AUTHOR QUERIES

DATE 12/16/2016
JOB NAME SCJ

ARTICLE SCJ-D-16-00087
QUERIES FOR AUTHORS Suchomel et al

THIS QUERY FORM MUST BE RETURNED WITH ALL PROOFS FOR CORRECTIONS

Please confirm the given names (pink) and surnames (blue) of authors have been identified correctly.

AU1) Please note that the running head has been taken from the provided PDF. Also note that the running head should contain only 50 characters as per style; the running head exceeds 50 characters. Please check and change.

AU2) Please note that the academic degrees of all the authors have been taken from the provided pdf. Please check.

AU3) Please confirm if the author affiliations are accurate.

AU4) Please confirm if the conflicts of interest and funding statement is accurate.

AU5) Please confirm if the author bios and headshots are accurate.

AU6) Please provide the date and month when the conference was held in references 32 and 105.

AU7) Please provide volume number and page range, and check the year of publication in reference 46.

AU8) Please provide volume number in references 34 and 65, and also check the page range in reference 65.

AU9) Please update the references 17, 60, 99, 102, and 107.

AU10) Please provide the location and date of the presentation in reference 109.

AU11) Please note that two different captions were present in the manuscript. Please check the retained one.

AU12) Please note that the author names "Stone and O'Bryant" and "DeWeese et al." cited near the references "80 and 20," respectively, in the footnotes of Tables 1–5 do not match with the author names provided in the reference list. Please check.

AU13) Please check the edits made to the footnotes of Table 1.

Enhancing the Force–Velocity Profile of Athletes Using Weightlifting Derivatives

AU2 Timothy J. Suchomel, PhD, CSCS*D,[1] Paul Comfort, PhD,[2] and Jason P. Lake, PhD[3]
[1]Department of Human Movement Sciences, Carroll University, Waukesha, Wisconsin; [2]Directorate of Sport, Exercise and Physiotherapy, University of Salford, Greater Manchester, United Kingdom; and [3]Department of Sport and
AU3 Exercise Sciences, University of Chichester, Chichester, United Kingdom

ABSTRACT

WEIGHTLIFTING MOVEMENTS AND THEIR DERIVATIVES MAY BE IMPLEMENTED IN A SEQUENCED PROGRESSION THROUGHOUT THE TRAINING YEAR TO OPTIMIZE THE DEVELOPMENT OF AN ATHLETE'S STRENGTH, RATE OF FORCE DEVELOPMENT, AND POWER OUTPUT. WEIGHTLIFTING MOVEMENTS AND THEIR DERIVATIVES CAN BE PROGRAMMED EFFECTIVELY BY CONSIDERING THEIR FORCE–VELOCITY CHARACTERISTICS AND PHYSIOLOGICAL UNDERPINNINGS TO MEET THE SPECIFIC TRAINING GOALS OF RESISTANCE TRAINING PHASES IN ACCORDANCE WITH THE TYPICAL APPLICATION OF PERIODIZED TRAINING PROGRAMS.

INTRODUCTION

Weightlifting movements (i.e., full lifts including the snatch, clean, and jerk) and their derivatives (i.e., variations that omit part of the full lift) have been shown to provide a superior lower extremity training stimulus compared with other forms of training including jumping (106), powerlifting (51), and kettlebell exercise (71). This is likely due to the similarities between the rate and pattern of hip, knee, and ankle triple extension that occur during weightlifting movements and sport skills such as vertical jumping (7,8,36,52,53,81), sprinting (52), and change of direction tasks (52), as well as the ability to provide an overload stimulus (95). In addition, it has been suggested that weightlifting movements may be used to train the muscular strength that is required during impact tasks, such as jump landing (68). As a result, many practitioners implement weightlifting movements and their derivatives into resistance training programs for athletes (95). The proper implementation and progression of resistance training exercises throughout the training year facilitates the optimal development of the force–velocity profile of athletes (22,23), which has been suggested to be an important aspect regarding athletic performance (4,69,83). Thus, information that may assist practitioners when it comes to programming exercises to optimally develop these characteristics would be beneficial.

Previous research has investigated the training effects of various resistance training methods; however, limited information exists beyond the manipulation of the sets and repetitions. Ebben et al. (31,32) investigated the effects of a 6-week plyometric training programs on the development of lower-body explosiveness. In addition to the manipulation of sets and repetitions, these studies programmed exercises within periodized programs to vary the intensity of the training stimulus. Regarding squat movements, the exercise stimulus may be varied based on the depth and variation of the squat (49) as well as the load that is prescribed. Ultimately, this will modify the force–velocity characteristics of the training stimulus, but may enable the full development of the athlete's force–velocity profile. Previous literature has indicated that the combination of heavy and light loads with different exercises, and during work sets, warm-up sets, and warm-down sets with the same exercise, enables the full development of the athlete's force–velocity profile (38). Although information on how to impact an athlete's force–velocity profile using plyometrics and other

Address correspondence to Dr. Timothy J. Suchomel, timothy.suchomel@gmail.com.

KEY WORDS:
resistance training; rate of force development; power output; periodization; power clean; snatch

forms of resistance training exists (3,10,20,64), less information exists on the implementation of weightlifting movements and their derivatives.

Traditionally, weightlifting movements and their derivatives are programmed into resistance training programs where the athletes usually perform the catch phase of the movement. Although previous research supports the notion that weightlifting catching derivatives may train an athlete's ability to "absorb" a load during impact activities (68), more recent studies indicate that weightlifting pulling derivatives that exclude the catch phase may produce a similar or greater load absorption stimulus (i.e., loading work, mean force, and duration) following the second pull compared with weightlifting catching derivatives (17,99). Moreover, further research has demonstrated that weightlifting pulling derivatives produce comparable (11,12) or greater (60,102,104,105) force, velocity, and power characteristics during the second pull compared with weightlifting movements that include a catch element. Although the complete removal of weightlifting catching derivatives is not being suggested, the integration of weightlifting pulling derivatives into resistance training programs should be considered for the comprehensive development of an athlete's force–velocity profile, as elimination of the catch phase permits the use of greater loads (i.e., greater forces) (14,16,39) and potentially greater velocities (95,101). By using higher loads (i.e., >100% 1 repetition maximum [RM] clean/snatch) during the pulling derivatives, it is likely that greater increases in strength may occur (2,88,89). Although the use of weightlifting movements typically results in a low injury rate (44), previous literature indicated that training exclusively with the full weightlifting movements involving the catch may result in a greater potential for injury (63,82). An additional benefit of the pulling derivatives is the reduced technical demand (i.e., removal of the catch phase), which may (a) make the movements easier for athletes to learn due to fewer technical components and (b) may reduce injury potential due to the relatively neutral position of the shoulders, elbows, and wrists during the second pull phase (89). To properly program weightlifting movements and their derivatives, additional information is needed. The purpose of this review is to discuss the sequenced implementation of weightlifting derivatives in resistance training programs based on their force–velocity characteristics for the optimal development of the rate of force development (RFD) and power characteristics of athletes.

