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Master of Science in Sport Science and Coach Education,
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by
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ABSTRACT

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The purpose of this study was to determine if concentric velocities of lighter loads of could be augmented if they are performed heavier working sets. Twelve trained males with experience in the barbell back squat performed a 5RM and completed two separate squat training session conditions that consisted of three sets of five repetitions with 85% of their 5RM. Both conditions differed in the placement of a reduced-load set that was either performed after the working sets or during the warm-up period. No significant differences were observed in the working set MCVs in both conditions. Additionally, no significant differences were observed amongst MCVs in the Down Set and equivalent warm-up set loads. The results of this study suggest that postactivation potentiation may not occur using a similar set-load scheme.

DEDICATION

This thesis is dedicated to everyone who has continuously invested in me throughout my life; you know who you are. Perhaps the greatest common denominator behind our bonds is the desire to continue evolving because we always challenged each other to be better. You have all taught me to think critically, to view everything with an unbiased lens, to develop my own principles, and the value of building up the people around me. Thank you all for all the time you've put aside to help me in my journey and I cannot live a life where I am not doing the same for others.

To my dearest grandparents, my tireless work ethic and obsession with the pursuit of excellence is a product of your life stories. The value and impact each of you individually made in my life is ineffable.

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Chapter 1: Introduction

Statement of the Problem

The ability to express high force and power in minimal time are foundational aspects of success in many sports (Stone et al. 2007; Turner et al. 2020a). Jumping, sprinting, change-of-direction, and other athletic abilities rely on strength-power characteristics (Haff, Whitley, & Potteiger 2001; Hawley et al. 1992; & Marques et al. 2011; Silva et al. 2015; Sperannza 2016; Bazyler et al. 2017; Hermassi et al. 2017). Previous research has shown that maximal strength and power output can differ significantly between athletes that are starters and non-starters (Barker et al. 1993; Young et al. 2005; & Gabbett et al. 2009). It has also been demonstrated that these characteristics may differentiate between levels of athletes (elite, college, high school, etc.) (Iguchi et al. 2011; Fry & Kraemer 1991; & Sands et al. 2005). Based on the current body of literature, the development of maximal strength, rate of force development, and power-generating capabilities should be the primary considerations during the design of a strength and conditioning program.

When designing and implementing periodized training plans, specific performance outcomes and physiological adaptations can be developed with the proper application of training principles. One critical training principle is implementing training variation to remove linearity from training and induce novel training stimuli at appropriate times (Busso et al. 2002; Foster, C. 1998; & Stone et al. 1991). Training variation can be implemented on an acute scale by altering the set configurations and loading sequence of exercises within a training session (Haff, Burgess, & Stone 2008).

Down Sets are a specific example of sequencing a single reduced-load set after performing a series of heavy sets with the same exercise and have been incorporated into resistance training programs for power development to complement strength-oriented training phases (Carroll et al. 2018; DeWeese et al. 2015b; Hornsby et al. 2017; Painter et al. 2012; Stone et al. 2003a; Stone et al. 2006; Taber et al. 2018). It is unclear to what degree the Down Sets influenced the initial adaptations in peak power during the strength-oriented training phase in the observational study by Stone et al. (2003a) that described the relationships between strength-power characteristics and throwing ability over an eight week training period in well-trained collegiate throwers. In addition, the literature on their acute and chronic effects in a resistance training protocol is scarce; thus, the purpose of this study was to determine if concentric velocities of lighter loads in could be augmented if they are performed after heavier working sets.

Operational Definitions

1. Power: The product of force and velocity, also characterized as a work-rate (P = Force x Distance/Time).
2. Strength: The ability to generate force against an external resistance. This force, having both a magnitude and direction, is measured in Newtons (Siff 2001).
3. Peak Velocity (PV): The highest instantaneous velocity value observed during the concentric portion of a squat and is measured in meters per second (m/s) for a single repetition.
4. Mean Concentric Velocity (MCV): The average concentric velocity of a movement throughout an entire set of repetitions, calculated from the velocities of all repetitions from a given set.
5. Five-Repetition Maximum (5RM): In resistance training, the maximum load an individual can successfully complete for 5 repetitions for a given exercise.
6. Linear Position Transducer (LPT): A device that uses a potentiometer and extendable wire affixed to a moving object to determine said object's position in one dimension.
7. Barbell Back Squat: A traditional resistance training exercise where the lifter begins the movement while standing upright with the barbell resting across the shoulders before flexing at the hip, knee and ankle joints to descend into a squat. Upon reaching the desired depth, the lifter extends at the hip and knee joints while plantar flexing at the ankle joint to return to standing (Schoenfeld, 2010).
8. Maximal Intent to Move: Describes a movement or exercise performed with the intent to move fast as possible, regardless of the load applied.

9. Working Sets (WS): Consists of several repetitions performed at a specified load for a particular exercise. The amount of repetitions per set depends upon the intended goals.

10. Warm-up Sets (WU): A series of progressively heavier sets performed before the working sets of a targeted load of a particular exercise. Typically done with the same amount of repetitions as the target working set.

11. Down Set (DS): A reduced-load set of five repetitions completed after target working-sets of a given exercise typically performed with 50-60% of the working-set load (Painter et al. 2012 & Stone et al. 2006). Down Sets are typically paired with strength-oriented exercises such as the barbell back squat, bench press, push press, and clean pulling variations (Carroll et al. 2018; DeWeese et al. 2015b; Hornsby et al. 2017; Painter et al. 2012; Stone et al. 2003a; Stone et al. 2006; Suarez et al. 2019; & Taber et al. 2018). Down Sets provide work with loads that generate high power outputs and may be moved with greater movement velocities due to postactivation potentiation.

12. Postactivation Potentiation (PAP): An acute enhancement of neuromuscular performance as a result of contractile history. The contractile history is typically modulated with a conditioning activity such as a heavy back squat to enhance subsequent performance of a task such as jumping or sprinting.

13. Potentiation Capabilities: The ability to express postactivation potentiation on subsequent performance tasks.

14. Strength-Power Potentiation Complex (SPPC): Describes the sequencing of a conditioning activity characterized by high-force or high-power production to enhance the performance of a subsequent exercise.

Chapter 2: Comprehensive Review of the Literature

The purpose of this literature review is to provide context into how muscular power is developed for enhancing sports performance and will address: the importance of muscular strength for power development; principles of power training; postactivation potentiation; programming for strength-power development; the use of Down Sets; and instrumentation for power assessment.

The Importance of Muscular Strength for Power Development

Muscular strength is the ability of the neuromuscular system to produce force against an external resistance (Siff 2001). Developing high levels of muscular strength is important for optimizing power-generating capabilities (Baker & Nance 1999; Cormie, McGuigan, & Newton 2010a; Stone et al., 2003b; Suchomel et al., 2016; & Zamparo et al. 2002). Simply performing strength-training alone can develop power to a greater extent than power-training alone in weaker or untrained individuals (Cormie et al., 2010b; Häkkinen & Komi 1985; Silva et al., 2015; Wenzel & Perfetto 1992). A meta-analysis by Seitz et al., (2014b) showed that increasing lower body strength through squatting can enhance sprint acceleration. Furthermore, Suchomel et al., (2016) compiled studies to show that stronger athletes outperformed weaker athletes in sporting competitions.

