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Samuel L. Buckner

Matthew B. Jessee

Grant J. Mouser

Scott J. Dankel

Kevin T. Mattocks

See next page for additional authors

Authors
Samuel L. Buckner, Matthew B. Jessee, Grant J. Mouser, Scott J. Dankel, Kevin T. Mattocks, Zachary W. Bell, Takashi Abe, and Jeremy P. Loenneke

The Basics of Training for Muscle Size and Strength: A Brief Review on the Theory

SAMUEL L. BUCKNER[1], MATTHEW B. JESSEE[2], J. GRANT MOUSER[3], SCOTT J. DANKEL[4], KEVIN T. MATTOCKS[5], ZACHARY W. BELL[6], TAKASHI ABE[6], and JEREMY P. LOENNEKE[6]

[1]USF Muscle Lab, Exercise Science Program, University of South Florida, Tampa, FL; [2]Department of Health, Exercise Science, and Recreation Management, University of Mississippi, University, MS; [3]Department of Kinesiology and Health Promotion, Troy University, Troy, AL; [4]Department of Health and Exercise Science, Exercise Physiology Laboratory, Rowan University, Glassboro, NJ; [5]Exercise Science, Lindenwood University, Belleville, IL; and [6]Department of Health, Exercise Science, and Recreation Management, Kevser Ermin Applied Physiology Laboratory, University of Mississippi, University, MS

ABSTRACT

BUCKNER, S. L., M. B. JESSEE, J. G. MOUSER, S. J. DANKEL, K. T. MATTOCKS, Z. W. BELL, T. ABE, and J. P. LOENNEKE. The Basics of Training for Muscle Size and Strength: A Brief Review on the Theory. *Med. Sci. Sports Exerc.*, Vol. 52, No. 3, pp. 645–653, 2020. The periodization of resistance exercise is often touted as the most effective strategy for optimizing muscle size and strength adaptations. This narrative persists despite a lack of experimental evidence to demonstrate its superiority. In addition, the general adaptation syndrome, which provides the theoretical framework underlying periodization, does not appear to provide a strong physiological rationale that periodization is necessary. Hans Selye conducted a series of rodent studies which used toxic stressors to facilitate the development of the general adaptation syndrome. To our knowledge, normal exercise in humans has never been shown to produce a general adaptation syndrome. We question whether there is any physiological rationale that a periodized training approach would facilitate greater adaptations compared with nonperiodized approaches employing progressive overload. The purpose of this article is to briefly review currently debated topics within strength and conditioning and provide some practical insight regarding the implications these reevaluations of the literature may have for resistance exercise and periodization. In addition, we provide some suggestions for the continued advancement within the field of strength and conditioning. **Key Words:** RESISTANCE EXERCISE, PERIODIZATION, PROGRAMMING, GENERAL ADAPTATION SYNDROME

Many foundational principles related to resistance exercise have been questioned over the past decade, including the hormone hypothesis (1–3) and the idea that high loads are required for inducing maximal muscle growth (1,4). Recent articles have added to this by questioning both the theoretical framework (the general adaptation syndrome [GAS]) underlying periodization (5,6), and whether periodization is, in and of itself, superior to nonperiodized resistance training for increasing muscle size and strength (7). Kiely (8) has suggested that "tradition-driven assumptions," rather than "evidence-based constructs," may underlie much of the periodization philosophy. If true, it is important to continue to question and refine our understanding of the evidence behind the periodization of resistance exercise.

In a review of the literature examining the role of periodization for increasing muscle size and strength, it was concluded that there was not sufficient evidence to suggest that periodized resistance training programs result in greater increases in muscle size and strength compared with nonperiodized approaches (7). This was followed by a review of the GAS (5), which provides the theoretical framework for periodized resistance training. An examination of Hans Selye's work on the GAS led to the conclusion that the GAS has been potentially misapplied to resistance exercise. Selye's experiments explore the physiological effects of toxic stressors in rodent models, which provides little insight as to how humans may adapt to exercise.

