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REVIEW ARTICLE

The Importance of Muscular Strength: Training Considerations

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Abstract This review covers underlying physiological characteristics and training considerations that may affect muscular strength including improving maximal force expression and time-limited force expression. Strength is underpinned by a combination of morphological and neural factors including muscle cross-sectional area and architecture, musculotendinous stiffness, motor unit recruitment, rate coding, motor unit synchronization, and neuromuscular inhibition. Although single- and multi-targeted block periodization models may produce the greatest strength-power benefits, concepts within each model must be considered within the limitations of the sport, athletes, and schedules. Bilateral training, eccentric training and accentuated eccentric loading, and variable resistance training may produce the greatest comprehensive strength adaptations. Bodyweight exercise, isolation exercises, plyometric exercise, unilateral exercise, and kettlebell training may be limited in their potential to improve maximal strength but are still relevant to strength development by challenging time-limited force expression and differentially challenging motor demands. Training to failure may not be necessary to improve maximum muscular strength and is likely not necessary for maximum gains in strength. Indeed, programming that combines heavy and light loads may improve strength and underpin other strength-power characteristics. Multiple sets appear to produce superior training benefits compared to single sets; however, an athlete's training status and the dose–response relationship must be considered. While 2- to 5-min interset rest intervals may produce the greatest strength-power benefits, rest interval length may vary based an athlete's training age, fiber type, and genetics. Weaker athletes should focus on developing strength before emphasizing power-type training. Stronger athletes may begin to emphasize power-type training while maintaining/improving their strength. Future research should investigate how best to implement accentuated eccentric loading and variable resistance training and examine how initial strength affects an athlete's ability to improve their performance following various training methods.

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Key Points

Muscular strength development is underpinned by a combination of morphological and neural factors including muscle cross-sectional area and architecture, musculotendinous stiffness, motor unit recruitment, rate coding, motor unit synchronization, and neuromuscular inhibition.

Bilateral training, eccentric and accentuated eccentric training, and variable resistance appear to offer some advantages in producing the greatest comprehensive strength adaptations. Bodyweight exercise, isolation exercises, plyometrics, unilateral exercise, and kettlebell training may be limited in their potential to improve maximal strength but are still relevant to strength development by challenging time-limited force expression and differentially challenging motor demands.

Weaker athletes should focus on developing a foundation of strength before emphasizing power-type training; however, stronger athletes may begin to emphasize power-type training while maintaining or improving their strength levels.

1 Introduction

A recent review highlighted the importance of muscular strength with regard to general and specific sport skills and their underpinning force characteristics, in addition to reducing injury rates [1]. Given the relationship that strength (i.e., the ability to produce force against an external resistance [2, 3]) has with a variety of attributes, information regarding how to improve strength and the underpinning physiological factors that affect muscular strength appears vital. If practitioners seek to improve their athletes' strength, they must first understand what physiological changes have occurred or may occur in order to effectively prescribe resistance training (RT) progressions. With a variety of training methods to choose from, it is important that practitioners consider the literature that is available in order to make informed programming decisions to produce the best programs relative to the individual characteristics and needs of their athletes. The purpose of this review is to identify underlying physiological factors and other training considerations (i.e., methods, loading strategies, set configurations, and training status) that may affect muscular strength development.

2 Literature Search Methodology

Original and review journal articles were retrieved from electronic searches of PubMed and Medline (EBSCO) databases. Additional searches of Google Scholar and relevant bibliographic hand searches with no limits of language or year of publication were also completed. The search strategy included the search terms 'periodization', 'muscular strength', 'hypertrophy', 'cross-sectional area', 'bodyweight training', 'machine resistance training', 'weightlifting', 'weightlifting derivatives', 'plyometric training', 'eccentric training', 'postactivation potentiation', 'unilateral resistance training', 'variable resistance training', 'kettlebell training', 'training to failure', 'training status', 'rest interval', 'inter-repetition rest interval', and 'cluster sets'. The search concluded in July 2017.

Muscular strength may be expressed in several different forms including maximal dynamic strength, isometric strength, and reactive strength [1]. This review primarily focuses on improving maximal dynamic strength. However, it should be noted that by improving maximal dynamic strength, an athlete may also enhance maximal isometric strength [4, 5] and reactive strength characteristics [6–8]. A number of RT methods are discussed in this article and those discussed were found to be the most prevalent within the existing literature.

3 Physiological Factors Affecting Muscular Strength

Muscular strength development is underpinned by a combination of several morphological and neural factors. However, the mechanisms that improve muscular strength are considered multifactorial and can be influenced by other confounders such as initial strength [9], training status [10], and genetics [11]. The following provides a brief overview of the morphological and neural factors that may combine to affect muscular strength. Understanding these factors before discussing training considerations sets the context for the variety of responses in each of these underpinning factors that culminate to elicit muscular strength improvements. Although a thorough discussion is beyond the scope of this review, it should be noted that an athlete's history of muscle contraction (e.g., fatigue, postactivation, temperature, etc.) may influence the expression of muscular strength [12, 13].

3.1 Muscle Hypertrophy and Architecture

Evidence indicates that residual effects from previous training phases carry-over into future training phases

[14, 15]. Therefore, increasing hypertrophy in an effort to subsequently improve one's strength has to do with potentiation and residual training effects [16–18]. Thus, it appears that there is a sequence or progression of training that, when followed, elicits the greatest benefits from RT. Specifically, evidence suggests that an order of first increasing the muscle's cross-sectional area (CSA) (i.e., hypertrophy) and work capacity (i.e., force production capacity) [17–19], followed by a subsequent phasic progression [20, 21], can produce superior strength-power gains. Alterations in skeletal muscle hypertrophy can greatly impact a muscle's ability to produce force and power. Simple observation offers some evidence as to the importance of larger CSAs in creating greater absolute force production; indeed, sports with body weight classes, such as powerlifting and weightlifting, support this observation. The rationale behind this is that a greater muscle fiber CSA, particularly type II fibers, may alter the force–velocity characteristics of the whole muscle [16, 22]. Previous research indicated that strong relationships ($r = 0.70$) existed between muscle CSA and greater force production [23]. Further literature suggested that muscle CSA increases and muscle architecture alterations may account for approximately 50–60% of the changes in force production following short-term RT [24], albeit with relatively untrained subjects. Physiologically, muscle CSA increases may improve force production due to an increase in the number of cross-bridge interactions between actin and myosin within the previously- and newly-formed sarcomeres. Kawakami et al. [25] indicated that muscle fiber pennation angles are greater in hypertrophied muscles than in normal muscles. Larger pennation angles may increase the number of cross-bridge interactions due to the packing of more muscle fascicles within the area. Despite some evidence to support the association between muscle hypertrophy and strength, it should be noted that changes in muscle size and strength can vary between individuals. Such variance between muscle hypertrophy and subsequent strength changes could be due to time-course differences between the measured adaptation, subsequent expression during the strength task, methodological issues associated with the determination of hypertrophy (e.g., physiological CSA vs. anatomical CSA; magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry (DEXA) measurements vs. girth measurements, etc.), or that enhanced strength can be affected by other physiological or neural factors beyond CSA [9]. In summary, increases in muscle CSA set a platform that combines with concomitant or subsequent changes in muscle architecture, fiber type, and other neural factors such as motor unit (MU) recruitment and muscle activation pattern to enhance the ability to increase maximum strength [17, 18, 26]. While a number of factors (e.g., muscle damage, metabolic alterations, tension, etc.) may affect the hypertrophic response, a thorough discussion of training methods is beyond the scope of this review. For further information, readers are directed to a series of recent systematic reviews and meta-analyses that discuss best training practices for improving muscle hypertrophy [27–31].