Power, speed, and agility result from strength characteristics (Hori et al., 2008; Haff et al., 2015). Given that power is the product of force and velocity (Knuttgen & Kraemer 1987), it is not surprising that stronger athletes are able to express higher power outputs (Baker 2001a; Haff & Stone 2015). It is also important to develop the ability to express high forces within short time frames, which is reflected by the rate of force development. Strength development is often associated with improved rates of force development and increased power-generating abilities (Aagard et al., 2002; Maffiuletti et al., 2016; Oliveira et al., 2013). The sequencing of training phases is also an important consideration for power development; a period or block of training focused on developing maximal strength completed prior to a block of training aimed at developing power and speed may maximize muscular power potential (Baker 1996; Behm et al., 2017; Harris et al., 2000; James et al., 2018; Stone et al., 2003a; Zamparo et al., 2002). Taken collectively, it is essential to improve muscular strength to enhance an athlete's ability to produce high rates of force development and power output.

The barbell back squat is a commonly prescribed exercise by strength & conditioning professionals to increase lower body strength and positively influence improvements in rate of force development and power (Aagard et al., 2002). The back squat is ideal for lower body strength development because it is a free-weight, closed-kinetic chain exercise that recruits a substantial quantity of skeletal muscle and has a high degree of sport specificity (Suchomel et al., 2018; Comfort et al., 2012; Robertson et al., 2008; Wisløff et al., 2004; Støren et al., 2008). These qualities make the back squat an ideal stimulus and primary exercise to drive the necessary neural and muscular adaptations underlying athletic performance.

The literature suggests that athletes who can perform a barbell back squat with at least twice their body mass are able to express higher power outputs and vertical jump heights (Stone et al., 2002; Wisløff et al., 2004). Once this strength standard has been met, athletes may be able to augment these benefits by including higher volumes of power-specific training (Cormie, McGuigan, & Newton 2010a). It is clear that strength should be prioritized as a foundational element of power development (Bompa and Haff 2009; Cormie, McGuigan, & Newton 2010a; Suchomel, Nimphius, & Stone 2016; & Taber et al., 2016;) and taken collectively, the ability to express high power outputs and greater athletic performance is dependent on an athlete's strength level. However, the relationship between strength and power diminishes once an athlete approaches their genetic ceiling for maximal strength; thus, power must be maximized through the inclusion of power-specific training (Kramer & Newton 2000).

Resistance Training Principles for Power Development

It is well established in the literature that heavy resistance training is required to induce the physiological and neural adaptations that underpin the ability to express high levels of strength (Campos et al., 2002; Häkkinen 1989; Kraemer & Ratamess 2004; Sale 2003). Once a foundation of strength is developed, it is important to develop the ability to couple high forces with high muscle fiber shortening velocity to maximize power production (Kraemer & Newton 2000). Mechanical power is a work rate and is the product of force and velocity (Knudson 2009; Knuttgen & Kraemer 1987). Maximal muscular power has been defined in the literature as: "greatest instantaneous power during a single movement performed with the goal of producing maximal velocity at takeoff, release, or impact" (Cormie, McGuigan, & Newton 2010a). Based on this mathematical relationship, strength & conditioning coaches must also overload velocity-generating capabilities to optimize muscular power development.

Training with the Optimal Load for Peak Power Output: Worthwhile Strategy?

It has been suggested that training at the load that maximizes mechanical power output, may be an appropriate strategy to improve muscular power development (Kawamori & Haff 2004). This approach is inherently limited for improving sport performance capacity since training solely with the optimal load can only maximize power output at or near the load that is being trained (McBride et al., 2002). An additional limitation with using optimal load to guide power-training is that maximum absolute strength levels may influence where peak power is achieved and that stronger individuals may maximize power output at higher percentages of 1RM (Baker et al., 2001a & Stone et al., 2003b). Stone et al., (2003b) found that in stronger individuals, maximal power output occurred at higher loads in jump squats compared to lower loads. Alternatively, Baker et al., (2001a; 2001c) observed maximal power output at lower loads in jump squats and bench throws in stronger athletes compared to weaker athletes. Considerable individual responses exist within relatively homogenous groups and may cause variance in where peak power occurs in individuals (Argus et al., 2014; Comfort et al., 2012). Lastly, power output is not static and fluctuates in response to training demands, training volume, and fatigue (Baker, 2001b, 2001d; & Stone et al., 2007).

The findings of other research found that a broad spectrum of loads can maximize power outputs in various exercises (Baker, Nance & Moore 2001; Cormie et al., 2011b; Cronin & Sleivert 2005; Kirby, Erickson, & McBride 2010; McBride et al., 2002). For instance, Cormie et al., (2007c.) found that power output in the back squat could be maximized with loads ranging from 30–70% of 1RM. Training approaches that only target strength or power development cannot maximize the capacities for either qualities, limiting sport performance capacity (Cormie et al., 2007b). Athletes in sports such as rugby and American football require the ability to produce high power outputs under a variety of loaded conditions (Baker 2001a; Baker 2001c; Turner et al., 2020a).

Power Training Strategies for Trained and Untrained Individuals

In untrained individuals, heavy strength-training alone can provide an adequate stimulus to cause simultaneous development of strength and power (Häkkinen 1989; Lyttle et al., 1996). However, individuals with greater resistance training experience and thus, strength levels would benefit from incorporating a mixed-methods approach that involves training across a spectrum of heavy and light loads to develop a complete force-velocity profile (Newton & Kraemer 1994; Moss et al., 1997; Cormie et al., 2011b; Haff & Nimphius 2012; Haff, Whitley, & Potteiger 2001; Lyttle et al., 1996; Toji et al., 1995; 1997; & 2004; James et al., 2018). In relatively strong athletes, training with lighter loads at high movement velocities has been shown to improve maximal power outputs that transfer to improvements in sprinting, jumping, throwing, and striking tasks (Cormie et al., 2011b; Kawamori & Haff 2004; Kaneko et al., 1983; McBride, Triplett-McBride, Davie, & Newton, 2002).

Harris et al., (2000) found that a combination of heavy strength training and high-power exercises resulted in a greater improvement in maximum strength and explosiveness performance among collegiate football athletes when compared with training programs that targeted high force or high-power alone. Mixed methods training and its efficacy for strength-power development is also evident in weightlifting training. Häkkinen et al., (1987) found that the average force-velocity profile curves calculated from loaded squat and countermovement jumps, improved in elite Finnish weightlifters after 12 months of weightlifting training that incorporated a wide variety of exercises that were high-power and high-force in nature. The use of heavy and light training days has been employed as a strategy to develop power within a training week. This strategy consists of repeating the same exercises on different days of the week and reducing the load used on the second day the exercise is performed (DeWeese et al., 2015b; Harris et al., 2000; Painter et al., 2012; Plisk & Stone 2003; Stone, Pierce, & Sands. 2006). The use of heavy and light days can develop power through training with a variety of loads and helps mitigate fatigue due to training with lighter loads on some days (DeWeese et al., 2015a; DeWeese et al., 2015b; Painter et al., 2012).

Performing Exercises with Maximal Intent to Move

Perhaps the simplest means of maximizing strength and power development is to encourage athletes to move external loads with the highest concentric velocity as possible, regardless of the load (Behm & Sale 1993; Cronin et al., 2001; Cronin et al., 2002; Jones et al., 2001; Kawamori & Newton 2006; Padulo et al., 2012; Pereira & Gomes 2003; Sale & MacDugall 1993; Young & Bilby 1993). Since submaximal warm-up sets are performed prior to prescribed working-sets, it has been suggested that the warm-up period can serve as an opportunity to develop power when athletes move with maximal intent (Haff & Nimphius 2012).