WEIGHTLIFTING DERIVATIVE FORCE–VELOCITY CURVE

Figure 1 illustrates the theoretical relationship between force and velocity with special consideration to weightlifting derivatives. The high force end of the force–velocity curve features weightlifting derivatives that develop the largest forces due to the loads that can be used. For example, previous literature has indicated that the midthigh pull (14,16,26,55), countermovement shrug (25), pull from the knee (29), and pull from the floor (27,39,110) tend to enable the use of loads in excess of the athlete's 1RM power or hang power clean/snatch. This is due to the decreased displacement of the external load during each movement. In contrast, the high velocity end of the force–velocity curve features weightlifting derivatives that are more ballistic in nature and typically use lighter loads. The placement of the jump shrug and hang high pull on the force–velocity curve is supported by previous research demonstrating that the jump shrug (104,105) and the hang high pull (104) produced higher velocities compared with the hang power clean. Moreover, previous research also indicates that these exercises may be best prescribed using lighter loads to maximize power and velocity (60,92,94,102–105). Additional research also supports the placement of the power clean, power clean from the knee, and midthigh power clean based on the 1RM (i.e., greater force or less force) that may be achieved for each exercise (56). F1

Although Figure 1 displays the general force–velocity characteristics of weightlifting catching and pulling derivatives, the load used during each exercise may influence its position on the force–velocity curve. For example, the midthigh pull is highlighted as the weightlifting derivative that enables the use of the heaviest loads (e.g., 140%

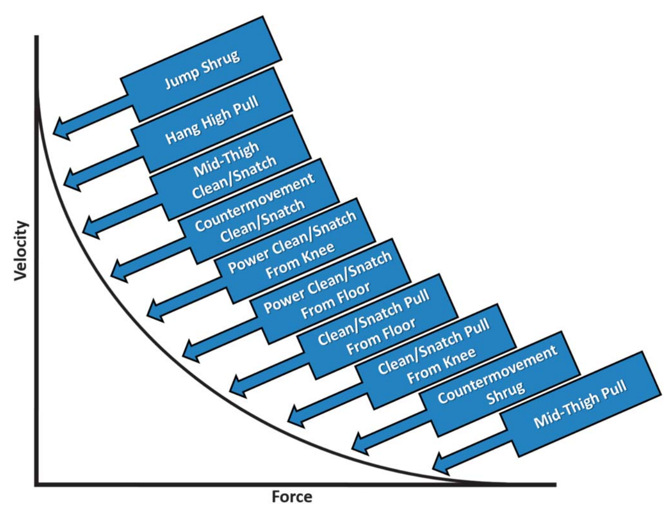


Figure 1. Force–velocity (power) curve with respect to weightlifting derivatives.

1RM of power clean) as indicated by Comfort et al. (14,16). However, the same studies indicated that velocity was maximized with the lightest load (i.e., 40% 1RM power clean), demonstrating that by manipulating the load, the exercise may change its position on the force–velocity curve. On the opposite end of the force–velocity curve, the jump shrug is highlighted as the weightlifting derivative that maximizes velocity (92,104). Despite its potential to produce greater peak forces compared to the hang high pull and hang power clean (102,104), using the jump shrug to develop speed–strength characteristics may be preferential to other exercises considering that higher velocities have been reported at the same or similar loads compared with the hang high pull, hang power clean, clean pull from the floor, and midthigh pull. Concurrently, using the midthigh pull to develop maximal strength qualities may be preferential to other exercises as research has examined loads upward to 140% 1RM (14,16), which would enhance high force production capacity. Although the previous information outlines just 2 examples, additional literature has described the versatility of weightlifting derivatives through a properly developed training plan using seamless and sequential programming (21,24). Figure 2 presents a more detailed proposal of how load may affect the force–velocity characteristics of the weightlifting derivatives described in Figure 1 that may aid strength and conditioning practitioners when it comes to implementing them in training.

PERIODIZATION MODEL FOR WEIGHTLIFTING DERIVATIVES

Previous literature has suggested that a seamless and sequential progression of training phases facilitates the optimal development of the athlete's force–velocity profile (22,23,38,67,84,85,112). This approach, which utilizes phase potentiation, is often found in models that use conjugate sequential programming (i.e., sequenced development and emphasis of fitness characteristics through block periodization) (21,24,84,85). Using similar concepts described in the literature (67,112), increases in work capacity and muscle cross-sectional area produced during a strength–endurance phase will enhance an athlete's ability to increase their muscular strength in subsequent training phases. From here, increases in muscular strength will then enhance an athlete's potential to improve their RFD and power output. A similar approach may be taken when prescribing weightlifting F2 derivatives. Because certain weightlifting derivatives place greater emphasis on either force or velocity, it seems that a sequential progression and combination of weightlifting derivatives may benefit the athlete when it comes to developing RFD and power. Moreover, the technique learned/refined during earlier training phases may facilitate increases in the load used for each exercise.

While much of the comparative literature indicates that a true block periodization model may provide superior training outcomes for individual sport athletes (22), it should be noted that weightlifting derivatives may also be implemented effectively with team sport athletes using a multilevel block model such as those discussed by Zatsiorsky (113), Verkhoshansky and Tatyan (109), and Bondarchuk (6). Using these training models, various attributes of athletes may be developed simultaneously while avoiding any potential increases in training volume that may result in an accumulation in fatigue.

RESISTANCE TRAINING PHASIC PROGRESSION

Each resistance training phase has its own unique characteristics that

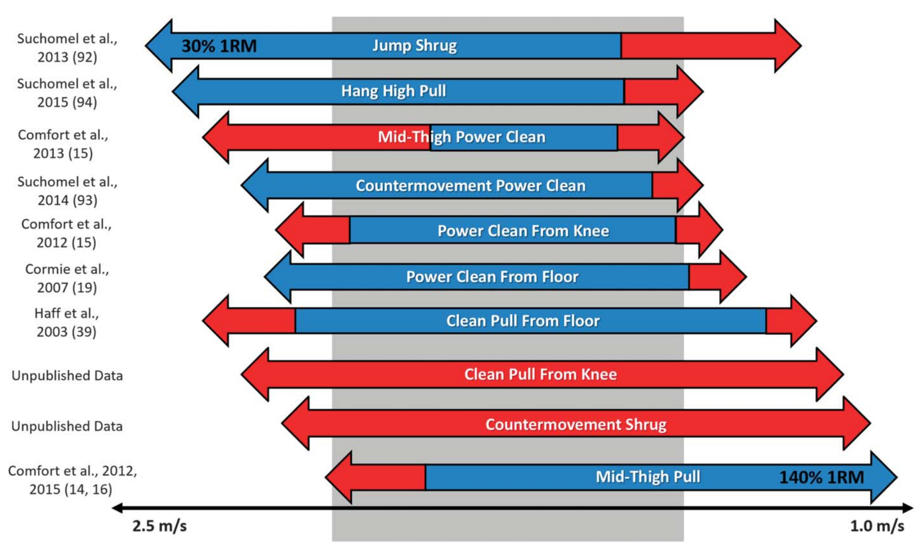


Figure 2. Proposed guidelines for the force–velocity characteristics of weightlifting derivatives with respect to load. Blue = studied loads; red = hypothetical loads; gray area = comparable force–velocity characteristics at given load ranges.