3.2 Musculotendinous Stiffness

Inherent to force production, and the subsequent force expression as a measure of strength, is the concept of our tissues expressing spring-like behavior which influences subsequent muscle performance [32]. Indeed, increased tissue stiffness (i.e., the relationship between a given force and the amount of stretch the tissue undergoes [33]) can enhance force transmission. Therefore, tendon stiffness adaptations [34], as well as the structures within the muscle (e.g., actin, myosin, titin, and connective tissue), can influence muscular strength and associated characteristics such as rate of force development (RFD) [35, 36] and power [34, 37]. However, a commonly overlooked aspect of skeletal muscle force generation and expression of strength using the aforementioned measures is the role of the large protein or viscoelastic spring within the sarcomere, titin [38]. Titin could be responsible for generating passive tension in the sarcomere [39], which may be why recent evidence has suggested greater importance of the role of titin in muscle function [35, 39–41]. However, it should be noted that increased sarcoplasmic calcium may actively increase the stiffness of titin, contributing to the stiffness of the entire sarcomere [40]. Therefore, changes in muscular strength and force transmission may be partially influenced by changes in tissue stiffness within and surrounding the muscle.

3.3 Motor Unit Recruitment

Henneman et al. [42] indicated that MUs are recruited in a sequenced manner based on their size (smallest to largest). Thus, a pool of MUs will be recruited based on the magnitude of force and RFD required during a given task. For example, smaller MUs that include slow-twitch type I fibers will be recruited when smaller force magnitudes and RFD are required, while larger MUs that include fast-twitch type IIa/IIx fibers may only be recruited if higher forces and RFD are required. The recruitment order may be maintained during slow, graded, isometric [43], and ballistic actions [44, 45]. Although lower thresholds for MU recruitment may occur during ballistic-type movements due to the required RFD, the size principle appears to hold [36, 46].

The type and intent of the activity may directly affect which MUs are recruited and how they adapt [46–49]. For example, distance runners may only recruit low-threshold, slow-fatiguing MUs that contain type I fibers given the moderate forces that are required repeatedly during a race. Due to the nature of the task, high-threshold MUs that contain type II fibers may only be recruited when MUs that contain type I fibers fatigue and additional force production is needed to sustain the activity. Thus, while type I MUs may increase force production capability, the maximal strength expressed when using a combination of all MU types may still be relatively low in distance runners because of infrequent recruitment of MUs that contain type II fibers during training. In contrast, weightlifters frequently perform ballistic tasks (e.g., snatch, clean and jerk, etc.) that require both high force and RFD magnitudes, and thus MUs that contain type II fibers are targeted. Based on the recruitment order and lower recruitment thresholds, weightlifters likely recruit MUs that contain both type I and type II fibers, allowing both MU types to be trained. Previous research demonstrated that while the orderly recruitment of MUs existed during both slow ramp and ballistic actions following ballistic-type training, MUs were recruited at lower force thresholds [46]. Regarding strength development, it appears to be beneficial to recruit high-threshold MUs during training. Moreover, ballistic training methods may promote the recruitment of larger MUs that contain type II fibers at lower thresholds, thus raising the potential for positive strength-power adaptations to occur.

3.4 Rate Coding (Firing Frequency)

After specific MUs are recruited, the frequency at which the α-motoneurons discharge action potentials to the MU's muscle fibers can modify its force production properties. Research indicated that force magnitude may increase 300–1500% when the firing frequency of recruited MUs increases from its minimum to its maximum [50]. Additional research indicated that RFD may be impacted by the firing frequency of MUs due to high initial firing frequencies being linked to increased doublet discharges (i.e., two consecutive MU discharges in $\leq$ 5-ms interval) [46]. Thus, it may be postulated that the increased firing frequency of MUs that results in greater force magnitudes and RFD may aid strength-power development. Previous research indicated that 12 weeks of ballistic training may enhance MU firing frequency [46]. Thus, it is possible that other ballistic training methods, such as weightlifting movements [51] and sprinting [52], may enhance MU firing frequency, ultimately benefitting strength-power characteristics.

3.5 Motor Unit Synchronization

While some literature indicates that MU synchronization may be more related to RFD than to force production magnitude [53], it is possible that simultaneous activation of $\geq$ 2 MUs enhances peak force production by expressing greater RFD over short time periods. Previous research indicated that 6 weeks of RT increased MU synchronization [54], while another study indicated that MU synchronization strength was larger in both the dominant and non-dominant hands of weightlifters compared to musicians and untrained individuals [55]. These findings are supported by research that suggested heavy RT may increase MU synchronization and force production [56]. While evidence strongly indicates that changes in muscular strength coincide with traditional RT, literature discussing MU synchronization changes following ballistic-type training is somewhat mixed. One study noted that MU synchronization did not change following ballistic-type training [46], while other studies indicated that MU synchronization was enhanced during ballistic tasks [46, 57]. Practically speaking, it appears that training strategies that include heavy RT and/or ballistic-type movements may improve MU synchronization. Although research examining changes in MU synchronization within RT literature associated with gross motor movements is limited, the link between improved neuromuscular activation patterns and subsequent force production cannot be discounted.

3.6 Neuromuscular Inhibition

Neuromuscular inhibition refers to a reduction in the neural drive of a given muscle group during voluntary muscle actions that may negatively affect force production due to the neural feedback received from muscle and joint receptors [58]. While the previous neural mechanisms may produce positive strength-power adaptations, a neural mechanism that negatively affects strength-power development may affect potential training adaptations. Previous research indicated that heavy RT may down-regulate Ib afferent feedback to the spinal motoneuron pool, leading to reductions in neuromuscular inhibition and increased force production [56]. Further research reported an enhanced neural drive from both the spinal and supraspinal levels following RT that simultaneously decreased neuromuscular inhibition [59], increased power output via reciprocal inhibition during complex training [60], downregulated recurrent inhibition following explosive-type training [61], and enhanced RFD [62].