Young and Bilby (1993) investigated the effects of execution speed on measures of strength, muscular power, and hypertrophy. Eighteen male subjects trained with the half-squat exercise using an 8- to 12RM load for 7.5 weeks, with eight subjects intentionally moving quickly, and ten subjects emphasizing slow, controlled movements. The slow group improved to a greater extent (31%) that the fast group (12.4%) in absolute isometric strength, whereas the percentage gains in hypertrophy were similar for both groups. Mean percentages in improvement of rate of force development were greater for the fast group (68.7%) than the slow group (23.5%).

A similar effect has also been observed in non-athletic populations; Fielding et al., (2002) compared two different training groups using women with self-reported disability, both of which trained completed three sets of 8-10 repetitions in the leg press at 70% 1RM and knee extensions at 70% of 1RM. One group emphasized the intention to move explosively, while the other group completed repetitions in a slow, controlled fashion. The fast training group increased muscular power significantly more than the slow training group (leg press peak power in Watts: 267 W vs

139 W; $P < 0.001$), although increases in maximum strength in the leg press and leg extension were similar for both groups ($P < 0.001$).

Davies et al., (2017) performed the first systematic review and meta-analysis to investigate the effect of movement velocity on muscular strength. The authors found 15 studies that met the following criteria: randomized and non-randomized comparative studies; published in English; included healthy adults; used isotonic resistance-exercise interventions directly comparing fast or explosive training to slower movement velocity training; matched in prescribed intensity and volume; duration greater than weeks; and measured dynamic muscular strength changes. Fast compared with moderate-slow resistance training performed at moderate intensities (60–79% 1RM) showed a trend for superior gains in dynamic muscular strength, with training status and age not influencing the results.

Recently, a systematic review with meta-analysis and meta-regression was done to determine the effects of velocity, the intent for fast force production, and movement pattern of training exercises on the improvement in isometric RFD from chronic resistance training. Meta-regression and meta-analytic methods were used to compute standardized mean differences (SMD ± 95% confidence intervals) to examine the effects of movement pattern similarity (between training and test exercises; specific- vs. non-specific) and movement speed (fast vs. slow vs. slow with intent for fast force production) for RFD. Significant increases relative to control groups were observed after training with high-speed (0.54 [0.05, 1.03]), slow-speed with intent for fast force production (0.41 [0.20, 0.63]), and movement pattern-specific (0.38 [0.17, 0.59]) exercises only. Training using faster movement speeds induces greater improvements in RFD; however, the intent to develop forces rapidly (regardless of actual velocity) and similarity between training and testing movement patterns can also influence the improvement (Blazevich et al., 2020).

Exercise Specificity

Specificity of exercise selection is a critical component to achieving performance enhancement in any strength and conditioning program. Conceptually, specificity describes the degree of similarity between the exercises used in training and performance (Stone M.H., Stone M.E., & Sands 2007). Additionally, specificity of training accounts for the bioenergetic and mechanical factors of training. The aim of increasing specificity throughout the training process is to enhance the transfer of training effect, which deals with how much the training transfers to actual sport performance (DeWeesee et al., 2015a; Stone M.H., Stone M.E., & Sands 2007). Simply performing strength-oriented exercises (barbell back squat, barbell bench press, etc.) with maximal intent cannot maximize power development alone (Wilson et al., 1993; Newton et al., 1996). Sánchez-Medina et al., (2013) compared the velocity and power-load relationships of the prone bench pull and bench press performed in a Smith machine and found that heavy loads did not optimize power levels to the same extent as lighter loads did. No statistically significant differences in power output were observed for loads between 20% and 60% of 1RM in the bench press and loads between 20% and 70% in the prone bench pull.

There is a substantial portion near the end of the concentric phase in a strength-oriented exercise where the barbell is decelerating prior to reaching zero velocity (Cronin et al., 2002; Elliott et al., 1989; Wilson et al., 1989). This is likely a protective mechanism that allows the athlete to maintain control of the barbell and reduce injury risks to the joints. Elliott et al., (1989) analyzed the bench press performance of ten elite powerlifters using three-dimensional cinematography and surface electromyography with loads of approximately 80% of 1RM, a

1RM, and an unsuccessful supramaximal attempt. The authors reported that deceleration accounted for 23.3% of the movement when performing the 1RM and 51.7% of the movement when performing the 80% 1RM. Conversely, ballistic exercises have a complete, rapid acceleration of the barbell or object when performed with maximal intent (Newton et al., 1996; Turner et al., 2020b). Newton et al., (1996) found that ballistic exercises produced significantly higher average velocity, peak velocity, average force, average power and peak power throughout the lift, especially during the later stages of the concentric phase. Almost all sport-specific skills and movements exhibit such an acceleration profile; therefore, training strategies that target this characteristic would likely result in a positive transfer of training effect.

Similarly, there is no deceleration of the barbell during the pulling phase of the clean and snatch, mimicking the acceleration profile of ballistic exercises (Hori et al., 2005). While performing these lifts and their derivatives, athletes extend their hips, knees, and ankle joints to push against the ground as hard and as rapidly as possible to accelerate the barbell, resulting in a kinematic and kinetic profile similar to jumping (Canavan, Garrett, & Armstrong 1996; Carlock et al., 2004). Additionally, greater loads can be applied to these exercises in comparison to ballistic exercises, which allows for an overload stimulus for lower-body strength-power characteristics (Suchomel, Comfort, & Stone 2015). Furthermore, Suchomel et al., (2017) outlined a theoretical relationship between specific weightlifting derivatives and the portions of the force-velocity curve they target. An example of a weightlifting derivative would be the hang high pull, which is derived from the power clean and emphasizes positional strength at the hang position above the knee, the transition to the second pull phase, and at the mid-thigh position (Suchomel, Comfort, & Stone 2015). Previous kinetic data from Suchomel and colleagues

(2014) showed that the hang high pull produced higher velocities compared to the hang power clean.

Weightlifting movements have been demonstrated to develop broader performance improvements than plyometric exercises in physically active subjects. Tricoli et al., (2005) compared the short-term effects of heavy resistance training combined with a training program that emphasized vertical jump training (VJ) or weightlifting derivatives (WL); a control group underwent no training and only underwent pre-test and post-test sessions. Pre-test and post-testing consisted of: squat and countermovement jump tests; 10- and 30-m sprint speeds; an agility test; a half-squat 1RM; and a clean-and-jerk 1RM (only for the WL group). Each training group performed the half-squat along with exercises specific to each group. The WL group's program included: the high pull, power clean, and clean & jerk. The VJ group's program included: double-leg hurdle hops, alternated single-leg hurdle hops, single-leg hurdle hops, and 40-cm drop jumps. The squat jump and 10-m sprint speed improved significantly for the WL group only (9.56% and 3.66%, respectively). CMJ improved in both groups, but the WL group had a higher increment than the VJ group (6.6% and 5.72%, respectively). These improvements in performance tests support the use of weightlifting derivatives for improving athletic performance.

A recent training study from Suchomel et al., (2020) found that using a force- and velocity-specific overload stimulus with weightlifting pulling derivatives may produce superior adaptations in relative strength, sprint speed, and change of direction compared to submaximally-loaded weightlifting catching and pulling derivatives. Taken collectively, ballistic exercises and weightlifting derivatives must complement maximal strength development in order to raise the ceiling for power development and transfer of training effect.

