term effect on muscle tissue if amino acids are replenished after exercise. Additionally, studies examining the effects of carbohydrate consumption prior to cardio on fat oxidation during exercise have shown mixed results. Some studies have found that carbohydrate consumption prior to cardio significantly reduces fat oxidation during exercise [124-126] while others have shown that pre-exercise carbohydrate consumption has no significant effect on fat oxidation during exercise [127,128]. However, acute changes in fat oxidation during exercise are not as important as the total fat oxidation over the course of the day and, as previously discussed, if more carbohydrates are oxidized during exercise, more fat is oxidized throughout the course of the day [121,129]. Therefore, consumption of carbohydrates prior to exercise resulting in a decreased fat oxidation during exercise may actually result in increased fat oxidation throughout the day [121]. In support of this contention, a recent study by Paoli et al. [130] demonstrated that respiratory exchange ratio was significantly lower at 12 and 24 hours after fed versus fasted cardio, indicating that consuming a meal prior to exercise results in a prolonged shift toward lipid use following the training bout. The effects of carbohydrate intake prior to endurance exercise on exercise performance have also shown mixed results with researchers reporting increased [127,131] or no difference [132,133] in performance. Interestingly, branched chain amino acid consumption prior to endurance exercise has been shown to increase fat oxidation and increase time to fatigue by 17% [134]. However, additional studies are needed to verify this finding and long-term studies need to conclusively determine if fasted cardio results in additional fat and/or muscle loss than fed cardio, especially in trained athletes at extremely low levels of body fat, such as competitive bodybuilders.

The ideal form of cardiovascular training for dieting bodybuilders has not been conclusively determined due to a lack of long-term studies comparing endurance training protocols and modalities in athletes. Based on the available data, it is recommended that bodybuilders perform the lowest number and duration of cardiovascular sessions possible (while still meeting their need to maximally reduce subcutaneous body fat) to reduce interference with strength training. Either full-body modalities or cycling may be preferred to further reduce interference. High intensity is recommended if possible, however, the intensity of cardio performed should be determined by individual recovery needs. Additionally, although fasted cardio may increase fatty acid oxidation during exercise, there is little evidence that fasted cardio increases fat loss long-term. If anything, fasted cardio may be detrimental due to increased amino acid oxidation and reduced performance during exercise. Therefore, it is not recommended that fasted cardio be performed by bodybuilders preparing for competition. Overall, long-term studies are needed to conclusively determine the ideal cardio protocol for dieting bodybuilders.

Conclusions:

With the increasing popularity of natural bodybuilding, and the relative lack of science-based information for bodybuilding competition, the recommendations herein can provide the framework for designing training plans for natural competitive bodybuilders. However, the successful reduction of body fat to levels seen in competitive bodybuilding requires an intense focus on diet and nutrition. Therefore, this article should not be used as a comprehensive set of guidelines for competitive bodybuilding, but rather in conjunction with appropriate nutritional strategies for maintaining LBM and maximizing subcutaneous fat loss. For more information on nutritional strategies for competing natural bodybuilders, readers are referred to the recent review by Helms et al. [25]. Furthermore, the relative paucity of research utilizing natural bodybuilders as participants necessitates that many of the recommendations herein be based on logical conjecture from long-term studies on skeletal muscle hypertrophy and body fat loss in dieting human populations.

We encourage future research to be undertaken on natural bodybuilders in the contest preparation phase to broaden these guidelines and confirm the efficacy of the recommendations. Furthermore, this review focuses on the traditional resistance training approach and acute variables as they relate to hypertrophy. However, there are intriguing nontraditional concepts relevant to bodybuilders such as utilizing: “flexible non-linear periodization” where session-selection is based on self-reported recovery[135], “auto-regulated” periodization which adjusts load based on current and prior session performance[136], blood flow restriction to augment the hypertrophic effects of resistance training[137], active aerobic recovery during the inter-set rest interval [138], or providing a stretch induced tension stimulus in addition to traditional resistance training [139] that merit future study. Finally, trainers and athletes reading these recommendations should always take care to assess the individual response to exercise and adjust accordingly to maximize results.