4 Periodization and Programming

There are many methods of programming that exist within the strength and conditioning field. While basic periodization and programming tactics to enhance muscular strength are covered in this section, additional literature provides more thorough discussions [19, 20, 63, 64]. Specifically, this section will discuss the annual plan (AP), differences between periodization and programming, and provide a brief introduction to block periodization (BP) and phase potentiation.

4.1 The Annual Plan and Periodization

Despite the importance of periodization, planning for athletic success begins with the construction of an AP. The AP includes all training, competition, and athlete-monitoring endeavors scheduled to take place over the entire training year [63]. Periodization is the logical, phasic method of manipulating training variables in order to increase the potential for achieving specific performance goals [65]. Thus, periodization is the concept used to organize the AP into fitness phases and timelines. Regarding maximal strength improvement, periodized training has been shown to produce greater benefits compared to non-periodized training [66].

Generally, periodization consolidates the AP into preparatory, competitive, and transition phases (Fig. 1), which are used to induce physiological adaptations in a manner that maximizes specific performance qualities at desired time-points of the competitive season [20]. These phases are performed over designated timelines (e.g., macrocycles, mesocycles, and microcycles), which are used to define the length of time invested in developing or emphasizing certain performance qualities. Similarly, various programming strategies can be used to emphasize desired fitness characteristics and effectively manage neuromuscular fatigue [63]. It is important to note that although the concept of periodization and practical programming aspects can appear to be similar, they are separate entities that play different roles in the training process. While periodization relates to the organization and timing of fitness adaptations, programming tactics "drive" the appropriate adaptation during training phases in order to achieve the desired fitness characteristic. Programming includes exercise selection, sets and repetitions, rest periods, and load selection. Indeed, programming strategies may differ markedly (e.g., daily-undulating vs. block) [63, 65].

While a recent review indicated that BP may produce superior training outcomes [63], a variety of programming methods that exist that may benefit the strength-power characteristics of individual and team-sport athletes [67–69]. The model of programming may not have a profound effect on the improvement of muscular strength in previously untrained athletes; however, it should be noted that each model may produce different strength-power outcomes on athletes with a greater training age. Further, in sports with consistent, year-long competition schedules (e.g., tennis, golf, etc.) or "non-traditional sports" (e.g., surfing, skateboarding, etc.), a realistic sport schedule requires considerable modification of the more formal training phases described in the previous paragraph. However, practitioners must recall that the role of maximal strength extends beyond the ability to produce maximal force. Instead, strength should be perceived as a "vehicle" driving the enhancement of several key performance variables, particularly RFD and power [1]. Because the timeframe needed to express maximal strength (e.g., ≥ 300 ms) often exceeds those inherent to most sport skills (e.g., sprinting, jumping, change-of-direction, etc.), the ability to express high RFD and power is often viewed as the most central quality to sport success [70–72]. Therefore, periodization and programming strategies should not only be viewed through the lens of developing maximal strength, but also RFD and power. There is sufficient evidence to suggest that these goals are effectively attained through the

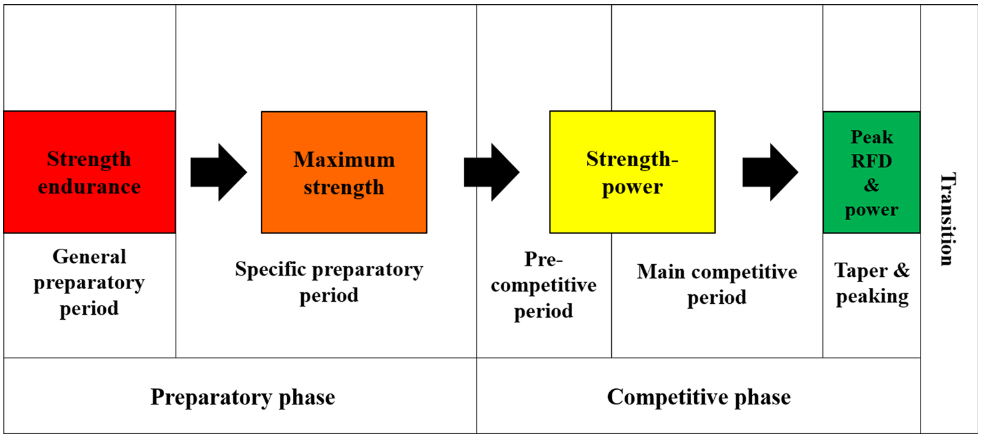

Fig. 1 Single-targeted block periodization and phase potentiation model implemented over an annual plan for strength-power enhancement. *RFD* rate of force development

use of sequenced training (i.e., BP and phase potentiation) (Fig. 1) [15, 26, 63–65, 73]. Thus, the periodization and programming tactics covered in this review will be discussed within the context of the BP paradigm, but the concepts should be considered within the limitations of the sport, athletes, and schedules.

4.2 Block Periodization

BP differs from other paradigms with respect to how fitness characteristics are matured throughout the training process [63–65, 74]. For example, other periodization models (e.g., classic model) aim to simultaneously develop several fitness qualities throughout the training process [65, 75]. While the limitations of the classic model are beyond the scope of this paper, previous literature suggested that this concept does not address contemporary issues in athletics, such as effective management of neuromuscular fatigue and fostering multiple peak performances during the competitive season [75]. Due to these modern issues, and depending upon the sport, BP can take two forms: single- or multi-targeted BP [74]. Table 1 provides an overview of single- and multi-targeted BP.

5 Resistance Training Methods

This section outlines a number of the most commonly implemented RT methods that may be used to develop an athlete's strength-power characteristics. Each of following may be implemented concurrently or during specific times of the training year to elicit the desired physiological adaptations. It should be noted that the areas of weakness that an athlete displays may be addressed by implementing one or several of the methods discussed in this section. Although dependent on the individualized needs of each athlete, Table 2 indicates, in relative terms, how beneficial each training method may be in terms of increasing muscle hypertrophy, strength, and power.