The ideas raised from these reexaminations of the literature have implications for both scientists and practitioners alike. As with any idea that challenges well-established beliefs, there is a great deal of misinterpretation coupled with a reluctance to reevaluate the evidence from which many of our conclusions are drawn. The purpose of this article is to briefly review currently debated topics within strength and conditioning and provide some practical insight regarding the implications these reevaluations of the literature may have for resistance exercise and periodization. Finally, we provide some suggestions for the continued advancement within the field of strength and conditioning.

PERIODIZATION

Periodization has been defined as "[an] exercise system that, if designed correctly, would help to prevent overtraining

Address for correspondence: Jeremy Paul Loenneke, Ph.D., P.O. Box 1848. University, MS 38677; E-mail: jploenne@olemiss.edu.
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while optimizing peak performance through progressive training cycles (9).” Thus, periodization is a strategy by which variables, such as volume, load, and training frequency are all varied with the intention of realizing these goals (10). Although the present article discusses the scientific evidence for periodization, it is worth noting that a history of periodized techniques exists outside the scientific literature. Highly cited is a textbook by Leonid Matveyev (11). Matveyv outlines his principles of training based on years of coaching and studying athletes (11). Although this work has been important for informing research and coaching, this text does not include citations/references for the claims being made within it. Although anecdotes can be useful for informing future research in our field, they are insufficient to make strong claims about the importance of periodization. This review will focus on the scientific literature which seeks to incorporate resistance exercise into training programs for athletes; the rationale being that muscle strength “is an essential component of human performance” (12).

The state of the literature. Periodization is perceived as the “gold standard” of resistance exercise organization, believed to be superior to nonperiodized approaches both for athletes and nonathletes alike. Although periodization was created to help manage the stress of sport with the stress of lifting weights, modern studies examine periodization with no stressor (i.e., sport) to periodize against (e.g., they are only lifting weights) (13–15). Thus, periodization of resistance training is recommended in position stands outside of sport. For example, the American College of Sports Medicine position stand for resistance exercise suggests that “variation, *or periodization* … allows for the training stimulus to remain challenging and effective” (16). Thus, variation of a training stimulus is thought important for continued adaptation to occur. The *Essentials of Strength Training and Conditioning* text suggests that “as athletes become more trained or have a greater training age, it becomes more difficult to stimulate performance gains” and that “increased variation is often required in the training program of more advanced athletes to facilitate long-term training and performance gains” (17). In addition, it has been suggested that periodization is necessary to help avoid “performance plateaus or decrements” (18). Although we agree that there are likely strategies or techniques more likely to “optimize” adaptation (i.e., training to or near failure for muscle growth with a load that can largely be determined by preference [30%–85% one-repetition maximum (1RM) (19) or training with high relative loads for maximal strength (1,20)]), we are skeptical that periodization is superior to or even necessary to achieve “optimal” increases in muscle size and strength compared with nonperiodized approaches.

A criticism of previous work comparing periodized to nonperiodized resistance training is that existing studies examine programming (part of periodization) as opposed to the larger overall concept itself (i.e., the yearly plan) (21). Indeed, the literature examining periodization is centered around short-term studies that employ either a “periodized” approach or a “nonperiodized” approach. Such studies provide some indication, but cannot predict adaptation across an entire training year. Cunanan et al. (21) pointed out that periodization “is a blueprint that permits the coach to forecast and assign periods of time toward the acquisition and realization of specific fitness characteristics,” with programming being the “micromanagement within these different stages of training.” The authors stress that periodization is a more global process and that the existing literature is comparing the effectiveness of mesocycles (periods lasting for weeks to months within the larger macrocycle). We recognize that strength coaches may be more concerned with the programming across an entire training year, as opposed to an 8- to 12-wk block. However, our examination of the literature is based on the current body of studies which have been performed and those studies which are cited as evidence for periodization in textbooks.