References:

1. Natural Bodybuilding Events. http://www.naturalbodybuidlingevents.com.
2. Sandoval WM, Heyward VH. Food selection patterns of bodybuilders. *Int. J. Sport Nutr.* Mar 1991;1(1):61-68.
3. Rossow LM, Fukuda DH, Fahs CA, Loenneke JP, Stout JR. Natural bodybuilding competition preparation and recovery: a 12-month case study. *Int J Sports Physiol Perform.* Feb 14 2013:[Epub ahead of print].
4. Kistler B, Fitschen P, Ranadive S, Fernhall N, Wilund K. Case study: Natural bodybuilding contest preparation. *Int. J. Sport Nutr. Exerc. Metab.* 2014:[Epub ahead of print].
5. Donnelly JE, Pronk NP, Jacobsen DJ, Pronk SJ, Jakicic JM. Effects of a very-low-calorie diet and physical-training regimens on body composition and resting metabolic rate in obese females. *Am. J. Clin. Nutr.* Jul 1991;54(1):56-61.
6. Gornall J, Villani RG. Short-term changes in body composition and metabolism with severe dieting and resistance exercise. *Int. J. Sport Nutr.* Sep 1996;6(3):285-294.
7. Ballor DL, Katch VL, Becque MD, Marks CR. Resistance weight training during caloric restriction enhances lean body weight maintenance. *Am. J. Clin. Nutr.* Jan 1988;47(1):19-25.
8. Kraemer WJ, Volek JS, Clark KL, et al. Influence of exercise training on physiological and performance changes with weight loss in men. *Med. Sci. Sports Exerc.* Sep 1999;31(9):1320-1329.
9. Stiegler P, Cunliffe A. The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Med.* 2006;36(3):239-262.
10. Walberg JL. Aerobic exercise and resistance weight-training during weight reduction. Implications for obese persons and athletes. *Sports Med.* Jun 1989;7(6):343-356.
11. Wood RJ, Gregory SM, Sawyer J, Milch CM, Matthews TD, Headley SA. Preservation of fat-free mass after two distinct weight loss diets with and without progressive resistance exercise. *Metab Syndr Relat Disord.* Jan 27 2012;10(3):176-174.
12. Demling RH, DeSanti L. Effect of a hypocaloric diet, increased protein intake and resistance training on lean mass gains and fat mass loss in overweight police officers. *Ann. Nutr. Metab.* 2000;44(1):21-29.
13. Donnelly JE, Sharp T, Houmard J, et al. Muscle hypertrophy with large-scale weight loss and resistance training. *Am. J. Clin. Nutr.* Oct 1993;58(4):561-565.
14. Geliebter A, Maher MM, Gerace L, Gutin B, Heymsfield SB, Hashim SA. Effects of strength or aerobic training on body composition, resting metabolic rate, and peak oxygen consumption in obese dieting subjects. *Am. J. Clin. Nutr.* Sep 1997;66(3):557-563.
15. Avila JJ, Gutierres JA, Sheehy ME, Lofgren IE, Delmonico MJ. Effect of moderate intensity resistance training during weight loss on body composition and physical performance in overweight older adults. *Eur. J. Appl. Physiol.* Jun 2010;109(3):517-525.
16. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. *J. Strength Cond. Res.* Oct 2010;24(10):2857-2872.
17. Goldberg AL, Etlinger JD, Goldspink DF, Jablecki C. Mechanism of work-induced hypertrophy of skeletal muscle. *Med. Sci. Sports.* Fall 1975;7(3):185-198.
18. Timmons JA. Variability in training-induced skeletal muscle adaptation. *J. Appl. Physiol.* Mar 2011;110(3):846-853.
19. Deschenes MR, Kraemer WJ. Performance and physiologic adaptations to resistance training. *Am. J. Phys. Med. Rehabil.* Nov 2002;81(11 Suppl):S3-16.