Postactivation Potentiation

Strength and conditioning practitioners implement a variety of programming strategies intended to take advantage of a phenomenon known as postactivation potentiation, which is an acute performance enhancement that is influenced by muscular contractile history (Robins 2005; Sale 2002; Seitz & Haff 2015; Weber et al., 2008). Practitioners typically design what is often referred to as a strength-power potentiation complex by sequencing a high-force or high-power movement to potentiate the performance of a subsequent high power or high velocity movement (Stone et al., 2008). The barbell back squat and variations are commonly used as a potentiation modality in numerous studies due to the high loads that can be applied to the lower body musculature (Chiu et al., 2013; Jo et al., 2010; Ruben et al., 2010; Seitz et al., 2014a; Talpey et al., 2014; Weber et al., 2008; Young et al., 1996).

Scientists have proposed several physiological mechanisms behind this phenomenon, and perhaps one of the most supported mechanisms is an increase in phosphorylation of the myosin light chains that may occur in response to a potentiating stimulus, which increases actin and myosin sensitivity to calcium and thus allows for a more rapid rate of cross-bridge cycling (Hodgson et al., 2005; Tillin & Bishop 2009; Vandenboom, Grange, & Houston 1995). Performing a conditioning activity can also increase neuromuscular activation that increases the amount of motor units recruited in the muscle (Gullich & Schmidtbleicher 1996; Tillin & Bishop 2009).

It has been proposed by Stone and colleagues that the fitness-fatigue paradigm serves as the theoretical basis for strength-power potentiation complexes (Stone et al., 2008). Based on this theory, a potentiation-inducing conditioning exercise will simultaneously induce an elevation in fitness and fatigue. Careful manipulation of the volume and intensity of the conditioning exercise is necessary to maximize fitness and minimize fatigue so that an acute performance enhancement will manifest in the subsequent exercise. Thus, the magnitude of work performed in the potentiation-inducing portion of the complex will dictate the recovery time-period necessary before performing the high-velocity or power movement (Ruben et al., 2010).

The results of meta-analysis by Seitz and Haff (2015) suggest that stronger individuals can express a greater PAP effect (ES = 0.41) than weaker individuals (ES = 0.32). This is in agreement with previous research that found that PAP may be a viable method of acutely enhancing performance in athletic, but not recreationally trained individuals (Chiu et al. 2003). Jo et al. (2010) sought to investigate the effect of rest duration after performing back squats at 85% of 1RM on Wingate performance in recreationally trained individuals. Their findings suggest that relative strength discrepancies might influence when subjects are potentiated, despite rest duration failing to influence performance after the potentiating stimulus ($r = -0.771$, $p = 0.003$). The subjects of this study had an average 1RM squat to body mass ratio of 1.4 ± 0.1, which does not meet the general strength criteria other authors determined necessary to harness the benefits of PAP (Ruben et al. 2010; Seitz et al. 2014a; Tillin & Bishop 2009). Seitz et al. (2014a) found that stronger rugby elite athletes (back squat 1RM ≥ 2.0 body mass) expressed a postactivation potentiation effect as early as 3-minutes post-conditioning activity during a squat jump test, whereas the weaker individuals (back squat 1RM ≤ 2.0 body mass) displayed a significant postactivation potentiation effect 6-minutes post-conditioning activity.

Programming Strategies for Strength-Power Development

Training variation can be introduced through manipulation of programmatic variables at the acute and chronic level including: the total training load, number of sets and repetitions, number of exercises, order of exercises, rest interval between sets, foci of the training blocks, and the sequencing of training blocks (Haff, Burgess, & Stone 2008). Training variation can also be introduced at the acute level through the manipulation of the training set structure (Haff et al., 2003; 2008). Manipulating the training set can lead to specific training adaptations that could favor the development of specific physiological characteristics (DeLorme 1945; Campos et al., 2002; McCaulley et al., 2009; & Schoenfeld et al., 2014). In a traditional training set, an exercise is performed for a specified number of repetitions in a continuous fashion (Haff et al., 2003; 2008; Tufano, Brown, & Haff 2017). Cluster Sets are a well-studied set configuration that typically incorporates a short rest period of at least 15-45 seconds between each repetition and can be efficacious for maximizing velocities and power outputs in each repetition (Haff et al., 2008). Other configurations such as the Rest-Pause and Drop Set methods have been used and studied specifically for developing muscular hypertrophy (Angleri, Ugrinowitsch, & Libardi 2017; Schoenfeld 2011; and Tufano, Brown, & Haff 2017).

Loading Patterns

Various loading patterns within resistance training sessions have been implemented and studied for strength-power development. The "Pyramid System" structure invented by Thomas DeLorme, incorporates incremental increases and/or decreases in loads for successive sets while the number of repetitions follow an inverse pattern with the loads (DeLorme & Watkins 1948; Bompa & Haff 2009; Ribeiro et al., 2016; Angleri et al., 2017; Costa et al., 2019). Another commonly used protocol is Wave-Loading, which involves alternating between heavy and light loads over several sets and is commonly implemented to take advantage of postactivation potentiation; however, few studies have been performed to verify this rationale (Tan 1999; Wardle & Wilson 1996; Bompa & Haff 2009). Wave-Loading protocols generally involve undulating the load on a set-per-set basis, with repetitions per set inversely changing in accordance. An example application of this protocol would be performing the first working-set of barbell snatches with a load that is 80% of an athlete's 1RM and performing that for three repetitions. In the subsequent sets, loads at 85%, 75%, 80%, and 85% are performed for two, three, three, and two repetitions, respectively. Since this protocol is intended to utilize PAP, it has been implemented during periods of speed-strength development in addition to high velocity sprint training in the training programs of bobsled athletes preparing for the Sochi Olympic Games (DeWeese et al., 2014).

Strength-Power Potentiation Complexes

Many commonly used programming methodologies that contrast the use of high-force exercises and high-velocity exercises or tasks within a resistance training session aim to exploit postactivation potentiation to simultaneously improve strength and power (Carter & Greenwood 2014; Cormier et al., 2020; Lim & Barley 2016). Fleck and Kontor (1986) have previously described the pairing of sets of a heavy strength-oriented exercise (≥85% 1RM) such as a barbell back squat with sets of a lighter resistance (30–45% 1RM) using a biomechanically similar power-oriented exercise such as a jump squat. The implementation of this specific pairing is known as Complex Training and theoretically exploits postactivation potentiation within a resistance training session (Carter & Greenwood 2014). In a recent systematic review and meta-analysis done by Cormier et al., (2020), Complex Training can be an effective strategy for improving lower-body strength, vertical jump ability, sprinting ability, and change-of-direction speed in team sport athletes.

In one study by Baker (2003), sixteen rugby league players were divided equally into control and experimental groups, with both groups performing a pre- and post-test bench press throw of 50kg for five repetitions in a Smith machine with a rotary encoder attached (Plyometric Power System; Norsearch, Lismore, Australia). The experimental group performed the barbell bench press for a set of six repetitions with 65% of their 1RM and rested for three minutes before performing a post-test bench throw. The 4.5% increase in the power output observed during the post-testing bench throw in the experimental group was determined to be significantly different from all other scores ($p \leq 0.05$). The results of this study support the possibility of postactivation potentiation occurring during complex training and suggest that heavy loads and high volumes of conditioning activity may not be necessary for eliciting the acute neuromuscular responses responsible for postactivation potentiation. Despite a 4.5% increase in power output observed, it is not known if this marginal acute enhancement would translate into any longitudinal improvements in performance in these athletes.