include specific goals, set and repetition schemes, and loads. However, another aspect that must be considered is the selection of exercises to meet the training goals of each resistance training phase. Although core exercises such as squatting, pressing, and pulling movements may be prescribed in every training phase, the characteristics of each weightlifting derivative depicted in Figure 1 may lead practitioners to prescribe certain derivatives in specific training phases. Specifically, the biomechanical and physiological characteristics of each weightlifting derivative may indicate that certain derivatives should be prescribed during certain training phases to meet the training goals of each phase. A recent article discussed the implementation of weightlifting derivatives when developing sprint speed (21). The authors noted that specific derivatives should be implemented during the general preparation, special preparation, early–midseason, and mid–late-season phases of training to achieve optimal adaptations of strength, RFD, and power while training through specific joint angles that are characteristic to different phases of sprinting.

The following paragraphs will discuss the characteristics of strength–endurance, maximal strength, absolute strength, strength–speed, and speed–strength resistance training phases and the recommended weightlifting derivatives to prescribe in each training phase for the optimal development of an athlete's force–velocity profile based on the biomechanical and physiological characteristics of each exercise. Examples of strength and power development programming using phase potentiation are displayed in Tables 1–5. It should be noted that the loads displayed in each table represent relative intensities based on the specific set and repetition configurations as described by previous literature (23,86). Using this method of load prescription, the load percentage is based off of a RM for each individual exercise. For example, performing 3 sets of 10 repetitions of the back squat at 90% is based on 90% of the athlete's 10RM back squat. It should also be noted that lighter intensities were prescribed on day 3 of each table to allow for adequate recovery and the reduced chance of accumulated fatigue and overtraining (23), but also to ensure that a variety of power outputs would be used resulting in positive adaptations to the power–load spectrum (48,72). Lastly, practitioners should note that the example training blocks may follow a return to fitness training period (typically 1–2 weeks), where large emphases are placed on exercise technique and recovery in preparation for the subsequent training blocks.

STRENGTH–ENDURANCE

The strength–endurance phase is characterized by a high volume of repetitions (usually 8–12) in exercises that use moderately heavy loads (~55–75% 1RM) (86). The goals of this

Table 1
Example strength–endurance training block using relative intensities based on attainable loads for sets and repetitions

Week	Objective	Volume	Day 1 (%)	Day 2 (%)	Day 3 (%)
1	Strength–endurance	3 × 10	85	85	75–77.5
2	Strength–endurance	3 × 10	90	90	80
3	Strength–endurance	3 × 10	92.5	92.5	80–82.5

The loads prescribed represent relative intensities based on the set and repetition configurations as discussed by Stone and O'Bryant (80) and DeWeese et al. (20).

Day 1 (push emphasis): back squat, overhead press, barbell lunges, and bench press.

Day 2 (pull emphasis): clean grip pull to knee (clean grip pull to knee performed for 3 × 5 throughout block to maintain technique integrity; clean grip/snatch grip pull from the floor may be substituted with advanced athletes using cluster sets of 2 or 5 repetitions to maintain technique integrity), clean grip shoulder shrug, stiff-legged deadlift, and pull-ups.

Day 3 (push–pull combo): snatch grip shoulder shrug, front squat, incline bench press, and dumbbell step-ups.

Table 2
Example maximal strength training block using relative intensities based on attainable loads for sets and repetitions

Week	Objective	Volume	Day 1 (%)	Day 2 (%)	Day 3 (%)
4	Maximal strength	3 × 5	87.5	87.5	75–77.5
5	Maximal strength	3 × 5	90	90	77.5–80
6	Absolute strength	3 × 5	95	95	80–82.5
7	Maximal strength	3 × 5	82.5	82.5	75–77.5

The loads prescribed represent relative intensities based on the set and repetition configurations as discussed by Stone and O'Bryant (80) and DeWeese et al. (20).

Day 1 (push emphasis): front squat, overhead press, barbell split squat, and incline bench press.

Day 2 (pull emphasis): clean grip midthigh pull, clean grip pull from floor, glute–ham raises, and bent over row.

Day 3 (push–pull combo): snatch grip midthigh pull, back squat, bench press, and reverse hyperextensions.

Table 3
Example transition to absolute strength training block using relative intensities based on attainable loads for sets and repetitions

Week	Objective	Volume	Day 1 (%)	Day 2 (%)	Day 3 (%)
8	Maximal strength	5 × 5	87.5	87.5	75–77.5
9	Maximal strength	3 × 5	92.5	92.5	80
10	Absolute strength	3 × 5	95–97.5	95–97.5	82.5
11	Maximal strength–strength–speed	3 × 3	80–82.5	80–82.5	75

The loads prescribed represent relative intensities based on the set and repetition configurations as discussed by Stone and O'Bryant (80) and DeWeese et al. (20).

Day 1 (push emphasis): push press, back squat, bench press, and squat and press.

Day 2 (pull emphasis): midthigh power clean, clean grip pull from floor, stiff-legged deadlift, and pull-ups.

Day 3 (push–pull combo): snatch grip countermovement shrug, back squat, incline bench press, and barbell split squat.

training phase are to increase the athlete's overall work capacity and to stimulate increases in muscle cross-sectional area. According to Minetti (67) and Zamparo et al. (112), the strength–endurance phase serves as a building block for subsequent resistance training phases. Specifically, the strength–endurance phase will enhance the athlete's force production (both magnitude and rate) characteristics in subsequent training phases (22,23,85). In addition, the technique learned during the strength–endurance phase is likely to carry over into later training phases. Thus, it is important to implement exercises that serve as a foundation for future exercise progressions.

Although foundational exercises such as squatting, pressing, and pulling variations are typically implemented, only one article has discussed the use of weightlifting derivatives within a strength–endurance phase (75). Scala et al. (75) indicated that implementing exercises, including weightlifting pulling derivatives (i.e., clean/snatch pull from floor, thigh, and knee and clean/snatch grip shoulder shrugs), that recruit large amounts of muscle mass during a high volume strength–endurance phase may result in positive adaptations in aerobic power and body composition, but would also meet many basic requirements for the preparation of strength–power athletes. Based on these findings and the goals of a strength–endurance phase, the weightlifting derivatives recommended for this phase are the clean/snatch pull from the floor (27,39,110), pull to the knee (28), and clean/snatch grip shoulder shrug. The rationale for the inclusion of these exercises is multifaceted. First, each derivative serves as a foundational exercise that enables the progression to more complex weightlifting movements. Without the ability to complete the above exercises, the technique of more complex derivatives may not be completed efficiently, potentially impacting the stimulus of the exercise. Second, the clean/snatch pull from the floor enables athletes to overload the triple extension of the hips, knees, and ankles without experiencing the additional stress and complexity of catching the load during every repetition as fatigue develops. Although the catch phase of certain weightlifting derivatives may enable the athlete to develop additional characteristics (e.g., improvement in skeletal and soft tissue characteristics (50,91), positional strength, external load acceptance, etc.), the high volume of repetitions experienced during the strength–endurance phase may lead to a deterioration in form due to acute fatigue. Moreover, this decline in technique could alter catch phase mechanics and thus increase the likelihood of injury or compression stress. Although declines in technique during weightlifting catching derivatives may be attenuated by using various cluster set configurations with higher repetitions (46), previous literature indicated that may be necessary to reduce the number of collisions with the bar, especially during heavy clean and