20. Wernbom M, Augustsson J, Thomee R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Med.* 2007;37(3):225-264.

21. Alway SE, Grumbt WH, Stray-Gundersen J, Gonyea WJ. Effects of resistance training on elbow flexors of highly competitive bodybuilders. *J. Appl. Physiol.* Apr 1992;72(4):1512-1521.

22. Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. *Sports Med.* 2004;34(10):663-679.

23. Seynnes OR, de Boer M, Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *J. Appl. Physiol.* Jan 2007;102(1):368-373.

24. Holloway JB, Baechle TR. Strength training for female athletes. a review of selected aspects. *Sports Med.* Apr 1990;9(4):216-228.

25. Helms ER, Aragon AA, Fitschen PJ. Evidence-based recommendations for natural bodybuilding contest preparation: nutrition and supplementation. *J. Int. Soc. Sports Nutr.* 2014;11(1):20.

26. Anthony T. The science and practice of periodization: a brief review. *Strength Cond J.* 2011;33(1):34-46.

27. Prestes J, De Lima C, Frollini AB, Donatto FF, Conte M. Comparison of linear and reverse linear periodization effects on maximal strength and body composition. *J. Strength Cond. Res.* Jan 2009;23(1):266-274.

28. Miranda F, Simao R, Rhea M, et al. Effects of linear vs. daily undulatory periodized resistance training on maximal and submaximal strength gains. *J. Strength Cond. Res.* Jul 2011;25(7):1824-1830.

29. Prestes J, Frollini AB, de Lima C, et al. Comparison between linear and daily undulating periodized resistance training to increase strength. *J. Strength Cond. Res.* Dec 2009;23(9):2437-2442.

30. Buford TW, Rossi SJ, Smith DB, Warren AJ. A comparison of periodization models during nine weeks with equated volume and intensity for strength. *J. Strength Cond. Res.* Nov 2007;21(4):1245-1250.

31. Apel JM, Lacey RM, Kell RT. A comparison of traditional and weekly undulating periodized strength training programs with total volume and intensity equated. *J. Strength Cond. Res.* Mar 2011;25(3):694-703.

32. Hoffman JR, Ratamess NA, Klatt M, et al. Comparison between different off-season resistance training programs in Division III American college football players. *J. Strength Cond. Res.* Jan 2009;23(1):11-19.

33. Rhea MR, Ball SD, Phillips WT, Burkett LN. A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *J. Strength Cond. Res.* May 2002;16(2):250-255.

34. Peterson MD, Dodd DJ, Alvar BA, Rhea MR, Favre M. Undulation training for development of hierarchical fitness and improved firefighter job performance. *J. Strength Cond. Res.* Sep 2008;22(5):1683-1695.

35. Monteiro AG, Aoki MS, Evangelista AL, et al. Nonlinear periodization maximizes strength gains in split resistance training routines. *J. Strength Cond. Res.* Jul 2009;23(4):1321-1326.

36. Bartolomei S, Hoffman JR, Merni F, Stout JR. A comparison of traditional and block periodized strength training programs in trained athletes. *J. Strength Cond. Res.* Apr 2014;28(4):990-997.

37. Painter KB, Haff GG, Ramsey MW, et al. Strength gains: block versus daily undulating periodization weight training among track and field athletes. *Int J Sports Physiol Perform.* Jun 2012;7(2):161-169.

38. Zourdos MC. *Physiological responses to two different models of daily undulating periodization in trained powerlifters* [Ph.D.]. Ann Arbor, The Florida State University; 2012.

39. Schoenfeld BJ, Ratamess NA, Peterson MD, Contreras B, Tiryaki-Sonmez G, Alvar BA. Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. *J. Strength Cond. Res.* Apr 7 2014.

40. Flann KL, LaStayo PC, McClain DA, Hazel M, Lindstedt SL. Muscle damage and muscle remodeling: no pain, no gain? *J. Exp. Biol.* Feb 15 2011;214(Pt 4):674-679.

41. Goto K, Nagasawa M, Yanagisawa O, Kizuka T, Ishii N, Takamatsu K. Muscular adaptations to combinations of high- and low-intensity resistance exercises. *J. Strength Cond. Res.* Nov 2004;18(4):730-737.