Stone et al., (2008) tested the effects of manipulating the loading sequence in a strength-power potentiation complex protocol (SPPC) on the potentiation capabilities of international-level USA weightlifting athletes. Four men and three women performed the following potentiation protocols using the dynamic mid-thigh pull: men performed a sequence of 60, 140, 180, 220, and 140 kg, and women at 60, 80, 100, 120, and 80 kg; each set was performed for two repetitions. Both dynamic and isometric midthigh pulls were performed on force platforms to collect kinetic data, and vertical velocity was measured with potentiometers attached to both ends of the barbell. Isometric midthigh pulls were assessed for peak force (PF) and rate of force development (RFD), while the dynamic lifts were assessed for PF, RFD, peak velocity (PV), and peak power (PP). The second and fifth set for all lifters were specifically analyzed to assess potentiation capabilities. While PF, PP, and RFD were higher post-potentiation, PV was the only statistically higher value as there was a significant 5.3% ± 4.3% increase noted for PV. This provides evidence for using a SPPC protocol to enhance subsequent performance in the lighter set.

The magnitude of the potentiation expressed may be limited when using dynamic, full range-of-motion (ROM) strength-oriented exercises such as the barbell back squat as a conditioning activity due to a potentially greater accumulation of peripheral fatigue compared to doing exercises with lesser ROM (Seitz & Haff 2015). The dynamic midthigh pull is well-suited as a potentiation modality because it is a concentric exercise performed through a limited range of motion (DeWeese et al., 2013).

Down Sets

Down-sets are reduced-load sets completed after an athlete's prescribed working-sets and they typically performed at 50-60% of the working-set load or 40-55% of 1 repetition-maximum (Painter et al. 2012; Stone et al. 2006). To the authors' knowledge, one of the earliest known rationales for adding Down Sets into a resistance training program was to potentially help counter against loss in lean body mass during later phases of strength training by providing additional training volume (Stone et al. 1981). However, no studies have been conducted to verify this rationale. Down Sets have been proposed as a power-training strategy because they provide additional work at loads that maximize power outputs since the Down Set loads generally correspond to the percentages of 1RM where optimal loads can occur for the exercises they are programmed with (DeWeese et al., 2015a; Kawamori & Haff 2004; Stone et al., 2006). In addition, performing heavier target set loads may induce a postactivation potentiation effect that would allow the subsequent Down Set to be moved at higher velocities than would be possible without prior heavy loading (Bompa & Haff 2009).

Stone et al., (2003a) observed the training of collegiate throwers during a planned preparation phase prior to the indoor season. They examined the relations between: maximum strength (peak isometric force) and dynamic peak force, rate of force development, and peak power measured in the dynamic and isometric mid-thigh pull and to related these variables to 1RM power snatch, and throwing ability (shot-put and weight-throw). The throwers followed an eight-week training program that emphasized increased maximum strength in the first four-week block and shifted towards strength-power development in the final four weeks. Down Sets were programmed in all weeks except for Week 5, which was the period of highest training volume; no rationale was provided about their exclusion and the overall program design. All major exercises such as barbell back squats and clean pull variations all had a single Down Set of five repetitions performed at 40–50% of the 1RM. The results of this correlational study indicated that maximum strength (determined by isometric peak force) is strongly related to peak power and dynamic sports performance, but not peak rate of force development. Mean peak power increased from baseline values 1,909 ± 858 Watts (W) to 2,243 ± 959 W after the first four weeks of training, with a 17.5% change. However, at the end of the training period, peak power did not increase by a notable amount, as the mean peak power was 2,326 ± 651 W with a 3.7% change from the previous testing battery. Part of the rationale the authors provided for this improvement in peak power during the first four weeks was that the Down Sets may have provided sufficient power-oriented training despite the training focus of developing maximal strength. There were also light training days in each week that were programmed at a 10-20% reduction of load intensity for all exercises from the first training day. The combination of Down Sets and light training days allowed the throwers to train across a broad spectrum of heavy and light loads in a variety of exercises, which may offer a sufficient stimulus to elicit power adaptations. However, it is not known to what extent incorporating the Down Sets may have had on the outcomes, as augmenting strength characteristics inherently leads to improvements in power due to their mathematical relationship and previous literature that showed improvements in strength-power characteristics in trained and untrained populations after a strength-training intervention (Behm et al., 2017; Cormie et al., 2011a; Haff & Nimphius 2012). Additionally, all throwers had completed a 6-week high-volume training period prior to the initiation of the study. Suarez et al., (2019) examined athlete monitoring data from nine experienced collegiate weightlifters to investigate the kinetic and morphological adaptations that occur during distinct phases of a block-periodized training cycle. Slight depressions in the rate of force development measured from the isometric mid-thigh pull were found after a high-volume, strength-endurance phase. Rate of force development rebounded above previous values as the training emphasis shifted from maximal strength to strength-power over the course of several weeks. This finding may explain the improvements in peak power Stone et al., (2003a) observed in the first four weeks of training, as the strength-endurance block Suarez et al., (2019) examined lasted three weeks as opposed to six.

In a training study conducted by Painter et al., (2012), Down Sets were introduced in both training groups during the strength and power blocks of a 10-week fall-semester preparation-phase program. The Down Sets were performed as a single set of five-repetitions at 60% of target set loads. Exercises that were programmed with Down Sets included: back squats, push press, push jerk, incline bench press, and mid-thigh pulls. Similarly, Down Sets were introduced in the same fashion during the strength-power and peaking/taper phases of a block-periodized training cycle in weightlifters (Suarez et al., 2019). In both studies, all Down Sets were performed as a set of five repetitions and were paired with several set-repetition schemes (3x5, 3x3, 3x2, and 5x5). Additionally, they were not programmed during strength-endurance blocks in both studies; however, no rationale was provided by the authors for their exclusion. Despite the importance of rest periods for modulating potentiation responses, they were not specified in other training studies using Down Sets.

Unpublished kinetic and kinematic data that may offer insights into whether Down Sets can be moved with greater velocities. Carter and colleagues (2013) sought to determine if there was any effect of accentuated eccentric dead-stop squats on kinetic and kinematic variables in comparison to normal dead-stop squats in collegiate weightlifters, particularly on the concentric portion. Additionally, they wanted to determine if there was an acute postactivation potentiation effect induced by accentuated eccentric squats when compared to normal dead-stop squats, particularly during the concentric portion of the squat. Eight (n=8; 2 females, 6 males; age 24.6 ± 5.6 years; squat 1RM/BW 1.91 ± 0.36 for the whole group) collegiate competitive weightlifters from the same team performed two different squat protocols. One session involved performing three sets of single repetition accentuated eccentric load (AEL) dead-stop squats using 110% of 1RM on the eccentric portion and 85% on the concentric portion. A second session involved three sets of single repetitions for normal dead-stop squats (NDS) done with 85% of 1RM on both the eccentric and concentric portion. Warm-up (WUP55) and down sets (POST55) were performed for five repetitions with 55% of 1RM before and after the three sets, respectively. A rest period of three minutes was applied between sets in both conditions. In similar fashion to Stone et al. (2008), WUP55 and POST55 were compared to detect for a postactivation effect. All squats were performed on force plates (Lake Weighing Systems, Rice Lake, WI, USA) with linear position transducers (Celesco, Chatsworth, CA, USA) attached at the top of the squat rack with wires recoiled around both ends of the barbell; the synchronized kinetic and kinematic data was collected and analyzed using a customized program (LABVIEW 2010, National Instruments, Austin, TX, USA).