Table 2 The theoretical potential of resistance training methods to benefit hypertrophy, strength, and power

Resistance training method	Hypertrophy	Strength	Power
Bodyweight exercise	+	+	++
Machine-based exercise	++	++	++
Weightlifting derivatives	+++	+++	+++++
Plyometrics	+	++	++++
Eccentric training	+++++	+++++	++++
Potentiation complexes	[a]	+++	+++++
Unilateral exercise	+++	++	+++
Bilateral exercise	++++	++++	+++
Variable resistance	+++++	++++	++++
Kettlebell training	++	++	+++
Ballistic training	++	+++	+++++

Resistance training methods ranked on scale from +, meaning low potential and +++++, meaning high potential

Assigned exercises, volume-load prescription, and an athlete's relative strength may influence adaptations

[a] Limited research available

Table 1 Description of single- and multi-targeted block periodization training models

	Purpose(s)	Rationale	Loading strategies	Additional benefits
Single-targeted block periodization	Aims to develop a single fitness characteristic while maintaining previously developed characteristics	Useful in sports where relatively few tasks are developed, especially those developed simultaneously Example: track and field	Concentrated loads Higher volume of compatible factors Minimal volume of non-compatible factors Summated microcycles Retaining loads	Superior delayed training effects following period of restitution Phase potentiation effects
Multi-targeted block periodization	Aims to develop multiple fitness characteristics simultaneously	Useful in sports in which different factors must be developed simultaneously Examples: basketball, soccer, hockey, etc.	Emphasis on training compatible fitness characteristics (e.g., strength-power, speed, and change-of direction ability) Incompatible stimuli avoided during training (e.g., speed and aerobic endurance training)	

Concentrated loads: unidirectional loading that fosters specific adaptations (e.g., hypertrophy) that underpin a desired fitness quality (e.g., maximal strength) [47]

Phase potentiation: enhancement of subsequent training phases through the exploitation of delayed training effects that are the product of sequenced concentrated loading [18, 20, 45–47]

Retaining loads: minimal load doses needed to maintain specific fitness characteristics [46]

Summated microcycles: consecutive microcycles that display a similar pattern of volume and loading intensity [46]

5.1 Bodyweight Exercise

Bodyweight exercises are basic RT exercises that may be used as training tools or as part of a progression to more complex or loaded movements. Common exercises include bodyweight squats, push-ups, pull-ups, and sit-ups. While bodyweight exercises have several advantages (e.g., closed-chain exercises, target multiple muscle groups, improve relative strength, accessibility, and versatility), the ability to provide an overload stimulus is limited, which may prevent significant improvements in maximum strength and related characteristics [76]. To continue overloading bodyweight exercises, practitioners often prescribe more repetitions or alter the movement (e.g., incline or elevated-feet push-ups). However, it should be noted that maximal strength adaptations may be compromised if practitioners continue to increase the repetition volume as this may develop endurance-type characteristics. In some cases, such as with young children, novices, or athletes returning to play, implementing bodyweight exercises to improve basic strength and movement characteristics could be considered before progressing to other training methods that may provide a greater overload stimulus. Furthermore, bodyweight or reduced-bodyweight activities may have implications for increasing explosive performance when training the low-load, high-velocity end of the force–velocity spectrum [77, 78]. Further detail will be included on this concept in Sect. 5.4.

5.2 Continuum of Isolated Machine-based to Multi-joint Free-weight Exercises

Machine-based exercises or free-weight isolation exercises are often used during injury rehabilitation for targeted tissue capacity development. However, using single-joint, machine-based exercises for enhancing strength-power characteristics that transfer to sport performance may be questioned given that athletic movements rarely include muscle groups working in an isolated manner [79, 80]. As a result, task specificity and the resulting transfer from isolation exercises to athletic performance is limited [80–83]. However, exercises that incorporate multiple muscle groups may provide a superior training alternative for developing strength-power characteristics [80, 84–86]. The isolation of a single-joint that is typically performed during machine-based exercises may improve an athlete's strength, but may fail to improve coordinative capacity to improve subsequent sporting performance due to a lack of transfer of coordinative patterns [80]. For example, throwing velocity, a direct measure of performance in softball, was only significantly improved after 12 weeks of closed-kinetic chain exercises (3.4%, $p < 0.05$) in comparison to open-kinetic chain exercises (0.5%, p value not specified) [87]. Further literature indicated that free-weight exercises may recruit muscle stabilizers to a greater extent compared with machine-based exercises [80, 88]. Collectively, it appears that free-weight, multi-joint exercises require greater coordination and muscle recruitment demands that may produce greater strength-power adaptations which transfer to sport performance. However, exercises may be selected along the continuum from those programmed primarily for enhanced tissue capacity (e.g., machine isolation exercises) to those with the greatest coordination requirement (e.g., free-weight multi-joint exercises) based on needs of the individual athlete. It should be noted that free-weight isolation and multi-joint machine exercises may serve as potential progressions or regressions within the aforementioned ends of the continuum.

5.3 Weightlifting Movements and Derivatives

Training with weightlifting movements (e.g., snatch, clean and jerk) and their derivatives (i.e., those that omit a portion of the full lift) has been shown to produce superior strength-power adaptations compared to traditional RT [89–92], jump training [93, 94], and kettlebell training [95]. Furthermore, weightlifting movements may allow for more effective absorption of an external resistance [96]. Thus, it is not surprising that weightlifting movements have become commonplace within RT programs. Weightlifting movements and their derivatives are unique in that they may exploit both the force and velocity aspects of power by moving moderate-heavy loads with ballistic intent [97]. Ultimately, this may produce favorable neuromuscular adaptations (i.e., MU recruitment, rate coding, etc.), which may improve strength-power characteristics.

Practitioners traditionally prescribe weightlifting movements that include the catch phase (e.g., power snatch/clean, hang power snatch/clean, etc.) [98–104]. While these exercises have been shown to produce favorable strength-power benefits, weightlifting pulling derivatives that omit the catch phase (e.g., snatch/clean mid-thigh pull, jump shrug, etc.) [105–110] may provide unique force–velocity overload stimuli that may further benefit strength-power adaptations [111]. The catch phase may be omitted for some athletes as it may not be necessary for the desired adaptation, but also due to technique complexity, mobility issues, or previous or current injuries. Previous studies indicated that weightlifting pulling derivatives produce similar [112, 113] or greater [114–118] force production characteristics during the propulsion phase (i.e., second pull) compared to catching derivatives. Moreover, weightlifting pulling derivatives may provide a similar [119] or greater [120] external load absorption stimulus compared to weightlifting catching movements. Practically speaking, weightlifting pulling derivatives allow practitioners the option to prescribe loads greater than an athlete's one repetition maximum (1RM) snatch/clean or power snatch/clean [111, 121–124], potentially benefitting maximal strength adaptations. Furthermore, certain weightlifting pulling derivatives may benefit power adaptations by producing greater RFD [112, 113, 115] and velocity [116, 117] magnitudes.

5.4 Plyometric Training

Plyometric exercises are explosive movements that utilize the stretch–shortening cycle, where a concentric muscle action is enhanced by a previous eccentric muscle action. Although not commonly prescribed to exclusively train muscular strength, their inclusion in RT programs is likely due to their ballistic nature and their ability to transfer maximal strength to power production and RFD. A meta-analysis indicated that plyometric training may produce similar improvements in vertical jump height compared to weightlifting movements [125]. However, other studies indicated that weightlifting movements may produce greater power adaptations and allow for improvements over a broader performance spectrum [93, 94]. Although conflicting literature exists, the effectiveness of plyometric training benefitting power cannot be overlooked.