Considering that the current base of literature examining periodized versus nonperiodized approaches is composed of 6 to 8 wk (22–24) and 10 to 15 wk (25–31) studies, any claims made regarding benefits or lack of benefits of periodization should be discussed in this context. Although the latest edition of the *Essentials of Strength Training and Conditioning* textbook does not dedicate a section to compare periodized versus nonperiodized programs, a similar approach can be observed in the textbook’s section (within the periodization chapter) titled: “Undulating versus Linear Periodization Models” (17). In this section, the authors discuss some studies’ suggestion that the undulating model is more effective than the traditional model, with others suggesting that there is no difference (17). The citations provided for these statements are all 9-wk (32), 10-wk (33), 12-wk (28,34–38), or 14- to 15-wk studies (39,40), with one study lasting 24 wk (41). If this approach can be used to suggest that one type of periodization is superior to another, it should also be adequate to suggest that a periodized approach in not superior to a nonperiodized approach. The subsequent sections within the present article will discuss the literature used to suggest that periodization is superior to nonperiodized approaches. Although many of these studies are short-term, this appears to be the current body of evidence.

Periodization for growth and strength. It is believed that periodized resistance training results in greater increases in muscle size compared with nonperiodized approaches (22,42). For example, Stone et al. (22) found that a periodized program increased lean body mass to a greater extent than a nonperiodized program after 3 wk of training. However, in the following 3 wk both groups continued to resistance train but both groups appeared to lose lean body mass (albeit to a less degree in the periodized group). The reason for this is unknown but it seems unlikely that resistance training would result in a decrease in lean mass. How this change compares to measurement error/random biological variability is unknown as a nonexercise time matched control group was not included. Another consideration of this study is that participants were allowed to progress at their own rate which may have limited the anabolic potential of the exercise stimulus. Although some studies suggest that periodization leads to greater increases in muscle size (22,43), others have shown that the increases are similar after periodized or nonperiodized resistance training programs

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(24,28). Most of these studies estimated muscle growth based on changes in lean body mass from indirect measures (i.e., skinfolds, underwater weighing), which may have a limited ability to detect actual skeletal muscle growth. When examining changes in quadriceps cross-sectional area (CSA) using magnetic resonance imaging (gold standard), Souza et al. (24) found no difference between periodized and nonperiodized training. In a follow up study, authors investigated the effects of periodized and nonperiodized approaches after 12 wk of training (44). Authors found that all groups increased similarly from pre to 12 wk (nonperiodized = 8.1%, traditional periodization = 11.3% and undulating periodization = 8.7%) (44). However, authors point out that only the undulating and linear periodization groups increased from 6 to 12 wk (44). Based on this, it was suggested that periodization may be more effective over the long term. However, all that can be stated is that the time-course of adaptation might be slightly different between programming techniques. It is important to note that their interpretation is driven by changes within each group rather than changes between each group. A within group difference across time should not necessarily be interpreted as a greater change between the different conditions. In addition, the training status is often pointed out as a shortcoming in periodization studies. For example, Souza et al. (41) utilized gold-standard measurements in recreationally trained individuals (nonresistance trained). Proponents of periodization have made the suggestion that periodization becomes more important as an individual becomes more trained, though there is a lack of evidence for this claim.

All of this considered, we are unaware of a mechanistic explanation as to how planned variations in training variables (as it exists in the periodization literature) could influence the hypertrophic response provided that a sufficient training stimulus is provided. For example, a variety of exercise loads (30%–80%1RM) can result in similar changes in muscle size (4,45–47). Thus, it is difficult to physiologically rationalize how a special combination of training loads, each one of which result in similar whole muscle skeletal muscle growth, would result in superior growth when combined in a program. Damas et al. (48) examined the acute and chronic effects of variable (modulating exercise load, volume, contraction type, and interset rest interval) or traditional progressive resistance training. Authors noted a higher total training volume and higher acute myofibrillar protein synthetic responses in response to the variable resistance training program compared with the traditional progressive program (48). However, this was not accompanied with a greater hypertrophic response over an 8-wk period (48).