Table 4
Example absolute strength training block using relative intensities based on attainable loads for sets and repetitions

Week	Objective	Volume	Day 1 (%)	Day 2 (%)	Day 3 (%)
12	Absolute strength	5 × 3	85–87.5	85–87.5	75
13	Absolute strength	3 × 3	92.5	92.5	75–77.5
14	Absolute strength	3 × 3	95	95	80–82.5
15	Strength–speed	3 × 2	80–82.5	80–82.5	75

The loads prescribed represent relative intensities based on the set and repetition configurations as discussed by Stone and O'Bryant (80) and DeWeese et al. (20).

Day 1 (push emphasis): push jerk, back squat, bench press, and parallel squat jumps.

Day 2 (pull emphasis): power clean, clean grip midthigh pull, and bent over row.

Day 3 (push–pull combo): midthigh power snatch, back squat, and push press.

Table 5
Example strength–speed and speed–strength training block using relative intensities based on attainable loads for sets and repetitions

Week	Objective	Volume	Day 1 (%)	Day 2 (%)	Day 3 (%)
16	Speed–strength	4 × 2	85	85	75
17	Strength–speed	3 × 2	90	90	77.5
18	Speed–strength	2 × 2	82.5–85	82.5	75

The loads prescribed represent relative intensities based on the set and repetition configurations as discussed by Stone and O'Bryant (80) and DeWeese et al. (20).

Day 1: push jerk, back squat, bench press, and ¼ squat jumps.

Day 2: countermovement power clean and clean grip jump shrug.

Day 3: countermovement power snatch, back squat, and push press.

jerks, to limit potential overuse injuries (82). Finally, the suggested derivatives enable the development of important lower- and upper-body musculature that will be used to enhance the force–velocity profile during later training phases in tandem with core exercises such as squatting, pressing, and pulling movements. An example strength–endurance training block is displayed in Table 1.

It should be noted that the athletic population may dictate which weightlifting movements are prescribed in a strength–endurance training block. For example, the clean/snatch pull from the floor may only be incorporated with an advanced athletic population whose movement mechanics are more stable and resilient to fatigue. As mentioned above, because of the high volume of repetitions within each exercise set, practitioners may consider prescribing cluster sets (i.e., exercise set split into smaller sets of repetitions separated by rest intervals) of either 2–5 repetitions for the clean/snatch pull from the floor (e.g., 10 total repetitions = 5 repetitions → 30-second rest → 5 repetitions). Through the use of cluster sets, athletes may maintain their technique, force, and power output in subsequent training phases that use heavier loads (39,46,47). This may also lead to high-quality work, enhanced work capacity, and force production adaptations with a high volume of repetitions (107). Moreover, the interrepetition rest period also provides the coach with the opportunity to provide additional feedback to the athlete.

MAXIMAL STRENGTH

Adaptations produced from the strength–endurance phase of training may enhance an athlete's ability to gain maximal strength (67,112). The primary goal of the maximal strength phase is to increase the athlete's force production capacity (5,89) using repetition schemes that include about 4–6 repetitions and moderately heavy loads (usually 80–90% 1RM, although potentially slightly higher with the pulling derivatives). Based on the goals of the maximal strength phase, practitioners may shift their focus to exercises that emphasize force production. From a biomechanical standpoint, the amount of force that must be applied to achieve the maximum potential movement velocity will be maximized by performing weightlifting movements that allow the heaviest loads to be used. With this in mind, a limitation to weightlifting catching derivatives is that the athlete cannot use loads greater than their 1RM. However, this is not the case for weightlifting pulling derivatives. The clean/snatch pull from the floor (27,39,110), clean/snatch pull from the knee (29), and the clean/snatch midthigh pull (14,16,26,55) all allow for loads greater than the athlete's 1RM to be used due to a decreased displacement of the load and the elimination of the catch phase. Ultimately, the use of heavier loads will emphasize force production and train the high force end of the force–velocity curve (Figure 1). Examples of maximal strength and transition training blocks are displayed in Tables 2 and 3, respectively.

ABSOLUTE STRENGTH

Although the maximal strength training block typically aims to increase the athlete's general strength characteristics during moderate repetition schemes (i.e., 4–6), the goals of an absolute strength training block are to improve the athlete's low repetition (i.e., 2–3) force production (both magnitude and rate) characteristics using near maximal loads (usually 90–95% 1RM, although this can increase to 120–140% 1RM with the pulling derivatives). As new force production demands are placed on the athlete, additional weightlifting derivatives may be prescribed to meet the training goals of the absolute strength resistance training phase. Weightlifting derivatives featured in the previous resistance training phase, including the clean/snatch pull from the floor, clean/snatch pull from the knee, and midthigh pull, will carry over into the absolute strength resistance training phase. Although these derivatives enable the athlete to retain their capacity for high force production, additional weightlifting derivatives that include a higher velocity may be prescribed during warm-up and warm-down sets and on training days where relative intensities are prescribed to lower the volume–load, while introducing or retaining a speed–strength characteristic. These might include the hang power clean/snatch (93), power clean/snatch, countermovement shrug (25), countermovement clean/snatch, midthigh clean/snatch (11,12,15), and the full clean and snatch. The combination of heavy and moderate loads that enable a higher velocity also enables the athlete to train the high force side in addition to aspects of the high velocity side. This is important during the absolute strength phase as it enables the athlete to improve their force–velocity profile. These adaptations will ultimately contribute to the athlete's ability to further develop impulse, RFD, and power characteristics (3). An absolute strength training block example is displayed in Table 4.

STRENGTH–SPEED

The primary goals of the strength–speed training phase are to further increase RFD and power, while also maintaining or potentially increasing strength levels. Practitioners should note the importance of maintaining or continuing to develop maximal strength during the strength–speed phase due to its influence on an athlete's sport performance and their fitness characteristics including both RFD and power (100). Because previous literature has indicated that RFD and power are 2 of the most important characteristics regarding an athlete's performance (4,69,83), it is important to prepare the athlete to maximize these adaptations using the previously discussed training phases (22,23). Based on the phasic progression of resistance training phases, increases in muscular strength (100) and RFD (3) from the previous training phases should, in theory, enhance the athlete's ability to augment their power characteristics.