A potential limitation of bodyweight plyometric exercises is the ability to continually provide an overload stimulus that produces positive strength adaptations. While small loads may be added to plyometric exercises, practitioners should note that heavier loads may result in greater impact forces and lengthen the transition time between eccentric and concentric muscle actions, thus diminishing the overall training stimulus. Instead of adding a load to a given plyometric exercise, practitioners may consider choosing a moderate-high intensity plyometric exercise [126–130] or adjusting the training volume to produce the desired adaptations. Given the limitation of loading plyometric exercises, the potential strength adaptations that may result from such training may be limited compared to other RT methods, yet they have clear benefit within the context of power development.

5.5 Eccentric Training

Eccentric actions are those in which the musculotendinous unit lengthens throughout the contraction as a result of greater force applied to the musculotendinous unit than force produced by the muscle. The molecular and neural characteristics of eccentric muscle actions have been outlined in recent reviews [131, 132]. It was concluded that eccentric training (ET) may benefit performance by producing favorable adaptations in mechanical function (i.e., strength, power, RFD, and stiffness), morphological adaptations (i.e., tendon and muscle fiber CSA), neuromuscular adaptations (e.g., fast MU recruitment and firing rate), and performance (e.g., vertical jumping, sprint speed, and change-of-direction) compared to concentric, isometric, and traditional (eccentric/concentric) training. Due to its potential adaptations, it is not surprising that ET has received considerable attention.

While previous literature briefly discussed ET methods including the 2/1 technique, two-movement technique, slow/superslow, and negatives with supramaximal loads ($>100\%$ 1RM) [133], limited research supports the use of these methods. In contrast, much literature supports the use of another ET method termed accentuated eccentric loading (AEL) [134]. AEL requires individuals to perform the eccentric phase of a lift with a heavier load than the concentric phase due to a portion of the load being removed by a weight-release system [135], spotters [136], or the athlete dropping it [137]. Collectively, the previous studies have indicated that AEL may produce greater jumping, sprinting, and power adaptations compared to other RT methods. Further literature indicated that AEL may lead to positive strength [136, 138, 139], RFD and power [140], and performance adaptations [137, 140], but also a decreased injury rate [141]. For a thorough discussion on AEL, readers are directed to a recent review [134].

To the authors' knowledge, only one article has provided general recommendations on implementing ET into RT programs [133]. Previous literature indicated that adaptations from eccentric exercise may be based on exercise intensity [142, 143] and contraction speed [144, 145]. Specifically, the previous studies suggested that heavier eccentric loads may produce favorable muscle hypertrophy and strength adaptations compared to lighter loads and that faster muscle actions produce greater adaptations compared to slower actions. From a loading standpoint, practitioners have the opportunity with ET to prescribe supramaximal loads ($>$1RM). The use of such loading with AEL has been shown to improve maximal strength [136, 138]. Despite the general recommendations made within previous literature and the current review, future research on ET, including AEL, should focus on the placement of eccentric exercise in training phases, training volume, inter-set rest intervals, and loads that should be prescribed to produce optimal results.

5.6 Potentiation Complexes

Postactivation potentiation refers to an acute performance enhancement based on the muscle's contractile history [146]. Traditionally, a high force or power exercise is used to potentiate the performance of a subsequent high power exercise, often termed a strength-power potentiation complex [146, 147]. An abundance of research has designed potentiation complexes to enhance the power output of a subsequent exercise. In contrast, only two studies using whole-body vibration [148, 149] and two studies using plyometric exercise [150, 151] as potentiating stimuli have sought to improve measures of muscular strength. Previous literature examined the acute effects of whole-body vibration on 1RM back squat [148] and half-squat performance [149]. While no differences in 1RM back squat were found during the whole-body vibration condition compared to the control condition examined in one study [148], untrained and recreationally-trained participants improved their 1RM half-squat during the whole-body vibration condition in another study [149]. While the latter findings are interesting, practitioners may question the applicability and safety of performing squatting movements on vibration platforms. Additional literature examined the effect of plyometrics on 1RM back squat performance [150, 151]. Bullock and Comfort [150] indicated that a single set of two, four, or six 33 cm depth jumps resulted in acute improvements in 1RM squat strength, with six jumps producing the greatest effects. Similar improvements were shown following tuck jumps and 43.2 cm depth jumps [151]. While mixed findings exist using potentiation complexes to benefit strength performance, plyometric exercises, such as depth jumps, may benefit strength the most. For further information on the use of plyometric exercises and other ballistic potentiating stimuli, readers are directed to a review by Maloney et al. [152].

5.7 Unilateral versus Bilateral Training

A frequently discussed topic within RT programming is the implementation of unilateral exercises given the unilateral nature of various sport tasks (e.g., sprinting, cutting, etc.). Unilateral/partial-unilateral movements are defined as those where the load is primarily lifted by a single limb (e.g., lunge), whereas bilateral movements are those that lift the load with two limbs [153]. An overwhelming amount of RT programs include predominantly bilateral exercises for the purposes of strength-power development. This is not surprising considering that strong relationships exist between bilateral strength and jumping, sprinting, and change-of-direction performance [1]. However, given the proposed specificity of unilateral exercises to sport tasks, additional information regarding the effectiveness of training with unilateral exercises is needed.

Limited research has compared the effects of unilateral and bilateral training on strength adaptations. McCurdy et al. [153] indicated that strength-power adaptations were similar following 8 weeks of unilateral or bilateral RT and plyometric exercise in untrained subjects, suggesting that both training methods may be equally as effective. Another study indicated that 5 weeks of training with either the rear-foot elevated split-squat or traditional back squat produced similar improvements in unilateral (estimated 1RM rear-foot elevated split-squat) and bilateral strength (estimated 1RM back squat), sprint speed (10 and 40 m), and change-of-direction speed (Pro Agility) in academy rugby players [154]. McCurdy et al. [155] also indicated that gluteus medius, hamstring, and quadriceps activation were greater during a modified split-squat compared to a traditional bilateral squat. While the latter findings are not surprising, practitioners should consider that the decreased stability of unilateral exercises may limit the safe prescription of heavier loads or performance in a fatigued state. As greater stability within movements leads to a greater ability to express force [79], bilateral exercises can inherently provide a greater total mechanical platform to improve an athlete's strength-power characteristics compared to unilateral exercises. This does not mean that unilateral exercises should be excluded when developing strength; however, they should be implemented during specific phases to supplement the primary bilateral lifts, particularly during preparation phases. Tables 3 and 4 display example strength-endurance and maximal strength training blocks in which unilateral exercises may be implemented as assistance exercises.