Of note, there has been some suggestion that low load resistance training (30% 1RM to failure) may lead to a greater time under load, which may maximize the stimulation of type I fibers and lead to a greater hypertrophic response of these fibers (49). Though this would provide some rationale for variation of load within a resistance training program, this idea remains speculative as type I fiber hypertrophy also occurs after high-load training and is not specific to training with lower loads (1,4,50,51). In addition, periodized resistance training does not typically include hypertrophy blocks employing such low relative loads, but instead utilize a more traditional 6 to 12 repetition range (67%–85% 1RM) (18). One consideration put forth by Fisher et al. (52) is that the variation in exercise selection may provide a more robust increase in muscle size. This is working under the idea that each exercise may target different muscles in different ways. As evidence, those authors cite Fonseca et al. (53) who appeared to observe a more homogeneous muscle growth response across the quadriceps muscles when incorporating a variety of exercises (squat, leg press, and deadlift) as opposed to a group that did not incorporate variety (squat only). Although there were subtle within group differences, there did not appear to be differences between the groups. Nevertheless, it seems possible that completing multiple exercises may have the ability to ensure sufficient activation of multiple muscle groups.

It may also be argued that periodization is necessary to maximize growth through stress/fatigue management. For example, a coach may alter more than just the exercise load (i.e., rest intervals, volume, tempo) throughout the course of a training program. In this light, one could suggest that a precise manipulation in exercise variables might be important in order to augment muscle growth over time. This hypothesis is largely based on the foundational principles of periodization (primarily the GAS), which would suggest that if not managed properly the stress accumulated from a training program could lead to "exhaustion" and compromise adaptation (discussed in subsequent sections) (21). Future studies could examine the role of overall stress (in addition to that of resistance training) on skeletal muscle growth (i.e., are there scenarios where growth is attenuated?) and the efficacy of periodization (amongst other more simplistic programming strategies) to mitigate any attenuation of growth that might be observed.

A recent meta-analysis suggests that periodization leads to greater strength gains compared with nonperiodized resistance training (12). The authors concluded that "while many variables must be accounted for in designing a resistance training program, […] daily, weekly, or phasic variations in training stimuli yield a greater effect on maximal strength" (12). However, the strength difference observed between periodized and nonperiodized resistance training can more often than not be explained by the principle of specificity. If an individual trains at a load approaching their 1RM, they will likely test better when performing a 1RM (1,54). This may relate to the importance of skill acquisition for strength adaptation, which was originally discussed in 1957 (55). Rasch and Morehouse (55) found that strength in the elbow flexors increased more when participants were tested in a position (erect vs supine) and manner (dynamic vs modified Martin technique) similar to how they had trained. We wish to extend their suggestion to also include the specificity of load as important for the strength adaptation, which we define as the range of relative loads (i.e., % 1RM) one would need to train at in order to maximize strength on a specific strength test. A recent pilot study provided preliminary evidence that a single-set, single-rep RPE-based

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"daily max" training program can increase strength similarly to a higher volume periodized approach in beginner-intermediate powerlifting athletes (56). Of course, it may be argued that the structure of periodization (e.g., sequential training models moving from general to specific) allows the athlete to enhance their training capacity in order for them to handle the training loads required within the more specific training periods. However, if the goal is to be able to handle a specific training load, it seems reasonable to suggest that progressive overload would be equally effective as a periodized approach.