Regarding the programming of weightlifting derivatives during the strength–speed phase, the enhancement of RFD and power characteristics may be achieved through the combination of heavy and light loads. However, the emphasis within this phase of training is to move relatively heavy loads quickly to enhance RFD characteristics (21). Using the derivatives displayed in Figure 1, the midthigh clean/snatch (11,12,15), countermovement clean/snatch (93), and power clean/snatch from the knee (15,98) may be used to develop the high velocity portion of the force–velocity curve, whereas the power clean (13,19), clean and snatch pull from the floor (27), clean and snatch pull from the knee (29), and midthigh pull (26) may develop the high force end of the force–velocity curve.

SPEED–STRENGTH

Explosive strength may be defined as the force development characteristics within the first 0–250 milliseconds of the concentric phase of a movement (1,65). The purpose of a speed–strength resistance training phase is to produce peak adaptations in RFD and power before competition. The adaptations and alterations in task specificity in the previous training phases enable athletes to progress in a desirable fashion to increase their speed–strength (i.e., explosiveness) (5,89,90). Specifically, increases in rate coding due to increased myelination, dendritic branching, and doublets (30,108) may have resulted because of the exposure of heavier loads in the maximal strength, absolute strength, and strength–speed training phases. Additional adaptations in neural drive (40,42,70), inter- and possibly intramuscular coordination (9,41,43,74), and motor unit synchronization (76,77) may also aid in the development of explosive force–time characteristics.

Optimal adaptations in RFD and power may be achieved by implementing a wide variety of the previously described weightlifting derivatives. Many of the previously described weightlifting derivatives may be prescribed during the speed–strength resistance training phase. However, the speed at which the movement is performed, and therefore the load, must be considered. The jump shrug (97) and hang high pull (96) are 2 of the most ballistic weightlifting derivatives that may be highlighted in a speed–strength training phase (95). Similar to the strength–speed phase, a combination of heavy and light loaded derivatives should be implemented to optimize RFD and power adaptations. Practitioners may consider implementing the combination of the midthigh pull or clean/snatch pull from the floor and the jump shrug and hang high pull to focus training on each extreme of the force–velocity curve (Figure 1). In addition, the combination of the above exercises enables the athlete to simulate overcoming the inertia of the external load from a static start (e.g., midthigh pull) and using the stretch-shortening cycle (e.g., jump shrug). This combination will ultimately place varying neurological demands on the athlete, allowing them to optimize impulse, RFD, and power characteristics.

Practitioners must also consider the loads implemented with each exercise within the speed–strength phase. To optimize power adaptations, it has been suggested that athletes should train at the load that maximizes power output, the "optimal load" (54,111). Research has indicated that loads of approximately 70–80% 1RM may provide the optimal load for weightlifting catching derivatives such as the power clean (13,18,19,78) and hang power clean (53,57,78). However, several of these studies indicated that there were no statistical differences in power output between loads ranging from 50 to 90% 1RM (13,18,19,53,57). Research investigating the optimal load for weightlifting pulling derivatives is limited because of the lack of criteria that indicates a successful repetition (100). However, several studies have suggested that lighter loads (i.e., 30–45% 1RM hang power clean) may optimize training stimuli for the jump shrug (60,92,102–105) and hang high pull (94,102,104). Similarly, Comfort et al. (14,16) indicated that during midthigh clean pulls, loads ranging from 40 to 60% of power clean 1RM maximized power, similar to the findings of Kawamori et al. (55). Additional literature has indicated that loads ranging 90–110% of the individual's 1RM power clean (39) or full clean/snatch (33–35,73) may produce the optimal training stimulus for velocity and power adaptations during the clean/snatch pull from the floor. Practitioners should however consider that the optimal load for power production may be specific to the joint, athlete plus load system, or the bar (66), may be altered based on the relative strength of the athlete (87), and may be impacted by movement pattern and the fatigue status of the athlete

(54). Although optimal loading studies may provide practitioners with a baseline for load prescription, it is suggested that a range of loads should be prescribed to train various aspects of an athlete's force–velocity profile (38). Support for this contention comes from a recent meta-analysis that displayed that optimal loading zones existed for a variety of lower-body exercises (78). An example of a strength–speed and speed–strength training block is displayed in Table 5.

ADDITIONAL CONSIDERATIONS

LOAD PRESCRIPTION

Two methods of load prescription can be used when implementing the weightlifting derivatives discussed in the previous paragraphs. Traditionally, loads for weightlifting derivatives may be prescribed based off of the 1RM of each exercise. Although this may still hold true for weightlifting catch derivatives, there are no criteria describing what constitutes a successful 1RM attempt during weightlifting pulling derivatives (100). Thus, practitioners are left prescribing the loads for weightlifting pulling derivatives based on a 1RM of a weightlifting catching derivative. The vast majority of literature that has examined weightlifting derivatives used a percentage of a 1RM completed with a catching derivative (11–14,16,19,37,39,45–47,53,55,57–62,79,80,92–94,102–105,110). Although this method may work for some practitioners, others may discourage the practice of 1RM tests, which may make it difficult to prescribe loads for pulling derivatives.

Another alternative to prescribing loads for weightlifting movements, which is highlighted in Tables 1–5, is the use of a method termed set–rep best (23,86). As mentioned above, the set–rep best method of load prescription is based on the loads that may be completed during specific set and repetition schemes in training. For example, an individual may complete a heavy resistance training block with a set and repetition scheme of 3 sets of 3 repetitions. In this scenario, the relative intensity percentage is based off of the 3RM for each individual exercise. Based on the load(s) completed during training, one may estimate the 1RM of the individual, but may also estimate loads that may be used during other repetition schemes. Advantages to this method of load prescription are that the athletes do not have to perform a 1RM test and that this method can be used with any exercise.

STATIC VERSUS DYNAMIC VARIATIONS

Certain weightlifting derivatives may be performed using weightlifting training blocks or squat rack safety bars (e.g., midthigh pull, clean/snatch pull from the knee, and clean/snatch from the knee). It should be noted that the use of certain variations may place different demands on the athlete. For example, a weightlifting derivative performed using a static start from either the blocks, safety bars, or even when held stationary at a specific position (e.g., midthigh or knee) may require a greater RFD compared with a dynamic start because the athlete would have to overcome the inertia of the training load from a dead-stop position, as previously observed (11,12). Although a dynamic variation will still require a large RFD, as is characteristic of all weightlifting derivatives, the athlete will already have developed a given amount of force. Practitioners should consider the differences between static and dynamic weightlifting variations as different demands will be required of the athletes performing the exercises.

CONCLUSIONS

Weightlifting movements and their derivatives may be programmed throughout the training year to fully develop and improve the athlete's force–velocity profile. Practitioners should consider the prescription of specific weightlifting derivatives during certain training phases based on their biomechanical and physiological characteristics. A combination of weightlifting catching and pulling derivatives may be used to develop the athlete's force–velocity profile. A sequenced approach should be taken when prescribing weightlifting derivatives to meet the goals of each training phase.

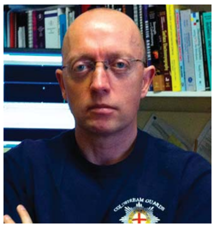
Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

ACKNOWLEDGMENTS

The authors thank Dr. Brad DeWeese for his insight regarding the programming of weightlifting derivatives in resistance training programs.