Table 3 Example strength-endurance training block integrating unilateral exercise

Day 1	Day 2	Day 3
Back squat	Clean grip pull to knee	Back squat
Bench press	Clean grip shoulder shrug	Bench press
Barbell split squat	Stiff-legged deadlift	Barbell split squat
Military press	Dumbbell row	Military press

General preparatory period; higher volume and lower intensity; relatively simple unilateral exercises; example set and repetition scheme: 3 × 10

5.8 Variable Resistance Training

Multi-joint RT exercises such as the back squat and bench press are commonly prescribed in RT programs. Traditionally, these exercises are performed using eccentric and concentric muscle actions with a constant external load through a full range-of-motion. While training in this manner can certainly improve strength, it is not without its limitations. For example, an athlete performing a back squat may be limited at specific knee and hip angles because of mechanical disadvantages [156]. As a result, athletes experience a "sticking point" as they ascend due to a diminished ability to produce external force [157]. In

Table 4 Example maximal strength training block integrating unilateral exercise

Day 1	Day 2	Day 3
Back squat	Mid-thigh pull	Back squat
Push press	Clean pull from floor	Push press
Barbell walking lunge	Bent over row	Barbell walking lunge
Bench press	Pull-up	Bench press

Special preparatory period; lower volume and higher intensity; more complex unilateral exercises; example set and repetition scheme: 3 × 5

contrast, external muscle force production (i.e., force applied to the external load that results from muscle contractile force) may continue to increase beyond the sticking point and peak during the finish of the squat [158–160]. Given these limitations, it would be advantageous to implement a training method that trains each portion of a lift based on its mechanical advantage/disadvantage.

Variable RT is a training method that attempts to modify the external resistance experienced by the athlete during each repetition in order to maximize external muscle force throughout the entire range-of-motion [161]. While there have been a number of attempts at variable loading using machines, these have generally not produced desired results [80]. More recently, the addition of chains or elastic bands to free-weight exercises has received considerable attention. Adding chains or elastic bands may alter an exercise's loading profile by altering force, velocity, and power production characteristics during the movement (e.g., greater force during the early eccentric phase and latter concentric phase of a back squat) [162]. This in turn may allow athletes to better match changes in mechanical advantage/disadvantage [67] and overcome greater detriments (i.e., greater mechanical disadvantages) at various joint angles [159, 163]. Some information indicates that variable RT produces its greatest effects at the range-of-motion in which the increased resistance occurs [80]. Thus, care must be taken in matching the athlete's physical characteristics to appropriate chain lengths, etc., as inappropriate loading could slow acceleration and appropriate adaptation [80]. Previous literature indicated that greater strength gains were produced following variable RT during the bench press [164] and back squat [165] compared to traditional RT. Further research displayed acute strength improvements following variable RT as part of a potentiation complex [166, 167]. The existing literature suggests that variable RT may be used as an effective training strategy for developing muscular strength. Thus, more training studies are needed to examine the effect that variable RT has on strength-power characteristics. For example, no studies have compared variable RT with traditional (full movement) plus partial movements in which additional loading of the stronger portion of the range-of-motion is overloaded during the partial movement. Therefore, the extent of transfer to sport movements for variable RT, and the underlying mechanisms driving these potential training outcomes, remain to be elucidated.

5.9 Kettlebell Training

Kettlebells are RT implements that consist of a weighted ball and handle [168]. Common kettlebell exercises include swings, goblet squats, and modified weightlifting exercises (e.g., one-arm snatch). Previous literature indicated that kettlebell training may improve various measures of muscular strength [95, 169–172] and vertical jump performance [95, 169]. However, additional studies indicated that vertical jump [172] and sprint performance [173] were not enhanced following kettlebell training when compared to a control group. The available research suggests that kettlebell training may produce strength improvements during various exercises (trivial to moderate effect sizes); however, more traditional training methods, such as weightlifting movements, may produce superior strength-power adaptations [95]. This notion is supported by the fact that kettlebell exercises are limited in their capacity to provide an overload stimulus to the lower extremities. For example, an athlete may be able to power clean 100 kg, but cannot perform a kettlebell swing with the same load using proper technique. Furthermore, a kettlebell's handle size may get larger as the load increases, potentially making it more difficult to grip the implement. Compared to other training methods, limited research has examined the long-term strength-power benefits of kettlebell training. Thus, further research is needed to determine the role of kettlebells within RT programs focused on strength development. However, given their explosive nature, practitioners may find value in implementing kettlebell exercises in training blocks where low load, high velocity training is an emphasis (e.g., speed-strength).

5.10 Ballistic Training Methods

Ballistic exercises are those that accelerate throughout the entire concentric movement. Commonly prescribed ballistic exercises may include jump squats, various weightlifting derivatives, and bench press throws. Previous literature displayed that ballistic exercises produced greater force, velocity, power, and muscle activation compared to the same exercises performed quickly [174, 175]. Further research displayed that ballistic exercises may also produce greater potentiation effects compared to non-ballistic exercises [176–178]. As noted in Sect. 3.3, ballistic exercises may lead to neural adaptations including the lowering of recruitment threshold of MUs [44, 46] and may also allow the entire motoneuron pool to be activated within a few milliseconds [49]. Recruiting a greater number of motor units will ultimately lead to greater force production, RFD, and eventually power development (see Sect. 4 above). Previous literature has highlighted the superiority of ballistic exercises as an explosive training stimulus. Suchomel and Comfort [179] displayed the relative power outputs produced during a variety of ballistic and non-ballistic exercises. It is clear that the ballistic exercises have the capability to produce greater relative power outputs compared to non-ballistic RT exercises such as the back squat, deadlift, and bench press. Thus, it should be obvious as to why ballistic exercises are so popular within RT programs. While these exercises may be implemented throughout the training year, the goals of each training phase may alter which exercises are prescribed. For example, jump squats may not be prescribed during a strength-endurance phase of training due to the focus on improving work capacity and muscle CSA as well as the repetitive landing that is included with the exercise. Finally, ballistic exercises may be prescribed for all athletes to benefit explosive strength (i.e., RFD and power characteristics), assuming the exercises are performed using appropriate technique. However, it should be noted that ballistic exercises may not be featured in an athlete's RT program until they have improved their maximal strength [180].

6 Loading Strategies

6.1 Training to Failure

There is little doubt that lifting heavy loads will improve muscular strength. A common belief is that by training to failure (TF), a relative maximum is achieved that mechanistically provides adequate overload for maximum hypertrophy and strength gains [181]. "Failure" was previously described as the point where the barbell stops moving, the sticking point lasts longer than one second, or full range-of-motion repetitions can no longer be completed [182]. The TF concept capitalizes on the idea that training with RM loads will lead to greater strength adaptations compared to submaximal loads. However, meta-analyses indicated that TF does not produce superior gains and is perhaps counter-productive [183, 184]. The same authors suggested that if practitioners program TF, it should be used sparingly to prevent potential injuries and overtraining. While TF likely stimulates high-threshold MU recruitment, it does not appear to be superior to non-failure training [185]. In addition, the ability to TF for long training periods may be limited, particularly if RT is part of a larger sport training program [184]. Furthermore, TF for consecutive sets may significantly reduce the number of repetitions an individual can perform at specific loads [186–188], which may require practitioners to reduce the prescribed loads for an individual in an effort to maintain the selected training volume for a given training phase. However, it should be noted that a reduction of load may result in a less effective stimulus for muscular strength adaptation [189–191]. While there are training phases in which the primary emphasis should be lifting very heavy loads (90–95% 1RM) to improve maximal strength qualities, TF is not required in an athlete's RT program.