The only statistically significant values were found during the eccentric portion of the lifts for the kinetic and kinematic variables. No statistically significant interaction was found between squat type and the down sets for: peak concentric velocity (p = 0.81); mean concentric velocity (p = 0.95); peak concentric power (p = 0.70); mean concentric power (p = 0.95); peak concentric force (p = 0.84); and mean concentric force (p = 0.92). For the NDS condition, the percent changes for the following were calculated: allometrically scaled (scaled to the athlete’s body mass (kg) raised to the 2/3 power) peak concentric force (1.9 ± 4.2); allometrically scaled peak concentric power (6.3 ± 13.0); and peak concentric velocity (3.0 ± 10.4). Taken together, no potentiation effects were observed in either condition. Given that the subjects could likely express potentiation within the rest periods applied due to their strength levels, it is unclear as to why this was observed since the protocol design was in line with the protocols that observed postactivation potentiation (Seitz and Haff 2015). Specifically, the results from Seitz and Haff (2015) showed that using loads above 85% 1RM (ES = 0.41) and performing multiple sets of a conditioning activity (ES = 0.69) may be more favorable for inducing postactivation potentiation. If potentiation was not observed in this protocol, set-repetition schemes coupled with Down Sets using higher volumes (3x5, 3x3, 4x2, & 3x2) may result in a similar effect since fatigue may mask the ability to express potentiation (Carroll et al., 2018; DeWeese et al., 2015b; Hornsby et al., 2017; Painter et al., 2012; Stone, Pierce, Sands, & Stone 2006; Suarez et al., 2019; Taber et al., 2018).

Instrumentation for Power Assessment

To monitor strength and power development, it can be helpful for practitioners to use valid and reliable instruments to quantify force and power metrics in movements that are relevant to an athlete's sport. Previously, many investigations have been conducted to determine the optimal loads (typically described as a percentage of 1RM) at which power output is maximized using various data collection methodologies to determine power outputs (Baker et al., 2001b; Esliger & Sleivert 2003; Haff et al., 1997; Kawamori et al., 2005; McBride et al., 1999; Sleivert & Taingahue 2004; Winchester et al., 2005). Baker et al., (2001b), Esliger & Sleivert (2003), and McBride et al., (1999) used a linear position transducer to collect kinematic data, specifically, vertical displacement. McBride et al., (1999) complemented the linear position transducer with kinetic data collected from a force plate. Sleivert & Taingahue (2004) used an accelerometer to measure the instantaneous accelerations during concentric squat jumps to yield an exact measurement of force and an integrated measurement of velocity to measure muscular power. Haff et al.,(1997), Kawamori et al., (2005), and Winchester et al., (2005) used force plates to determine the optimal loads for power output in the power clean. In addition to force plates, Winchester et al., (2005) incorporated videography to examine the barbell displacement in both vertical and horizontal planes.

Force Plate Technology

Force plates are commonly used to calculate power from vertical ground reaction forces generated during dynamic movements (Delecluse et al., 2005; French et al., 2004; Haff et al., 1997; Iossifidou et al., 2005; McBride et al., 1999, 2002; Sands et al., 2005). The force plate methodology can be used to determine power output because the initial vertical velocity of the system is always zero (Cormie et al., 2007a). Since force is the product of mass and acceleration, acceleration can be calculated by dividing the vertical ground reaction forces by the system mass at each time point. To ensure that only the acceleration produced by the subject was used to determine velocity, acceleration due to gravity was subtracted from the calculated acceleration data in the aforementioned studies. The instantaneous vertical velocity of the system's center of mass was determined by multiplying the acceleration data and time at each data point. Finally, this derived velocity data is then multiplied with the original force data to calculate the power output. However, this process requires extensive data manipulation and results in noise amplification; this inherent risk of producing erroneous data limits the force plate methodology's accuracy to calculate power output (Wood 1982). Secondly, force plates cannot account for barbell movement that occurs independently of the body. As a result, velocity is underestimated in comparison to linear position transducer calculations, and thus under-representing power output (Haff et al., 1997). Hori et al., (2005) observed significant differences in peak force, velocity, and power during the hang snatch when comparing the use of a single linear position transducer to calculations derived from a force plate.

Linear Position Transducer Technology

In contrast to the kinetic data obtained from force plates, linear position transducers solely collect kinematic data by measuring the displacement of an object using a steel cable attached to a barbell and typically use a linear encoder to convert the voltage generated from displacement data into power calculations; other devices use rotary encoders and/or potentiometers to perform this conversion. The derivative of displacement can be used to calculate velocity and acceleration via double differentiation (Cormie et al., 2007a; Harris et al., 2010). A drawback of solely relying on kinematic data is that it also requires extensive data manipulation to determine force output from displacement data (Cormie et al., 2007a). An additional disadvantage associated with this methodology is it does not account for body movements that occur independently of the barbell, resulting in values that are only representative of the barbell and not the entire system (Cormie et al., 2007c; Garhammer 1993). Furthermore, this method only accounts for the power applied to the barbell and does not consider the acceleration of the individual center of mass during various weightlifting exercises and other ballistic exercises (Soriano et al., 2020).

Since force plates are typically expensive and limited to laboratory settings, linear position transducer technology has become an increasingly popular tool in strength & conditioning practice for power assessment because of its affordability and ease of use (Banyard et al., 2017). Practitioners find value using real-time feedback they provide to motivate athletes to train with greater intent and generate load-velocity profiles for specific exercises (Weakley et al., 2013). More recently, researchers and practitioners have taken interest in using these devices to normalize intensity based on velocities of major strength exercises and create respective load-velocity profiles (Guerriero et al., 2018).

The TENDO Weightlifting Analyzer (TWA; Tendo Sport Machines, Trencin, Slovak Republic) is a commonly used device in applied settings. While most linear position transducers use a linear encoder that encodes position, the TWA uses a rotary encoder that consists of two components to measure displacement and time: a velocity sensor unit and a microcomputer. The velocity sensor unit is made up of a slotted disk with an optical sensor and a light source. A cord is wrapped around a slotted disk, and the loose end of this cord is used to attach to a barbell. When the load is moved, the cord unravels and causes the slotted disk to spin. Light shines through the slots of the spinning disk and is read by the optical sensor. The rate of pulsation corresponds to a given displacement, and the sensor relays the information to an onboard microcomputer that determines the rate at which the cord is being displaced (Willardson 2010). From this data, average and peak velocity is calculated. The mass of the load is inputted into the TWA device so that the microcomputer can calculate force using gravitational acceleration ($9.81 m/s^2$). The TWA device provides real-time feedback of peak power, peak velocity, average power, and average velocity. Another product of the same company known as FitroDyne uses a different microcomputer software and only displays average power and average velocity (Pustina et al., 2011).

A common limitation of linear position transducers is their high price (~$2,000 US dollars for a TWA). Recently, more affordable options have appeared on the market; for instance, the new device named “Speed4Lift” (Speed4Lift; Madrid, Spain) is currently available with a considerably lower price (~$340 US dollars). The Speed4Lift utilizes a linear encoder to obtain displacement data to determine velocity, acceleration, and power. While this device has not been studied to the extent of the TENDO Weightlifting Analyzer, a recent study by Castilla et al., (2019) explored the reliability and concurrent validity of the Speed4Lift and six other commercially available velocity-measuring devices. The optical motion sensing system (V120: Trio, OptiTrack; NaturalPoint, Inc., USA) was considered the gold standard of mean concentric velocity measurement in this study. The following commercially available devices were also used for velocity measurement: 1) the T-Force Dynamic Measurement System linear velocity transducer (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain); 2) Chronojump linear position transducer (Chronojump Boscosystem, Barcelona, Spain); 3) a camera-based optoelectronic system (Velowin, DeporTeC); 4) the smartphone application Powerlift (v.6.0.1); 5) PUSH Band wearable inertial measurement unit (IMU) (PUSH band, PUSH, Inc., Toronto, Canada); and 6) Beast Sensor wearable IMU (Beast sensor, Beast Technologies Srl., Brescia, Italy).