Timothy J. Suchomel *is an assistant professor in the Department of Human Movement Sciences at Carroll University.*

Paul Comfort *is a senior lecturer and program leader of the MSc Strength and Conditioning in the Directorate of Sport, Exercise, and Physiotherapy at the University of Salford.*



Jason P. Lake *is a senior lecturer and program leader of the MSc Strength and Conditioning in the Department of Sport and Exercise Sciences at the University of Chichester.*

REFERENCES

1. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, and Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle

following resistance training. *J Appl Physiol (1985)* 93: 1318–1326, 2002.

2. Aján T and Baroga L. *Weightlifting: Fitness for All Sports*. Budapest, Hungary: International Weightlifting Federation, 1988.
3. Arabatzi F, Kellis E, and de Villarreal ESS. Vertical jump biomechanics after plyometric, weight lifting, and combined (weight lifting + plyometric) training. *J Strength Cond Res* 24: 2440–2448, 2010.
4. Baker D. A series of studies on the training of high-intensity muscle power in rugby league football players. *J Strength Cond Res* 15: 198–209, 2001.
5. Bompa TO and Haff G. *Periodization: Theory and Methodology of Training*. Champaign, IL: Human Kinetics, 2009.
6. Bondarchuk A. Periodization of sports training. *Legkaya Atletika* 12: 8–9, 1986.
7. Canavan PK, Garrett GE, and Armstrong LE. Kinematic and kinetic relationships between an Olympic-style lift and the vertical jump. *J Strength Cond Res* 10: 127–130, 1996.
8. Carlock JM, Smith SL, Hartman MJ, Morris RT, Ciroslan DA, Pierce KC, Newton RU, Harman EA, Sands WA, and Stone MH. The relationship between vertical jump power estimates and weightlifting ability: A field-test approach. *J Strength Cond Res* 18: 534–539, 2004.
9. Carolan B and Cafarelli E. Adaptations in coactivation after isometric resistance training. *J Appl Physiol (1985)* 73: 911–917, 1992.
10. Channell BT and Barfield JP. Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *J Strength Cond Res* 22: 1522–1527, 2008.
11. Comfort P, Allen M, and Graham-Smith P. Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *J Strength Cond Res* 25: 1235–1239, 2011.
12. Comfort P, Allen M, and Graham-Smith P. Kinetic comparisons during variations of the power clean. *J Strength Cond Res* 25: 3269–3273, 2011.
13. Comfort P, Fletcher C, and McMahon JJ. Determination of optimal loading during the power clean, in collegiate athletes. *J Strength Cond Res* 26: 2970–2974, 2012.
14. Comfort P, Jones PA, and Udall R. The effect of load and sex on kinematic and kinetic variables during the mid-thigh clean pull. *Sports Biomech* 14: 139–156, 2015.
15. Comfort P, McMahon JJ, and Fletcher C. No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *J Strength Cond Res* 27: 363–368, 2013.
16. Comfort P, Udall R, and Jones PA. The effect of loading on kinematic and kinetic variables during the midthigh clean pull. *J Strength Cond Res* 26: 1208–1214, 2012.
17. Comfort P, Williams R, Suchomel TJ, and Lake JP. A comparison of catch phase force-time characteristics during clean deriatives from the knee. *J Strength Cond Res* 2016 [Epub ahead of print].
18. Cormie P, McBride JM, and McCaulley GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *J Appl Biomech* 23: 103–118, 2007.
19. Cormie P, McCaulley GO, Triplett NT, and McBride JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340–349, 2007.
20. de Villarreal ESS, Izquierdo M, and Gonzalez-Badillo JJ. Enhancing jump performance after combined vs. maximal power, heavy-resistance, and plyometric training alone. *J Strength Cond Res* 25: 3274–3281, 2011.
21. DeWeese BH, Bellon CR, Magrum E, Taber CB, and Suchomel TJ. Strengthening the springs. In: *Techniques Magazine*, 2016. pp. 8–20.
22. DeWeese BH, Hornsby G, Stone M, and Stone MH. The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *J Sport Health Sci* 4: 308–317, 2015.
23. DeWeese BH, Hornsby G, Stone M, and Stone MH. The training process: Planning for strength–power training in track and field. Part 2: Practical and applied aspects. *J Sport Health Sci* 4: 318–324, 2015.
24. DeWeese BH, Sams ML, Williams JH, and Bellon CR. The nature of speed: Enhancing sprint abilities through a short to long training approach. *Techniques* 8: 8–22, 2015.
25. DeWeese BH and Scruggs SK. The countermovement shrug. *Strength Cond J* 34: 20–23, 2012.
26. DeWeese BH, Serrano AJ, Scruggs SK, and Burton JD. The midthigh pull: Proper application and progressions of a weightlifting movement derivative. *Strength Cond J* 35: 54–58, 2013.
27. DeWeese BH, Serrano AJ, Scruggs SK, and Sams ML. The clean pull and snatch pull: Proper technique for weightlifting movement derivatives. *Strength Cond J* 34: 82–86, 2012.
28. DeWeese BH, Serrano AJ, Scruggs SK, and Sams ML. The pull to knee—Proper biomechanics for a weightlifting movement derivative. *Strength Cond J* 34: 73–75, 2012.
29. DeWeese BH, Suchomel TJ, Serrano AJ, Burton JD, Scruggs SK, and Taber CB. The pull from the knee: Proper technique and application. *Strength Cond J* 38: 79–85, 2016.
30. Duchateau J, Semmler JG, and Enoka RM. Training adaptations in the behavior of human motor units. *J Appl Physiol (1985)* 101: 1766–1775, 2006.
31. Ebben WP, Feldmann CR, Vanderzanden TL, Fauth ML, and Petushek EJ. Periodized plyometric training is effective for women, and performance is not influenced by the length of post-training recovery. *J Strength Cond Res* 24: 1–7, 2010.
32. Ebben WP, Suchomel TJ, and Garceau LR. The effect of plyometric training volume on jumping performance. Presented at: XXXIInd International Conference of Biomechanics in Sports, 2014, Johnson City, TN. AU6
33. Ermakov AD. The training load of weightlifters in pulls and squats. In: *1980 Weightlifting Yearbook*. Livonia, MI: Sportivny Press, 1980. pp. 34–38.
34. Frolov VI, Efimov NM, and Vanagas MP. The training weights in the snatch pull. *Tyazhelaya Atletika*: 65–67, 1977.
35. Frolov VI, Efimov NM, and Vanagas MP. Training weights for snatch pulls. *Sov Sports Rev* 18: 58–61, 1983.
36. Garhammer J and Gregor R. Propulsion forces as a function of intensity for weightlifting and vertical jumping. *J Strength Cond Res* 6: 129–134, 1992.
37. Haff GG, Carlock JM, Hartman MJ, Kilgore JL, Kawamori N, Jackson JR, Morris RT, Sands WA, and Stone MH. Force-time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. *J Strength Cond Res* 19: 741–748, 2005.
38. Haff GG and Nimphius S. Training principles for power. *Strength Cond J* 34: 2–12, 2012.
39. Haff GG, Whitley A, McCoy LB, O'Bryant HS, Kilgore JL, Haff EE, Pierce K, and Stone MH. Effects of different set configurations on barbell velocity and displacement during a clean pull. *J Strength Cond Res* 17: 95–103, 2003.