42. Kraemer WJ, Ratamess N, Fry AC, et al. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Am. J. Sports Med.* Sep-Oct 2000;28(5):626-633.

43. Rhea MR, Alderman BL. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Res. Q. Exerc. Sport.* Dec 2004;75(4):413-422.

44. Willoughby DS. The effects of mesocycle-length weight training programs involving periodization and partially equated volumes on upper and lower body strength. *J. Strength Cond. Res.* 1993;7(1):2-8.

45. O'Bryant HS, Byrd R, Stone MH. Cycle ergometer performance and maximum leg and hip strength adaptations to two different methods of weight-training. *J. Strength Cond. Res.* 1988;2(2):27-30.

46. Hartman MJ, Clark B, Bembens DA, Kilgore JL, Bemben MG. Comparisons between twice-daily and once-daily training sessions in male weight lifters. *Int J Sports Physiol Perform.* Jun 2007;2(2):159-169.

47. Hakkinen K, Kallinen M. Distribution of strength training volume into one or two daily sessions and neuromuscular adaptations in female athletes. *Electromyogr. Clin. Neurophysiol.* Mar 1994;34(2):117-124.

48. Hakkinen K, Pakarinen A. Serum hormones in male strength athletes during intensive short term strength training. *Eur. J. Appl. Physiol.* 1991;63(3-4):194-199.

49. Raastad T, Kirketeig A, Wolf D, Paulsen G. Powerlifters improved strength and muscular adaptations to a greater extent when equal total training volume was divided into 6 compared to 3 training sessions per week. *17th annual conference of the ECSS, Brugge 4-7* 2012.

50. McLester JR, Bishop, E., Guilliams, M.E. Comparison of 1 day and 3 days per week of equal-volume resistance training in experienced subjects. *J. Strength Cond. Res.* 2000;14(3):273-281.

51. Newton LE, Hunter GR, Bammon M, Roney RK. Changes in psychological state and self-reported diet during various phases of training in competitive bodybuilders. *J. Strength Cond. Res.* 1993;7(3):153-158.

52. Maestu J, Eliakim A, Jurimae J, Valter I, Jurimae T. Anabolic and catabolic hormones and energy balance of the male bodybuilders during the preparation for the competition. *J. Strength Cond. Res.* Apr 2010;24(4):1074-1081.

53. Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. *J. Strength Cond. Res.* Apr 2010;24(4):1150-1159.

54. Ronnestad BR, Egeland W, Kvamme NH, Refsnes PE, Kadi F, Raastad T. Dissimilar effects of one- and three-set strength training on strength and muscle mass gains in upper and lower body in untrained subjects. *J. Strength Cond. Res.* Feb 2007;21(1):157-163.

55. Selye H. Stress and the general adaptation syndrome. *Br. Med. J.* 1950;1(4667):1383.

56. ACSM. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* 2009;41(3):687-708

57. Bickel CS, Cross JM, Bamman MM. Exercise dosing to retain resistance training adaptations in young and older adults. *Med. Sci. Sports Exerc.* Jul 2011;43(7):1177-1187.

58. Holm L, Reitelseder S, Pedersen TG, et al. Changes in muscle size and MHC composition in response to resistance exercise with heavy and light loading intensity. *J Appl Physiol (1985).* Nov 2008;105(5):1454-1461.

59. Campos GE, Luecke TJ, Wendeln HK, et al. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur. J. Appl. Physiol.* Nov 2002;88(1-2):50-60.

60. Schuenke MD, Herman JR, Gliders RM, et al. Early-phase muscular adaptations in response to slow-speed versus traditional resistance-training regimens. *Eur. J. Appl. Physiol.* Oct 2012;112(10):3585-3595.

61. Popov DV, Tsvirkun DV, Netreba AI, et al. [Hormonal adaptation determines the increase in muscle mass and strength during low-intensity strength training without relaxation]. *Fiziol. Cheloveka.* Sep-Oct 2006;32(5):121-127.

62. Tanimoto M, Ishii N. Effects of low-intensity resistance exercise with slow movement and tonic force generation on muscular function in young men. *J Appl Physiol (1985).* Apr 2006;100(4):1150-1157.