Periodization and overtraining. Much of the discussion on periodization for strength adaptation focuses on the importance of variation to avoid overtraining. A recent review explains that "extended periods of training at a high intensity can greatly increase the risk of stagnation and overtraining (12)." Notwithstanding issues regarding the definition of 'intensity' within the context of periodization (52), the authors provide evidence for this statement from the findings of Herrick and Stone (29) who observed similar increases in strength between periodized and nonperiodized resistance exercise after a 15-wk period. Despite similar strength increases, the authors discuss how the nonperiodized resistance training group was "showing less strength improvement or tapering toward the final stages of the study" while the periodized group was continuing to improve in a more linear fashion. Based on extrapolation of the strength slopes, the authors suggest that the periodized training group would show greater strength gains in a year-round training period. This is an interesting discussion; however, they did not discuss how the pattern of strength changes may be driven by the principle of specificity, or the fact that a hypothetical extrapolation of strength based on slope would assume a linear (and continuous) increase in strength over time. Fisher et al. (52) discussed the idea of continued strength and hypertrophy adaptations, questioning "whether it is even possible to produce continued long-term improvements and overcome the so-called stagnation," pointing out that this idea lacks sufficient empirical evidence. The other citation provided for evidence of "overtraining and stagnation" is a 1994 review by Kraemer and Ratamess (10). Therein, the authors suggest that variation in a training program "allows for the training stimulus to remain optimal," pointing out that "…it has been shown that systematically varying volume and intensity is most effective for long-term progression compared with programs that did not vary any acute program variable." However, the citations provided for this statement are another review on periodization (57) and the "Hypothetical model of Strength Training" by Stone et al. (22) in which strength differences can also be explained by the principle of specificity and likely have little to do with overtraining differences between periodized and nonperiodized protocols. Undoubtedly, overtraining can occur; however, when eliciting overtraining using resistance exercise in humans the protocols are quite extreme. For example, Fry et al. (58) observed a 5% decrease in 1RM strength after a high-intensity resistance training protocol. This is not surprising as this protocol involved 10 separate repetitions at 100% of 1RM daily for 2 wk which was compared with a group performing lower intensity training twice per week. Protocols like this cannot be used as a justification for periodization of resistance exercise as a simple reduction in the number of 1RM attempts performed (140 over 2 wk) would likely prevent overtraining from occurring. For example, an earlier study by the same research group was unable to induce overtraining despite having participants engage in three consecutive weeks of daily (Monday to Friday) high-intensity training (8 single repetitions at 95%1RM) (59).

Androulakis-Korakakis et al. (56) provides additional evidence in a powerlifting population, demonstrating that a single-set, single-rep RPE based "daily max" training program can increase strength in some individuals without producing overtraining (while also not employing periodization). In this pilot study, some individuals were able to increase their powerlifting total through a protocol that only incorporated near maximal attempts. There may be a point at which too much exercise volume may lead to performance decrements (58); however, this can likely be avoided as lower volume approaches often lead to similar changes in muscle size and strength as more high volume approaches (60,61). Of course, there were also participants in the Androulakis-Korakakis et al. (56) investigation who decreased their 1RM across the study period. In the 1RM training group, two participants increased strength while 3 saw decreases. In the periodization group, two of three participants increased strength, and one had no change. In addition, two participants in the periodization group dropped out of the study due to injury (one of which was related to the study). Given the sample size, it is hard to draw strong conclusions from this study. However, it seems that both approaches can be effective.