6.2 Combined Heavy and Light Loading

As mentioned in the previous section, training with heavy loads benefits muscular strength. However, given the nature of strength phase goals (e.g., enhanced force production and early RFD development), it may be useful to implement a combined loading strategy that uses heavy and light loads. Previous literature indicated that both maximal strength and RFD underpin power [1, 16, 71]. Thus, while the primary emphasis will be using heavier loads during maximal and absolute strength phases, lighter loads may benefit an athlete's RFD, ultimately facilitating RFD and power development during subsequent phases that are often termed strength-speed and speed-strength. Previous literature supports the use of a combined loading strategy for the development of an athlete's force–velocity profile [70]; however, it should be noted that an emphasis may be placed on either force- or velocity-dominant training based on an athlete's force and velocity characteristics in ballistic actions [192].

The prescribed training loads should complement the exercises that are being used. For example, heavier loads may be prescribed using core exercises (e.g., squats, presses, and pulls) and certain weightlifting movements (e.g., power clean, pull from the knee, mid-thigh pull) which have the goal of emphasizing high force production. In contrast, lighter loads may be prescribed to emphasize higher velocities during ballistic exercises (e.g., lighter pulling movements, jump squat, bench press throw). Combination loading may also be achieved through the implementation of both weight training (high force) and plyometric exercise (high velocity). An effective method is to program heavy/light training days in which the same exercises are prescribed on different days [15, 193, 194], and the second day is lighter than the first. This method provides a velocity-power spectrum across the week and emphasizes fatigue management [63, 64]. Previous literature examined this method of programming for track and field athletes [15, 64, 73]. For example, Harris et al. [15] found superior training responses using a combined loading method performing back squats at 80% 1RM on their heavy day and back squats at 60% 1RM on their light day. Finally, a combined loading stimulus within a single training session is realized through working, warm-up, and warm-down sets of each exercise, provided maximum efforts are used. While the high force portion of combined loading will likely improve maximal strength characteristics, the velocity portion will favor RFD and power. Thus, a combined loading method may produce the desired strength adaptations while also underpinning RFD and power adaptations that are important to sport performance. However, it should be noted that improvements in strength and strength-related characteristics do not always show statistical differences (e.g., p-value) when comparing different programs of strength training. This was the case within a previous study by Painter et al. [73] that compared daily undulating programming versus BP programming among strength-power track and field athletes. In this study, the BP programming, that included substantial combinations of heavy and light loading, showed advantages in dynamic and isometric maximum strength and isometric RFD based on effect size magnitude. Furthermore, these gains were achieved using substantially less volume load therefore demonstrating significantly better training efficiency [73].

7 Exercise Set Considerations

7.1 Single Versus Multiple Sets

While some literature indicated that single exercise sets produce similar adaptations to multiple sets [195–200], a larger body of literature indicates that multiple sets produce greater hypertrophy, strength, and power adaptations [189, 201–216]. It should be noted, however, that an athlete's training status, as well as the dose–response relationship for muscular strength development, must be taken into consideration [183, 217]. Specifically, smaller doses of RT (e.g., 2–3 sets per exercise) may be sufficient to enhance muscular strength in less-trained individuals, whereas larger doses of RT (e.g., 4–6 sets per exercise) may be required to attain the same level of improvement in well-trained athletes. Practitioners must also be cautious of venturing beyond the athlete's ability to adapt to prescribed training loads, as chronically elevated training volumes may expose the athlete to overtraining syndrome [65]. Additionally, the inclusion of more sets may also come at the cost of sufficient training intensity (e.g., ~ 80% of set-rep best), possibly limiting further CSA and strength enhancements [16]. Collectively, it appears that performing multiple exercise sets, to a certain extent, is advantageous in developing maximal strength. However, practitioners must consider the training status and current goal(s) of the athlete because there is an optimal number of sets that is specific for each individual. Furthermore, a comprehensive monitoring protocol should be implemented to ensure sufficient loading and prevention of excess fatigue and overtraining [218, 219].

7.2 Set Configurations

Exercise sets are traditionally completed by performing every repetition in succession until the desired number of repetitions is reached. Indeed, set length is used as a programming tool to achieve specific goals (e.g., hypertrophy, metabolic work capacity, etc.). Thus, higher repetitions per set may be reasonable depending upon training goals; however, the length of the set performed may result in a performance decline (e.g., force, velocity, etc.). This in turn may negatively impact the desired strength-power adaptations. Previous research has indicated that a longer set length resulted in an increased metabolic demand (ATP turnover, phosphagen and glycogenolysis ATP production, and blood lactate concentration) in recreational male athletes, which was correlated with decreased mean power production [220]. In a follow-up study with similar subjects and multiple sets, Gorostiaga and colleagues [221] indicated that an increased metabolic demand during longer sets may be the result of decreased energy stores, which may contribute to fatigue. While the above performance changes were noted during a traditional set of 10 repetitions, performance was maintained during traditional sets of five repetitions. Although traditional sets remain commonplace within RT programs, previous literature has challenged this method regarding hypertrophy, strength, and especially power development.

A growing body of literature has examined the use of cluster sets (CS) during RT. CS are defined as traditional exercise sets that are split into smaller sets of repetitions separated by rest intervals. The theory behind CS is that short intra-set/inter-repetition rest periods allow individuals to maintain their velocity and power throughout an exercise set [222]. This in turn would increase the overall quality of work (i.e., ability to improve and/or maintain performance during an exercise set) [122] and potentially allow the use of greater loads, collectively leading to greater performance adaptations. Previous literature indicated that CS may be beneficial during exercise sets focused on

Table 5 Cluster set rest interval recommendations for specific resistance training goals [234]

Training goal	Cluster set rest interval length (s)
Hypertrophy	5–15
Strength	20–25
Power	30–40

hypertrophy [223–227] and power [122, 226, 228, 229]; however, mixed findings were found when investigating the effects of CS on muscular strength. While Oliver et al. [225] indicated that CS produced greater strength improvements compared to a traditional set configuration, additional literature indicated that CS offered no additional benefit to isometric or dynamic elbow flexion strength [230], bench press or leg press 1RM [231], or bench press 6RM [232]. Therefore, longitudinal training using CS may benefit muscle hypertrophy and power; however, limited research supports their use for strength development. For a more thorough discussion on the theoretical and practical applications of cluster sets, readers are directed to a recent review by Tufano et al. [233]. Cluster set rest interval recommendations from Haff [234] are presented in Table 5.