63. Ogasawara R, Loenneke JP, Thiebaud RS, Abe T. Low-load bench press training to fatigue results in muscle hypertrophy similar to high-load bench press training. *International Journal of Clinical Medicine.* 2013;4:114.

64. Schoenfeld BJ. Is there a minimum intensity threshold for resistance training-induced hypertrophic adaptations? *Sports Med.* 2013;43(12):1279-1288.

65. Moss BM, Refsnes PE, Abildgaard A, Nicolaysen K, Jensen J. Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *Eur J Appl Physiol Occup Physiol.* 1997;75(3):193-199.

66. Simao R, de Salles BF, Figueiredo T, Dias I, Willardson JM. Exercise order in resistance training. *Sports Med.* Mar 1 2012;42(3):251-265.

67. Simão R, Figueiredo T, Leite RD, Jansen A, Willardson JM. Influence of exercise order on repetition performance during low-intensity resistance exercise. *Res. Sports Med.* 2012/07/01 2012;20(3-4):263-273.

68. de Salles BF, Simao R, Miranda F, Novaes Jda S, Lemos A, Willardson JM. Rest interval between sets in strength training. *Sports Med.* 2009;39(9):765-777.

69. Willardson JM. A brief review: factors affecting the length of the rest interval between resistance exercise sets. *J. Strength Cond. Res.* Nov 2006;20(4):978-984.

70. West DW, Phillips SM. Associations of exercise-induced hormone profiles and gains in strength and hypertrophy in a large cohort after weight training. *Eur. J. Appl. Physiol.* Nov 22 2011;112(7):2693-2702.

71. de Souza TPJ, Fleck SJ, Simão R, et al. Comparison Between constant and decreasing rest intervals: influence on maximal strength and hypertrophy. *J. Strength Cond. Res.* 2010;24(7):1843-1850

72. Buresh R, Berg K, French J. The effect of resistive exercise rest interval on hormonal response, strength, and hypertrophy with training. *J. Strength Cond. Res.* 2009;23(1):62-71

73. Ahtiainen JP, Pakarinen A, Alen M, Kraemer WJ, Häkkinen K. Short vs.long rest period between the sets in hypertrophic resistance training: Influence on muscle strength, size, and hormonal adaptations in trained men. *J. Strength Cond. Res.* 2005;19(3):572-582.

74. Ehrnborg C, Ellegard L, Bosaeus I, Bengtsson BA, Rosen T. Supraphysiological growth hormone: less fat, more extracellular fluid but uncertain effects on muscles in healthy, active young adults. *Clin. Endocrinol. (Oxf.).* Apr 2005;62(4):449-457.

75. Schoenfeld BJ. Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training. *Sports Med.* Mar 2013;43(3):179-194.

76. Headley SA, Henry K, Nindl BC, Thompson BA, Kraemer WJ, Jones MT. Effects of lifting tempo on one repetition maximum and hormonal responses to a bench press protocol. *J. Strength Cond. Res.* Feb 2011;25(2):406-413.

77. Pryor RR, Sforzo GA, King DL. Optimizing power output by varying repetition tempo. *J. Strength Cond. Res.* Nov 2011;25(11):3029-3034.

78. Westcott WL, Winett RA, Anderson ES, et al. Effects of regular and slow speed resistance training on muscle strength. *J. Sports Med. Phys. Fitness.* Jun 2001;41(2):154-158.

79. Hunter GR, Seelhorst D, Snyder S. Comparison of metabolic and heart rate responses to super slow vs. traditional resistance training. *J. Strength Cond. Res.* 2003;17(1):76-81.

80. Kim E, Dear A, Ferguson SL, Seo D, Bemben MG. Effects of 4 weeks of traditional resistance training vs. superslow strength training on early phase adaptations in strength, flexibility, and aerobic capacity in college-aged women. *J. Strength Cond. Res.* 2011;25(11):3006-3013

81. Keeler LK, Finkelstein LH, Miller W, Fernhall BO. Early-phase adaptations of traditional-speed vs. superslow resistance training on strength and aerobic capacity in sedentary individuals. *J. Strength Cond. Res.* 2001;15(3):309-314.