Fourteen physically active men (age: 22.9 ± 1.6 years; height: 1.76 ± 0.06 m; body mass: 76.9 ± 7.8 kg; concentric-only Smith machine bench press 1RM: 86.1 ± 11.9 kg) underwent a 1RM testing session and a second session that consisted of performing 3 repetitions against 5 different loads (45, 55, 65, 75, and 85% of 1RM) in the concentric-only bench press performed in a Smith machine. Fifteen seconds of inter-repetition rest was given, with inter-set rest fixed to 4 minutes. All devices were ranked from the most to the least reliable as follows: 1) Speed4Lift (coefficient of variation [CV] = 2.61%); 2) Velowin (CV = 3.99%), PowerLift (3.97%), Trio-OptiTrack (CV = 4.04%), T-Force (CV = 4.35%), and Chronojump (CV = 4.53%); 3) PUSH band (CV = 9.34%); and 4) Beast sensor (CV = 35.0%). Additionally, there was a practically perfect association observed between the Trio-OptiTrack system and the different devices (Pearson's product-moment correlation coefficient (r) range = 0.947–0.995; $p < 0.001$) with the only exception of the Beast sensor ($r = 0.765$; $p < 0.001$). Taken together, the results of this study suggest that the Speed4Lift device can be an appropriate device to measure concentric velocities; however, further studies are warranted to determine if these results can be replicated in commonly used free-weight, lower-body strength exercises such as the back squat and deadlift.

Chapter 3: The Effects of Different Set Configurations on Concentric Velocities in the Back Squat

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Original Investigation

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Abstract

Purpose: The purpose of this study was to determine if mean concentric velocities (MCV) of lighter loads in the barbell back squat could be augmented if they are performed after heavier working-sets. Methods: Twelve trained males with experience in the back squat volunteered to perform a 5RM and completed two separate squat sessions consisting of three sets of five repetitions with 85% of their 5RM. One condition involved performing a "Down Set" that was equivalent to 60% of the working-set load that was also performed during the warm-up. A "No Down Set" condition (NDS) involved performing an additional warm-up set with 60% of the working-set load instead of the Down Set to determine if velocity was augmented due to postactivation potentiation in the Down Set (DS) condition. In both conditions, three minutes of rest were applied between all sets. Results: No significant difference was observed in the working-set MCVs in both conditions. Additionally, no significant differences were observed amongst MCVs in the Down Set and equivalent warm-up set loads ($p = 0.303$). Conclusions: The results of this study did not show an improvement in velocity when a Down Set was performed after heavy working-sets.

Introduction

High levels of muscular strength and power are crucial physical characteristics impacting sport success (Baker & Nance 1999; Cormie, McGuigan, & Newton 2010a; Silva et al., 2015; Stone et al., 2003b; Zamparo et al., 2002). It is well established in the literature that heavy resistance training is required to induce the physiological and neural adaptations that translate into augmented force-generation capabilities (Campos et al., 2002; Häkkinen 1989; Kraemer & Ratamess 2004; Sale 2003). Since power is the product of force and velocity, strength-oriented training is an essential foundational element for long-term power development; in order to maximize overall power development, it is crucial to develop the ability to express high forces with greater muscle contraction velocities (Haff & Nimphius 2012). Training approaches that only target strength or power development could limit sport performance capacity since athletes in sports such as rugby and American football require the ability to produce high power outputs under a variety of loaded conditions (Baker 2001a; Baker 2001c; Cormie et al., 2007b; Turner et al., 2020a). Muscular power is typically developed by training across a broad spectrum of loads ranging from 30% to 70% of 1RM in strength exercises, using ballistic exercises and plyometrics, and training weightlifting derivatives (Cormie et al., 2007c; Cormie et al., 2011b; Haff & Nimphius 2012; Kirby et al., 2010; McBride et al., 2002).

Postactivation potentiation is an advanced training technique often used to simultaneously develop strength and power and refers to an acute performance enhancement that is influenced by muscular contractile history (Robins 2005; Sale 2002; Seitz & Haff 2015; Weber et al., 2008). A strength-power potentiation complex typically applies this concept by performing a high-force conditioning activity such as heavy sets of back squat and subsequently performing a high-velocity movement such as a jump after a rest period (Seitz and Haff 2015;

Stone et al., 2008). Careful manipulation of the volume and intensity of the conditioning exercise is necessary to maximize performance capacity and minimize fatigue so that an acute performance enhancement will manifest in the subsequent exercise (Stone et al., 2008). The results of meta-analysis by Seitz and Haff (2015) suggest that stronger individuals can greater potentiation effects (ES = 0.41) than weaker individuals (ES = 0.32) primarily due to greater resistance to fatigue. Additionally, they found that using loads above 85% of 1RM (ES = 0.41) and performing multiple sets of a conditioning activity (ES = 0.69) made be more favorable for inducing postactivation potentiation.

In a study by Baker (2003), sixteen rugby league players were divided equally into control and experimental groups, with both groups performing a pre- and post-test bench press throw of 50kg for five repetitions in a Smith machine with a rotary encoder attached (Plyometric Power System; Norsearch, Lismore, Australia). The experimental group performed a set of barbell bench press for six repetitions with 65% of their 1RM after the pre-test bench throw and rested for three minutes before performing a post-test bench throw. There was a 4.5% increase in the power output observed during the post-testing bench throw in the experimental group that was determined to be significant ($p \leq 0.05$). These results suggest that a single set of a conditioning activity may be of sufficient volume to induce a potentiation effect on a subsequent high velocity movement. Additionally, this suggests that this effect may be achieved by using a broad spectrum of intensities in the conditioning activity.

Manipulating the structure of the training set and sequence of loads is known to induce specific training adaptations that could favor the development of specific physiological characteristics (Campos et al., 2002; DeLorme 1945; McCaulley et al., 2009; Schoenfeld et al. 2014). Many commonly used programming methodologies contrast the use of heavy and light loads within a resistance training session are intended to exploit postactivation potentiation in order to simultaneously improve strength and power (Carter & Greenwood 2014; Cormier et al., 2020; Lim & Barley 2016). In many training scenarios, Down Sets are performed after heavy working-sets using 50-60% of the working-set load and are thought to provide a power-training stimulus during strength-oriented training blocks (Painter et al., 2012; Stone et al., 2003a; Stone et al., 2006; Suarez et al., 2019). Theoretically, Down Sets can achieve this purpose by providing additional work with loads that can maximize power outputs (Stone et al., 2006; DeWeese et al., 2015). Additionally, it has been postulated that the working-sets can induce a postactivation potentiation effect that allows the Down Sets to be moved with greater velocities (Bompa & Haff 2009).

While there have been no studies to verify the rationale that Down Sets can be potentiated to the authors' knowledge, some studies may provide insight into whether that effect occurs. Stone et al., (2008) tested the effects of manipulating the loading sequence on the potentiation capabilities of international-level USA weightlifting athletes. Four men and three women performed the following potentiation protocols using the dynamic mid-thigh pull: men performed a sequence of 60, 140, 180, 220, and 140 kg, and women at 60, 80, 100, 120, and 80 kg; each set was performed for two repetitions. The peak velocities (PV) of the second and fifth set were specifically analyzed to assess potentiation capabilities. A significant 5.3% ± 4.3% increase was observed for PV, possibly lending support for the rationale that a Down Set can be moved with greater velocities.