Periodization for strength potential. It has been suggested that periodization of resistance exercise increases "strength potential" through the incorporation of a hypertrophy phase before a strength phase. For example, the "Theoretical Model of Strength Training" presented by Stone et al. (22) suggests that a "hypertrophied muscle can be expected to have a higher potential to gain strength and power than a nonhypertrophied muscle" (22). Interestingly, the Morehouse and Miller citation provided as support for this suggestion does not include muscle hypertrophy as a potential mechanism behind increases in strength (62). While Morehouse and Miller note the relationship between muscle size and strength at baseline, they do not appear to consider it as a mechanism for changes in strength. Conversely, the authors (62) suggest that "It has not been proved that hypertrophy is necessarily a desirable reaction" and discuss how skeletal muscle hypertrophy "may simply be a by-product of training, perhaps a noxious one." They go on to suggest a need for further explanations for the change in strength by stating "Since hypertrophy is a questionable explanation for the increased strength in trained muscles, other reasons must be examined." The assumption that muscle hypertrophy contributes to strength adaptation appears to be largely rooted in baseline relationships between muscle size and strength (63,64) as opposed to exercise induced changes in muscle size and exercise induced changes in muscle strength. Thus, its incorporation into the training program may not contribute largely to strength performance. Despite a lack of causal evidence that changes in muscle size contribute to changes strength, it may be the preference of the strength coach to still include hypertrophy work. This seems reasonable based on the current lack of agreement within the literature (65,66). However, if coaches scale its focus to the weight of the evidence, much less time can be spent on hypertrophy, and more time can be dedicated to specific sport practice or rest.

THE GENERAL ADAPTATION SYNDROME

The GAS is a concept introduced in the 1900s by Hans Selye after a series of rodent studies examining the stress response to sublethal and lethal doses of different drugs (e.g., morphine, atropine), and stimuli (e.g., temperature, forced exercise) (67). Selye observed a similar phenomenon in all conditions: gastrointestinal ulceration, thymicolymphatic atrophy, and adrenocortical ulceration (67,68). This knowledge on the physiological stress response was later extended and speculated to apply to exercise in humans (69,70). Most notably, Stone et al. (71) presented a "Theoretical Model of Strength Training," in which the authors describe how the GAS, when applied to resistance exercise, provides us with three phases of adaptation: alarm, resistance, and overtraining. Following the principles of the GAS, the authors propose that the different training variables (frequency, duration, intensity, variation, and specificity) should be interwoven in a fashion that reduces the possibility of overtraining (71). It has been suggested that if the stress is properly managed, "specific biochemical, structural, and mechanical adjustments to further elevate the athletes performance capacity can occur" (17). This adaptive process has been termed "supercompensation" (17).

Selye himself referred to the GAS as a "syndrome" that appears when "severe injury is inflicted upon the organism" (72). Indeed, it has been questioned whether "lethal" and "graded" doses of different agents can truly provide insight into the physiological adaptations that would occur with nontoxic levels/doses of resistance exercise (5). For example, in Selye's original model the exhaustion phase was represented by *death* of the organism (67). We believe it is important to question how much relevance that these responses to varied stressors in animals has in the context of exercise in humans. Nonetheless, considering that the original application of the GAS to resistance exercise was to avoid overtraining (5), we believe it may provide some relevance for athletes who must balance stress from everyday life, from sport, and from supplemental exercise (5). However, the greater question lies in whether the complex programming strategy known as periodization is the only way or the appropriate way to manage this stress. We suggest that normal doses of exercise would pose no threat and require no advanced programming. Even large quantities of exercise in some athlete populations are unlikely to cause a GAS, as this has only been demonstrated with involuntary exercise in rodents (67).

There has been some debate around the topic of the GAS and its applications for resistance training (21,73,74). The primary criticism being that Buckner et al. (5) restricted their discussion to Selye's earliest work. Despite this criticism, no later work has been uncovered that would redefine what the GAS is. In addition, previous communications have failed to explain how the actual experimental components of the GAS relate to regular exercise in humans (21,73,74). It has been suggested that the acute resistance training literature may provide evidence on a GAS in humans. Conchola et al. (75) observed a decrease in isometric knee extensor torque following different fatiguing protocols in the back squat. This decrease in torque was nearly recovered 30 min after exercise. Given the directional similarities this torque curve shares with some of the curves depicted by Hans Selye's GAS, it is tempting to apply the GAS to this response. However, it is important to note that Conchola was observing "acute fatigue" and recovery, as opposed to involution of the organs. This same phenomenon has been documented on several occasions as an acute response to exercise (76–78). If this stimulus was provided again it would likely result in a similar fatigue response. If this stimulus was continually applied, it would result in adaptation. Selye's GAS would suggest that the stimulus would eventually lead to death of the organism. We do not believe that the acute exercise response is evidence of a GAS in humans.