82. Neils CM, Udermann BE, Brice GA, Winchester JB, McGuigan MR. Influence of contraction velocity in untrained individuals over the initial early phase of resistance training. *J. Strength Cond. Res.* 2005;19(4):883-887.

83. Shepstone TN, Tang JE, Dallaire S, Schuenke MD, Staron RS, Phillips SM. Short-term high- vs. low-velocity isokinetic lengthening training results in greater hypertrophy of the elbow flexors in young men. *J. Appl. Physiol.* May 1, 2005 2005;98(5):1768-1776.

84. Blazevich AJ, Cannavan D, Coleman DR, Horne S. Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. *J. Appl. Physiol.* Nov 2007;103(5):1565-1575.

85. Blazevich AJ, Horne S, Cannavan D, Coleman DR, Aagaard P. Effect of contraction mode of slow-speed resistance training on the maximum rate of force development in the human quadriceps. *Muscle Nerve.* Sep 2008;38(3):1133-1146.

86. Tanimoto M, Sanada K, Yamamoto K, et al. Effects of whole-body low-intensity resistance training with slow movement and tonic force generation on muscular size and strength in young men. *J. Strength Cond. Res.* Nov 2008;22(6):1926-1938.

87. Roig M, O'Brien K, Kirk G, et al. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. *Br. J. Sports Med.* Aug 2009;43(8):556-568.

88. Brentano MA, Martins Kruel LF. A review on strength exercise-induced muscle damage: applications, adaptation mechanisms and limitations. *J. Sports Med. Phys. Fitness.* Mar 2011;51(1):1-10.

89. Schoenfeld B. Does exercise-induced muscle damage play a role in skeletal muscle hypertrophy? *J. Strength Cond. Res.* Feb 15 2012;26(5):1441-1453.

90. Gillies EM, Putman CT, Bell GJ. The effect of varying the time of concentric and eccentric muscle actions during resistance training on skeletal muscle adaptations in women. *Eur. J. Appl. Physiol.* Jul 2006;97(4):443-453.

91. Snyder BJ, Leech JR. Voluntary increase in latissimus dorsi muscle activity during the lat pull-down following expert instruction. *J. Strength Cond. Res.* Nov 2009;23(8):2204-2209.

92. Willardson JM. The application of training to failure in periodized multiple-set resistance exercise programs. *J. Strength Cond. Res.* May 2007;21(2):628-631.

93. Izquierdo M, Ibanez J, Gonzalez-Badillo JJ, et al. Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *J Appl Physiol (1985).* May 2006;100(5):1647-1656.

94. Schoenfeld B. The use of specialized training techniques to maximize muscle hypertrophy. *Strength Cond J.* 2011;33(4):60-65

95. Ramires Alsamir T, Jonato P, Dahan da Cunha N, Sandor B. Comparison of the number of repetitions and perceived exertion between multi-joint and single-joint exercise at different intensities in untrained women. *Braz J Biomotricity.* 2011;5(2):96-105.

96. Kraemer WJ, Ratamess NA, French DN. Resistance training for health and performance. *Curr. Sports Med. Rep.* Jun 2002;1(3):165-171.

97. Kraemer WJ, Ratamess NA. Hormonal responses and adaptations to resistance exercise and training. *Sports Med.* 2005;35(4):339-361.

98. Bird SP, Tarpenning KM, Marino FE. Designing resistance training programmes to enhance muscular fitness: a review of the acute programme variables. *Sports Med.* 2005;35(10):841-851.

99. Schoenfeld B. Repetitions and muscle hypertrophy. *Strength Cond J.* 2000;22(6):67.

100. Ronei PS, Gomes N, Radaelli R, Botton CE, Brown LE, Bottaro M. Effect of range of motion on muscle strength and thickness. *J. Strength Cond. Res.* Oct 24 2011.