40. Häkkinen K. Neuromuscular and hormonal adaptations during strength and power training. A review. *J Sports Med Phys Fitness* 29: 9, 1989.

41. Häkkinen K, Alen M, Kallinen M, Newton RU, and Kraemer WJ. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *Eur J Appl Physiol* 83: 51–62, 2000.

42. Häkkinen K, Alen M, and Komi PV. Changes in isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand* 125: 573–585, 1985.

43. Häkkinen K, Newton RU, Gordon SE, McCormick M, Volek JS, Nindl BC, Gotshalk LA, Campbell WW, Evans WJ, and Häkkinen A. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol A Biol Sci Med Sci* 53: B415–B423, 1998.

44. Hamill BP. Relative safety of weightlifting and weight training. *J Strength Cond Res* 8: 53–57, 1994.

45. Hardee JP, Lawrence MM, Utter AC, Triplett NT, Zwetsloot KA, and McBride JM. Effect of inter-repetition rest on ratings of perceived exertion during multiple sets of the power clean. *Eur J Appl Physiol* 112: 3141–3147, 2012.

46. Hardee JP, Lawrence MM, Zwetsloot KA, Triplett NT, Utter AC, and McBride JM. Effect of cluster set configurations on power clean technique. *J Sports Sci* 2012. AU7

47. Hardee JP, Triplett NT, Utter AC, Zwetsloot KA, and McBride JM. Effect of interrepetition rest on power output in the power clean. *J Strength Cond Res* 26: 883–889, 2012.

48. Harris GR, Stone MH, O'Bryant HS, Proulx CM, and Johnson RL. Short-term performance effects of high power, high force, or combined weight-training methods. *J Strength Cond Res* 14: 14–20, 2000.

49. Hartmann H, Wirth K, Klusemann M, Dalic J, Matuschek C, and Schmidtbleicher D. Influence of squatting depth on jumping performance. *J Strength Cond Res* 26: 3243–3261, 2012.

50. Heinonen A, Sievänen H, Kannus P, Oja P, and Vuori I. Site-specific skeletal response to long-term weight training seems to be attributable to principal loading modality: A pQCT study of female weightlifters. *Calcif Tissue Int* 70: 469–474, 2002.

51. Hoffman JR, Cooper J, Wendell M, and Kang J. Comparison of Olympic vs. traditional power lifting training programs in football players. *J Strength Cond Res* 18: 129–135, 2004.

52. Hori N, Newton RU, Andrews WA, Kawamori N, McGuigan MR, and Nosaka K. Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *J Strength Cond Res* 22: 412–418, 2008.

53. Kawamori N, Crum AJ, Blumert PA, Kulik JR, Childers JT, Wood JA, Stone MH, and Haff GG. Influence of different relative intensities on power output during the hang power clean: Identification of the optimal load. *J Strength Cond Res* 19: 698–708, 2005.

54. Kawamori N and Haff GG. The optimal training load for the development of muscular power. *J Strength Cond Res* 18: 675–684, 2004.

55. Kawamori N, Rossi SJ, Justice BD, Haff EE, Pistilli EE, O'Bryant HS, Stone MH, and Haff GG. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *J Strength Cond Res* 20: 483–491, 2006.

56. Kelly J, McMahon JJ, and Comfort P. A comparison of maximal power clean performances performed from the floor, knee and mid-thigh. *J Trainology* 3: 53–56, 2014.

57. Kilduff LP, Bevan H, Owen N, Kingsley MI, Bunce P, Bennett M, and Cunningham D. Optimal loading for peak power output during the hang power clean in professional rugby players. *Int J Sports Physiol Perform* 2: 260–269, 2007.

58. Kipp K, Harris C, and Sabick M. Correlations between internal and external power outputs during weightlifting exercise. *J Strength Cond Res* 27: 1025–1030, 2013.

59. Kipp K, Harris C, and Sabick MB. Lower extremity biomechanics during weightlifting exercise vary across joint and load. *J Strength Cond Res* 25: 1229–1234, 2011.

60. Kipp K, Malloy PJ, Smith J, Giordanelli MD, Kiely MT, Geiser CF, and Suchomel TJ. Mechanical demands of the hang power clean and jump shrug: A joint-level perspective. *J Strength Cond Res* 2016 [Epub ahead of print].

61. Kipp K, Redden J, Sabick M, and Harris C. Kinematic and kinetic synergies of the lower extremities during the pull in olympic weightlifting. *J Appl Biomech* 28: 271–278, 2012.

62. Kipp K, Redden J, Sabick MB, and Harris C. Weightlifting performance is related to kinematic and kinetic patterns of the hip and knee joints. *J Strength Cond Res* 26: 1838–1844, 2012.

63. Kulund DN, Dewey JB, Brubaker CE, and Roberts JR. Olympic weightlifting injuries. *Phys Sportsmed* 6: 111–119, 1978.

64. Lake JP and Lauder MA. Kettlebell swing training improves maximal and explosive strength. *J Strength Cond Res* 26: 2228–2233, 2012.

65. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, and Duchateau J. Rate of force development: Physiological and methodological considerations. *Eur J Appl Physiol* 1–26, 2016 [Epub ahead of print]. AU8

66. McBride JM, Haines TL, and Kirby TJ. Effect of loading on peak power of the bar, body, and system during power cleans, squats, and jump squats. *J Sports Sci* 29: 1215–1221, 2011.

67. Minetti AE. On the mechanical power of joint extensions as affected by the change in muscle force (or cross-sectional area), ceteris paribus. *Eur J Appl Physiol* 86: 363–369, 2002.

68. Moolyk AN, Carey JP, and Chiu LZF. Characteristics of lower extremity work during the impact phase of jumping and weightlifting. *J Strength Cond Res* 27: 3225–3232, 2013.

69. Morrissey MC, Harman EA, and Johnson MJ. Resistance training modes: Specificity and effectiveness. *Med Sci Sports Exerc* 27: 648–660, 1995.

70. Narici MV, Roi GS, Landoni L, Minetti AE, and Cerretelli P. Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps. *Eur J Appl Physiol Occup Physiol* 59: 310–319, 1989.

71. Otto WH III, Coburn JW, Brown LE, and Spiering BA. Effects of weightlifting vs. kettlebell training on vertical jump, strength, and body composition. *J Strength Cond Res* 26: 1199–1202, 2012.

72. Painter KB, Haff GG, Ramsey MW, McBride J, Triplett T, Sands WA, Lamont HS, Stone ME, and Stone MH. Strength gains: Block versus daily undulating periodization weight training among track and field athletes. *Int J Sports Physiol Perform* 7: 161–169, 2012.