8 Rest Intervals

The rest intervals implemented in training may be overlooked when it comes to improving maximal strength. Although previous recommendations have promoted shorter rest intervals for the development of muscle hypertrophy [235, 236], longer rest intervals may produce superior strength-power adaptations [237]. Previous research displayed that 1.5- to 3-min rest intervals produced greater muscle hypertrophy, strength, and power adaptations compared to 0.5- to 1-min rest intervals [238, 239]. Further research indicated that 2.5- to 5-min rest intervals resulted in a greater volume of work completed during a workout [188, 240], ability to train with heavier loads [186], and strength increases [239, 241, 242] compared to 0.5- to 2-min rest intervals. In contrast, no statistical differences in strength gains were found between 2- and 4-min rest intervals [240]; however, those who trained with longer rest intervals produced larger practical effects [243]. In line with previous recommendations [235, 236, 244], it is suggested that practitioners implement 2- to 5-min rest intervals when training to improve strength-power characteristics. However, it should be noted that the rest interval length range may be determined by the prescribed training loads, an athlete's training age [240], fiber type, and genetics [245].

9 Training Status Considerations

An athlete's training status may dictate: (1) what exercises and loads they can tolerate and (2) what their training emphasis should be. As with any type of training, practitioners should be mindful of an athlete's abilities as exercise competency will dictate whether it is appropriate to implement certain exercises or progress using various training methods. Relative strength (i.e., load lifted/athlete's body mass) is commonly used to determine if an athlete is considered "weak" or "strong" [1]. While no specific standards of relative strength exist, the following paragraphs discuss general RT recommendations based on the existing literature for athletes who may fall into either category.

9.1 Weaker/Less-Skilled Athletes

As muscular strength serves as the foundation upon which a number of other abilities are enhanced [1], the training emphasis for weaker and/or less-skilled athletes should be increasing their maximal strength. It should be noted that almost any RT method discussed in Sect. 5 may make an untrained participant stronger through the neural adaptations discussed in Sect. 3. Although a common error, practitioners emphasize high velocity/power training too early during an athlete's development. Increased maximum strength is strongly associated with the ability to produce not only higher forces, but also increased RFD, velocity, and power [1, 16]. Furthermore, considerable evidence indicates that increased maximum strength lays the foundation for future gains in RFD, velocity, and power [1, 16–18, 246]. Indeed, it was concluded in a recent meta-analysis that youth would benefit more from RT prior to completing power-type training [247]. Furthermore, strength training in youth would initially assist in optimizing motor control and coordination followed by a shift to adaptations associated with neural and morphological changes. Therefore, power-type exercises (e.g., jumping, bounding) are not intended to be omitted from a weaker athlete's program as they provide valuable execution context for motor coordination; however, they may not be featured as exclusively until an athlete improves their maximum strength using core RT exercises (i.e., squats, presses, and pulls).

9.2 Stronger/More-Skilled Athletes

While weaker and/or less well-trained athletes should focus on improving maximal strength before emphasizing power-type training, the training focus may shift for those with greater relative strength. Previous literature indicated that while muscular strength influences an athlete's performance, the magnitude of its influence may diminish when athletes maintain high strength levels [248]. Thus, the opportunity to continue to make large strength improvements decreases while an athlete continues to get stronger. Additional literature suggested that a shift towards power-type training while maintaining or increasing strength levels is necessary after achieving specific strength standards to allow an athlete to continue to improve their performance [1, 16, 64, 65]. While research investigating different strength standards is lacking, several studies indicated that individuals who squatted ≥ 2 × their body mass produced greater vertical jump power [72, 249], sprinted faster and jumped higher [250], and potentiated earlier [177, 251] and to a greater extent [177, 251, 252] compared to weaker individuals. Through achieving high levels of maximum strength, an athlete may maximize the benefits of incorporating training methods such as plyometrics and potentiation complexes. This does not mean that an emphasis on improved strength should be abandoned, but rather the long-term training process is one of emphasis/de-emphasis (e.g., if maximum strength decreases, power may also decrease) [1]. Thus, a greater requirement for unique training strategies that enhance the utilization of one's strength within the context of their sport may be required for further performance enhancement.

10 Conclusions

Muscular strength development is underpinned by a combination of several morphological and neural factors including muscle CSA and architecture, musculotendinous stiffness, MU recruitment, rate coding, MU synchronization, and neuromuscular inhibition. There are a number of periodization methods that can improve muscular strength; however, single- or multi-targeted BP may produce the greatest improvements in strength and related force–time characteristics (e.g., RFD and power). While a variety of RT methods exist, bilateral training, ET, AEL, and variable RT may have the greatest potential to improve muscular strength. In contrast, bodyweight exercise, isolation exercises, plyometrics, unilateral exercise, and kettlebell training may be limited in their potential to produce large maximal strength improvements but are still relevant to strength development by challenging time-limited force expression and differentially challenging motor demands. Therefore, no single exclusive training method can achieve the range of adaptations required for strength and related force–time characteristics. The extant literature suggests that TF is not necessary when the goal is to improve muscular strength. Combining heavy and light loads may produce the desired strength adaptations while underpinning RFD and power characteristics that are important to sport performance. Multiple sets may produce superior training benefits compared to single sets; however, prescription of sets should be based on an athlete's training status and the dose–response relationship for muscular strength development. While CS may benefit hypertrophy and power adaptations, they may not benefit strength improvements. Inter-set rest intervals ranging from 2 to 5 min may provide the greatest strength-power benefits; however, rest interval length may vary based on an athlete's training age, fiber type, and genetics. Weaker/less-skilled athletes should focus on developing a strength foundation before power-type exercises and training methods (plyometrics and potentiation complexes) are emphasized. In contrast, stronger/more-skilled athletes may begin to emphasize power-type exercises and training strategies while maintaining/improving their strength levels.

Despite the information presented within this review, additional research questions exist. Given the potential benefits of AEL and variable RT, future research should consider investigating the placement of AEL and variable RT within training phases as well as the volume, inter-set rest intervals, and loads that should be prescribed to produce optimal results. Further research should investigate what effect, if any, CS may have on strength development. Research should also examine how initial strength levels affect an athlete's ability to improve their performance using the described training methods or how best to transfer one's strength to specific motor demands required across various sports and activities. Finally, the evaluation and determination of individual adaptations by regimented monitoring should be explored to highlight and understand the varying rates of change and responsiveness of different athletes to the proposed training methods and periodization models discussed in the current review.

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