101. Bloomquist K, Langberg H, Karlsen S, Madsgaard S, Boesen M, Raastad T. Effect of range of motion in heavy load squatting on muscle and tendon adaptations. *Eur. J. Appl. Physiol.* Aug 2013;113(8):2133-2142.

102. Barlow JC, Benjamin BW, Birt P, Hughes CJ. Shoulder strength and range-of-motion characteristics in bodybuilders. *J. Strength Cond. Res.* Aug 2002;16(3):367-372.

103. Woodley SJ, Mercer SR. Hamstring muscles: architecture and innervation. *Cells Tissues Organs.* 2005;179(3):125-141.

104. Glass SC, Armstrong T. Electromyographical activity of the pectoralis muscle during incline and decline bench presses. *J. Strength Cond. Res.* Aug 1997;11(3):163-167.

105. Antonio J. Nonuniform response of skeletal muscle to heavy resistance training: Can bodybuilders induce regional muscle hypertrophy? *J. Strength Cond. Res.* 2000;14(1):102-113.

106. Fonseca RM, Roschel H, Tricoli V, et al. Changes in exercises are more effective than in loading schemes to improve muscle strength. *J. Strength Cond. Res.* May 14 2014.

107. Hall KD, Heymsfield SB, Kemnitz JW, Klein S, Schoeller DA, Speakman JR. Energy balance and its components: implications for body weight regulation. *Am. J. Clin. Nutr.* Apr 2012;95(4):989-994.

108. Wilson JM, Marin PJ, Rhea MR, Wilson SM, Loenneke JP, Anderson JC. Concurrent training: a meta analysis examining interference of aerobic and resistance exercise. *J. Strength Cond. Res.* Oct 13 2011.

109. Nader GA. Concurrent strength and endurance training: from molecules to man. *Med. Sci. Sports Exerc.* Nov 2006;38(11):1965-1970.

110. Leveritt M, Abernethy PJ, Barry BK, Logan PA. Concurrent strength and endurance training. A review. *Sports Med.* Dec 1999;28(6):413-427.

111. Dolezal BA, Potteiger JA. Concurrent resistance and endurance training influence basal metabolic rate in nondieting individuals. *J. Appl. Physiol.* Aug 1998;85(2):695-700.

112. Hakkinen K, Alen M, Kraemer WJ, et al. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur. J. Appl. Physiol.* Mar 2003;89(1):42-52.

113. Hickson RC. Interference of strength development by simultaneously training for strength and endurance. *Eur J Appl Physiol Occup Physiol.* 1980;45(2-3):255-263.

114. Kraemer WJ, Patton JF, Gordon SE, et al. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J. Appl. Physiol.* Mar 1995;78(3):976-989.

115. Balabinis CP, Psarakis CH, Moukas M, Vassiliou MP, Behrakis PK. Early phase changes by concurrent endurance and strength training. *J. Strength Cond. Res.* May 2003;17(2):393-401.

116. McCarthy JP, Pozniak MA, Agre JC. Neuromuscular adaptations to concurrent strength and endurance training. *Med. Sci. Sports Exerc.* Mar 2002;34(3):511-519.

117. Little JP, Safdar A, Wilkin GP, Tarnopolsky MA, Gibala MJ. A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: potential mechanisms. *J. Physiol.* Mar 15 2010;588(Pt 6):1011-1022.

118. Gibala MJ, Little JP, van Essen M, et al. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *J. Physiol.* Sep 15 2006;575(Pt 3):901-911.

119. Rhea MR, Oliverson JR, Marshall G, Peterson MD, Kenn JG, Ayllon FN. Noncompatibility of power and endurance training among college baseball players. *J. Strength Cond. Res.* Jan 2008;22(1):230-234.

120. Borsheim E, Bahr R. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Med.* 2003;33(14):1037-1060.

121. Schoenfeld B. Does cardio after an overnight fast maximize fat loss? *Strength Cond J.* 2011;33(1):23-25.

122. Tremblay A, Simoneau JA, Bouchard C. Impact of exercise intensity on body fatness and skeletal muscle metabolism. *Metabolism.* Jul 1994;43(7):814-818.