73. Roman RA. *The Training of the Weightlifter*. Livonia, MI: Sportivny Press, 1988.

74. Sale DG. Neural adaptations to strength training. In: *Strength and Power in Sport*. Komi PV, ed. Oxford, United Kingdom: Blackwell Science, 2003. pp. 281–313.

75. Scala D, McMillan J, Blessing D, Rozenek R, and Stone MH. Metabolic cost of a preparatory phase of training in weight lifting: A practical observation. *J Strength Cond Res* 1: 48–52, 1987.

76. Semmler JG. Motor unit synchronization and neuromuscular performance. *Exerc Sport Sci Rev* 30: 8–14, 2002.

77. Semmler JG, Kornatz KW, Dinenno DV, Zhou S, and Enoka RM. Motor unit synchronisation is enhanced during slow lengthening contractions of a hand muscle. *J Physiol* 545: 681–695, 2002.

78. Soriano MA, Jiménez-Reyes P, Rhea MR, and Marín PJ. The optimal load for maximal power production during lower-body resistance exercises: A meta-analysis. *Sports Med* 45: 1191–1205, 2015.

79. Souza AL and Shimada SD. Biomechanical analysis of the knee during the power clean. *J Strength Cond Res* 16: 290–297, 2002.

80. Souza AL, Shimada SD, and Koontz A. Ground reaction forces during the power clean. *J Strength Cond Res* 16: 423–427, 2002.

81. Stone MH, Byrd R, Tew J, and Wood M. Relationship between anaerobic power and olympic weightlifting performance. *J Sports Med Phys Fitness* 20: 99–102, 1980.

82. Stone MH, Fry AC, Ritchie M, Stoessel-Ross L, and Marsit JL. Injury potential and safety aspects of weightlifting movements. *Strength Cond J* 16: 15–21, 1994.

83. Stone MH, Moir G, Glaister M, and Sanders R. How much strength is necessary? *Phys Ther Sport* 3: 88–96, 2002.

84. Stone MH, O'Bryant H, and Garhammer J. A hypothetical model for strength training. *J Sports Med Phys Fitness* 21: 342–351, 1981.

85. Stone MH, O'Bryant H, Garhammer J, McMillan J, and Rozenek R. A theoretical model of strength training. *Strength Cond J* 4: 36–39, 1982.

86. Stone MH and O'Bryant HS. *Weight Training: A Scientific Approach*. Minneapolis, MN: Burgess International, 1987.

87. Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, and Schilling B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. *J Strength Cond Res* 17: 140–147, 2003.

88. Stone MH, Pierce KC, Sands WA, and Stone ME. Weightlifting: A brief overview. *Strength Cond J* 28: 50–66, 2006.

89. Stone MH, Pierce KC, Sands WA, and Stone ME. Weightlifting: Program design. *Strength Cond J* 28: 10–17, 2006.

90. Stone MH, Stone M, and Sands WA. *Principles and Practice of Resistance Training*. Champaign, IL: Human Kinetics, 2007.

91. Storey A and Smith HK. Unique aspects of competitive weightlifting: Performance, training and physiology. *Sports Med* 42: 769–790, 2012.

92. Suchomel TJ, Beckham GK, and Wright GA. Lower body kinetics during the jump shrug: Impact of load. *J Trainol* 2: 19–22, 2013.

93. Suchomel TJ, Beckham GK, and Wright GA. The impact of load on lower body performance variables during the hang power clean. *Sports Biomech* 13: 87–95, 2014.

94. Suchomel TJ, Beckham GK, and Wright GA. Effect of various loads on the force-time characteristics of the hang high pull. *J Strength Cond Res* 29: 1295–1301, 2015.

95. Suchomel TJ, Comfort P, and Stone MH. Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Med* 45: 823–839, 2015.

96. Suchomel TJ, DeWeese BH, Beckham GK, Serrano AJ, and French SM. The hang high pull: A progressive exercise into weightlifting derivatives. *Strength Cond J* 36: 79–83, 2014.

97. Suchomel TJ, DeWeese BH, Beckham GK, Serrano AJ, and Sole CJ. The jump shrug: A progressive exercise into weightlifting derivatives. *Strength Cond J* 36: 43–47, 2014.

98. Suchomel TJ, DeWeese BH, and Serrano AJ. The power clean and power snatch from the knee. *Strength Cond J* 38: 98–105, 2016.

99. Suchomel TJ, Lake JP, and Comfort P. Load absorption force-time characteristics following the second pull of weightlifting derivatives. *J Strength Cond Res* 2016 [Epub ahead of print].

100. Suchomel TJ, Nimphius S, and Stone MH. The importance of muscular strength in athletic performance. *Sports Med* 46: 1419–1449, 2016.

101. Suchomel TJ and Sato K. Baseball resistance training: Should power clean variations be incorporated? *J Athl Enhancement* 2, 2013.

102. Suchomel TJ and Sole CJ. Force-time curve comparison between weightlifting derivatives. *Int J Sports Physiol Perform* 2016 [Epub ahead of print].

103. Suchomel TJ, Taber CB, and Wright GA. Jump shrug height and landing forces across various loads. *Int J Sports Physiol Perform* 11: 61–65, 2016.

104. Suchomel TJ, Wright GA, Kernozek TW, and Kline DE. Kinetic comparison of the power development between power clean variations. *J Strength Cond Res* 28: 350–360, 2014.

105. Suchomel TJ, Wright GA, and Lottig J. Lower extremity joint velocity comparisons during the hang power clean and jump shrug at various loads. Presented at: XXXIInd International Conference of Biomechanics in Sports, 2014, Johnson City, TN.

106. Tricoli V, Lamas L, Carnevale R, and Ugrinowitsch C. Short-term effects on lower-body functional power development: Weightlifting vs. vertical jump training programs. *J Strength Cond Res* 19: 433–437, 2005.

107. Tufano JJ, Conlon JA, Nimphius S, Brown LE, Seitz LB, Williamson BD, and Haff GG. Cluster sets maintain velocity and power during high-volume back squats. *Int J Sports Physiol Perform* 2016 [Epub ahead of print]. AU9

108. van Cutsem M, Duchateau J, and Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol* 513: 295–305, 1998.

109. Verkhoshansky Y and Tatyan V. Speed-strength preparation for future champions. Presented at: Legkaya Atletika, 1973. AU10

110. Wicki B, Culici J, DeMarco N, Moran M, and Miller J. Comparison of rate of force development during a light and moderate load snatch pull. *J Undergrad Kinesiol Res* 9: 20–30, 2014.

111. Wilson GJ, Newton RU, Murphy AJ, and Humphries BJ. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 25: 1279–1286, 1993.

112. Zamparo P, Minetti A, and di Prampero P. Interplay among the changes of muscle strength, cross-sectional area and maximal explosive power: Theory and facts. *Eur J Appl Physiol* 88: 193–202, 2002.

113. Zatsiorsky V. *Science and Practice of Strength Training*. Champaign, IL: Human Kinetics, 1995.