Within the field of molecular exercise physiology, it has been suggested that the GAS and its resulting supercompensation hypothesis of adaptation "should no longer be used in an attempt to explain adaptation to exercise" (79). Authors outline several flaws with this hypothesis including: 1) Supercompensation happens with glycogen, but not with most other systems (i.e., mitochondria, capillaries or neurons); 2) The supercompensation hypothesis is a time course and not a mechanism; 3) The supercompensation hypothesis implies that recovery is essential for adaptation, yet the heart adapts to exercise despite continuous contraction; 4) There is little actual evidence that the supercompensation is essential for adaptation (79). Alternatively, it has been suggested that the signal transduction hypothesis of adaptation is more appropriate for explaining adaptations. This hypothesis suggests that sensor proteins respond to exercise signals, working through various pathways to regulate gene, protein synthesis/breakdown, and other adaptive responses. Unlike the GAS and the supercompensation hypothesis of adaptation, this hypothesis explains how adaptations occur and is supported by what happens in a human model after exercise (79). Bjornsen et al. (80) suggested that a supercompensation of strength was observed after two 5-d blocks of blood flow restriction (BFR) training. Of note, authors observed a decrease in strength during the "rest week" (4 d after the last BFR session of the first training block), with a significant increase in strength not observed until 20 d after the exercise intervention. Although authors suggest that this is a supercompensation, it is also possible that the strength testing itself (five strength tests performed, three of which occurred postintervention) lead to neural and peripheral adaptations resulting in the gradual increase in strength after the exercise intervention. In addition, it is important to note that the initial posttraining strength assessment was after seven training sessions performed over 5 d. This amount of exercise, in those previously naïve to resistance exercise, may have contributed to the lack of initial strength change. Nevertheless, they appeared to increase strength as they were allowed more practice with the strength assessment.

It may also be argued that Bjornsen et al. (80) observed a supercompensation of skeletal muscle growth. For example, authors observed a decrease in type I and type II muscle fiber CSA from baseline to day 4, with increases not being noted until 10 d posttraining (not reaching significance for type II fiber CSA) (80). Interestingly, when using ultrasound imaging, the CSA of the rectus femoris and the muscle thickness of the vastus lateralis both increased with resistance training, remaining elevated both 3 and 10 d posttraining (80). In addition, the average CSA of the rectus femoris, vastus lateralis, and total quadriceps measured by magnetic resonance imaging increased from baseline to 5 d after the last BFR session (80). Indeed, the imaging data follows a more typical pattern of what one might anticipate after resistance exercise (i.e., atrophy would not be expected). It is unclear if the discrepant findings in the muscle fiber data are indicative of a supercompensation. Although the supercompensation hypothesis can often describe the time-course of adaptation (in this case the direction of change in strength and perhaps changes in muscle fiber CSA), it does not appear to provide a complete or consistent explanation as to how we adapt (strength did not increase because it was depleted). Strength and conditioning should consider revisiting the GAS and the resulting supercompensation hypothesis' role as the theoretical framework for exercise programming and adaptation. It may be able to describe the time-course (regarding directionality of changes) of some adaptations in a predictable manner, however, it cannot describe why we adapt to an exercise stimulus.

IF NOT PERIODIZATION, WHAT?