123. Lemon PW, Mullin JP. Effect of initial muscle glycogen levels on protein catabolism during exercise. *Journal of Applied Physiology.* April 1, 1980 1980;48(4):624-629.

124. Coyle EF, Jeukendrup AE, Wagenmakers AJ, Saris WH. Fatty acid oxidation is directly regulated by carbohydrate metabolism during exercise. *Am. J. Physiol.* Aug 1997;273(2 Pt 1):E268-275.

125. Rowlands DS, Hopkins WG. Effect of high-fat, high-carbohydrate, and high-protein meals on metabolism and performance during endurance cycling. *Int. J. Sport Nutr. Exerc. Metab.* Sep 2002;12(3):318-335.

126. Wallis GA, Dawson R, Achten J, Webber J, Jeukendrup AE. Metabolic response to carbohydrate ingestion during exercise in males and females. *Am. J. Physiol. Endocrinol. Metab.* Apr 2006;290(4):E708-715.

127. Febbraio MA, Chiu A, Angus DJ, Arkinstall MJ, Hawley JA. Effects of carbohydrate ingestion before and during exercise on glucose kinetics and performance. *J. Appl. Physiol.* Dec 2000;89(6):2220-2226.

128. Horowitz JF, Mora-Rodriguez R, Byerley LO, Coyle EF. Substrate metabolism when subjects are fed carbohydrate during exercise. *Am. J. Physiol.* May 1999;276(5 Pt 1):E828-835.

129. Hansen K, Shriver T, Schoeller D. The effects of exercise on the storage and oxidation of dietary fat. *Sports Med.* 2005;35(5):363-373.

130. Paoli A, Marcolin G, Zonin F, Neri M, Sivieri A, Pacelli QF. Exercising fasting or fed to enhance fat loss? Influence of food intake on respiratory ratio and excess postexercise oxygen consumption after a bout of endurance training. *Int. J. Sport Nutr. Exerc. Metab.* Feb 2011;21(1):48-54.

131. van Essen M, Gibala MJ. Failure of protein to improve time trial performance when added to a sports drink. *Med. Sci. Sports Exerc.* Aug 2006;38(8):1476-1483.

132. Palmer GS, Clancy MC, Hawley JA, Rodger IM, Burke LM, Noakes TD. Carbohydrate ingestion immediately before exercise does not improve 20 km time trial performance in well trained cyclists. *Int. J. Sports Med.* Aug 1998;19(6):415-418.

133. Snyder AC, Moorhead K, Luedtke J, Small M. Carbohydrate consumption prior to repeated bouts of high-intensity exercise. *Eur. J. Appl. Physiol.* 1993;66(2):141-145.

134. Gualano AB, Bozza T, Lopes De Campos P, et al. Branched-chain amino acids supplementation enhances exercise capacity and lipid oxidation during endurance exercise after muscle glycogen depletion. *J. Sports Med. Phys. Fitness.* Mar 2011;51(1):82-88.

135. McNamara JM, Stearne DJ. Flexible Nonlinear Periodization in a Beginner College Weight Training Class. *J. Strength Cond. Res.* 2010;24(1):17-22

136. Mann JB, Thyfault JP, Ivey PA, Sayers SP. The effect of autoregulatory progressive resistance exercise vs. linear periodization on strength improvement in college athletes. *J. Strength Cond. Res.* 2010;24(7):1718-1723

137. Loenneke JP, Fahs CA, Wilson JM, Bemben MG. Blood flow restriction: The metabolite/volume threshold theory. *Med. Hypotheses.* 2011;77(5):748-752.

138. Mohamad NI, Cronin J, Nosaka K. Brief review: Maximizing hypertrophic adaptation—Possible contributions of aerobic exercise in the interset rest period. *Strength & Conditioning Journal.* 2012;34(1):8-15 10.1519/SSC.1510b1013e3182308969.

139. Mohamad NI, Nosaka K, Cronin J. Maximizing Hypertrophy: Possible Contribution of Stretching in the Interset Rest Period. *Strength & Conditioning Journal.* 2011;33(1):81-87 10.1519/SSC.1510b1013e3181fe7164.