The idea that variation is necessary for continued adaptation as one becomes more trained (17) lacks physiologic support. If one considers periodization the management of stress (albeit not equivalent to the stress outlined in the GAS), any technique utilized should be designed to appropriately address the actual stress of exercise. This would start by acknowledging well known physiological adaptations to various resistance training stimuli. For example, the literature has demonstrated that a wide variety of exercise stimuli result in similar muscle growth (19). There is no physiological reason, aside from the potential for selective type I muscle fiber growth previously mentioned, that variation of these stimuli would result in superior growth if some form of progression is implemented (i.e., increase load, reps, sets, etc.) to account for the adaptations to exercise. For strength, it seems that specificity is the most important consideration. Movements that mimic the sport the most closely (i.e., actually performing the specific tasks required for that sport) will likely provide the greatest sports benefits (81). There is likely benefit to improving aspects of strength and power for sports performance; however future studies are necessary to better understand how much generality exists among strength adaptations (81,82). Regarding the management of physiologic stress, it seems that this process can be largely intuitive. If an athlete experiences fatigue that impacts sports performance, it is not necessary to implement advanced programming, but decrease the component which likely has least influence on their sports performance (e.g., time dedicated to strength and conditioning practices). This may be achievable in the form of flexible nonlinear periodization (35) and autoregulatory progressive resistance training (83). In addition, it seems unlikely that any combination of sport and resistance exercise would produce a GAS in a human as described by Hans Selye. Thus, training strategies can likely adopt a more simplistic approach to manage the physiological stress that occurs with exercise. Herein, we acknowledge that a linear periodized approach may provide a useful organizational strategy for a strength coach. However, there is no experimental evidence suggesting this approach is necessary for inducing maximal changes in muscle size and strength. We suggest future studies may want to consider examining the integration of goal-based autoregulatory approaches of strength and conditioning in athletic populations. If hypertrophy is the goal, utilize the wide range of exercise loads (in combination with sufficient volume) which have been demonstrated to induce hypertrophy (20). The chosen load can be based on the athlete's recovery status/mood/preference. If the goal is maximal strength in a given lift, coaches can utilize a similar autoregulatory approach with heavy singles, doubles or triples. Variation does not seem necessary; however, adequate rest and recovery are always vital. It is not anticipated that this would produce superior outcomes to existing periodized approaches, but would likely result in similar outcomes (56,84,85).

WHERE NEXT?

The periodization of resistance exercise is based on a model that does not seem to accurately represent what occurs during normal resistance exercise in humans. In addition, evidence that periodization of resistance exercise is superior to other forms of training is lacking. This creates a dilemma for educators preparing students for examinations/certifications. Specifically, is it more important to teach for the examination to ensure certification and future employment, or is it more important to teach physiologic concepts and the relationship between a stimulus and adaptation? Although they would ideally be congruent, disagreement and different interpretations of the data make this process difficult. As a field, we must encourage scientific inquiry and an openness to emerging data and reevaluation of the existing data. A point-counterpoint between differing views (21,73,74) on the GAS demonstrates our ability as a field to acknowledge and bring disagreement to the forefront. Provided the disagreement is based on sound physiologic principles, new ideas should be given thorough consideration. Given the perceived importance of periodization of resistance exercise within the field of strength and conditioning, strong experimental support for the various claims made is warranted. In the absence of strong data, it is important not to let tradition and convention outweigh the data. This was recently pointed out by Kiely et al. (86) in a letter written in response to a review on the block periodization (87). Kiely criticized the evidence used to suggest that block periodization is superior to other models as an endurance planning model. Kiely notes "Sagan's Standard" (extraordinary claims requires extraordinary evidence) and points out that this standard "firmly places the burden of proof on those who *propose*" (86). Periodization (as presented in the available literature) does not appear necessary for achieving optimal increases in muscle size and strength within a training program. In the context of sports performance, no evidence exists outside of anecdotal reports (87) that longer term periodization strategies (wherein adaptations are planned [i.e., yearly plan] and within that variation is used [i.e., periodized programming]) support enhanced sports performance over merely repeated deliberate practice of that specific task. Further, there is an inconsistency within the literature regarding the definition of periodization, with some focusing on programming strategies and others focusing on more broad approaches (i.e., yearly organization). If the applications of periodization are most important for long-term adaptations, longer studies are necessary to determine the efficacy of periodization. Until such data is produced, position stands should be tempered to align with the evidence.

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