The findings of Stone et al., (2008) may not be replicated with the strength-based exercises which require more work to perform through a greater range-of-motion and are often performed various set-load configurations that may result in excessive fatigue. The dynamic mid-thigh pull is a concentric exercise with a limited range of motion, making the mid-thigh pull well-suited as a potentiation modality (DeWeese et al., 2013). The barbell back squat is an ideal exercise for lower body strength development because it is a free-weight, closed-kinetic chain exercise that recruits a large amount of muscle fibers, can be trained through a high range-of-motion, has a high degree of sport specificity, and can be overloaded with high loads; in many cases, it is used as a conditioning activity in strength-power potentiation complexes for these reasons (Aagard et al., 2002; Comfort et al., 2012; Robertson et al., 2008; Seitz and Haff 2015; Støren et al., 2008; Suchomel et al., 2018; Wisløff et al., 2004). Dynamic exercises with an eccentric component may possibly induce greater peripheral fatigue, which may not be optimal for potentiation purposes (Tillin and Bishop 2009). Furthermore, the velocity at which the eccentric phase is executed has been shown to affect the concentric velocity in the squat and bench press (Carzoli et al., 2019), which may be an important factor in modulating the expression of postactivation potentiation (Batista et al., 2011; Esformes et al., 2011).

Unpublished data from Carter et al., (2013) did not reflect any potentiation effect when weightlifting athletes performed a similar squat protocol used in training scenarios described in the literature. Eight (n=8; 2 females, 6 males; age 24.6 ± 5.6 years; squat 1RM/BW 1.91 ± 0.36 for the whole group) collegiate competitive weightlifters performed two different squat protocols on force plates and potentiometers attached to the barbell. One of the protocols involved performing three sets of single repetitions with normal dead-stop squats (NDS) using 85% of 1RM and three-minute rest periods. Warm-up (WUP55) and Down Sets (POST55) were performed for five repetitions with 55% of 1RM before and after the three sets, respectively; similar to Stone et al., (2008), these sets were specifically analyzed for postactivation potentiation outcomes. The insignificant percent changes in concentric peak power and peak velocity reflected an absence of a postactivation potentiation effect from this loading protocol. The subjects' squat 1RM to bodyweight ratio of 1.91 ± 0.36 indicated that they are more likely to express potentiation within the rest period that was applied between sets. The design of this protocol was also in line with the results from Seitz and Haff (2015) showing that using loads at or above 85% 1RM (ES = 0.41) and performing multiple sets of a conditioning activity (ES = 0.69) may be more favorable for inducing potentiation. If potentiation was not observed in this protocol, set-repetition schemes coupled with Down Sets using higher volumes at high intensities (3x5, 3x3, 4x2, & 3x2) may also result in no potentiation since the additional fatigue from performing greater volumes may mask the ability to express potentiation (Carroll et al., 2018; DeWeese et al., 2015b; Hornsby et al., 2017; Painter et al., 2012; Stone, Pierce, Sands, & Stone 2006; Suarez et al., 2019; Taber et al., 2018).

Therefore, the purpose of this study is to determine if manipulating the loading of successive sets in the barbell back squat can result in a postactivation potentiation effect that augments concentric velocities in the Down Set. It is hypothesized that there will be no increase in mean concentric velocity in the Down Sets due to accumulated fatigue from working-sets.

Methods

Experimental Approach to the Problem

The barbell back squat was chosen for this study due to its ubiquity in strength and conditioning programs and its biomechanical and neuromuscular specificity to a variety of sporting skills. All subjects attended a familiarization session before performing a maximal strength assessment and two experimental testing sessions. During the familiarization session, subjects were thoroughly informed of the study procedures and were subsequently tested for their five-repetition maximum (5RM) in the back squat to determine experimental loads. Depending on each subject's schedule, at least 48-72 hours separated the five-repetition maximum testing and the experimental conditions. To account for daily biorhythms, all conditions were tested at approximately the same time of the day. The order of conditions conducted was allocated in a randomized, counterbalanced design. A within-subject design was used to determine the effect of load sequencing on mean concentric velocities. All participants were encouraged to maintain their dietary, sleeping, and drinking habits. Although they were instructed to refrain from any training at least 24 hours before testing, all subjects were permitted to continue their routine training outside of their individual testing sessions.

Subjects

Twelve trained male subjects (n=12; Age = 25.6 ± 5.9; Height = 177.8 ± 7.5 cm; Body Mass = 91.2 ± 17.8 kg; 5RM = 130 ± 32.6 kg; Estimated Back Squat to Body Mass Ratio = 1.61 ± 0.25) with a back squat-to-body mass ratio of at least 1.5x bodyweight were recruited for this study. All subjects were required to, 1) have at least two years of resistance training experience with the back squat; 2) be able to squat at least 1.5 times their body weight; and 3) have no major injuries within the previous three months. After explaining the risks and benefits of the study, all subjects signed an informed consent document prior to participation in accordance with the University's Institutional Review Board.

Procedures

Five Repetition Maximum Testing All testing took place in the Exercise and Sport Science Laboratory on the campus of East Tennessee State University in accordance with East Tennessee State Institutional Review Board guidelines. Participants were instructed to cease training for at least a 24 hrs. before testing. Prior to all sessions, participants performed a dynamic warm-up that included, 25 jumping jacks, 10 leg swings each leg, 10 reverse lunges with overhead reaches each leg, 10 lateral lunges each leg, 20 step-back with trunk rotations, 10 squat to toe-touches and 10 bodyweight squats. Subjects then began performing a 5RM protocol modified from Comfort and McMahon (2019). The warm-up sets followed the loading scheme described in Table 1. The first recorded trial was done at their reported 5RM and jumps were made by 2.5-5% until a maximum was reached. Full depth was defined as the subject's hip crease being below the knees and was verified by multiple Certified Strength and Conditioning Specialists. Since a one-repetition maximum (1RM) in the back squat was not tested, the participants' 5RMs were used to calculate estimated 1RMS using the Bryczki formula to verify that participants met the strength criteria.

Table 1: 5RM Warm-up Loading Scheme

Set 1	Ten repetitions with 20 kg barbell
Set 2	Five repetitions with 50% of the estimated 5RM
Set 3	Five repetitions with 60% of the estimated 5RM
Set 4	Five repetitions with 70% of the estimated 5RM
Set 5	Three repetitions with 80% of the estimated 5RM
Set 6	Three repetitions with 90% of the estimated 5RM
Set 7	5RM Attempt 1
Set 8	5RM Attempt 2
Set 9	5RM Attempt 3

Adapted from: Performance Assessment in Strength and Conditioning by Comfort, P., Jones, P.A., & McMahon, J.J., 2018, Oxon: Routledge.

Experimental Conditions.

All subjects completed the same standardized dynamic warm-up as performed during 5RM testing. Subjects completed the Down Set (DS) and No Down Set (NDS) conditions in random order separated by 48-72 hrs. Both conditions required subjects to complete 3 working-sets of 5 repetitions at 85% of their 5RM with 3 minutes of rest between sets; this rest period was consistent for warm-up sets and Down Sets. The configuration of the DS condition and use of 85% relative intensity in both conditions were designed to replicate the exact scheme used in training scenarios (Carroll et al. 2018; DeWeese et al. 2015b; Hornsby et al. 2017; Painter et al. 2012; Stone, Pierce, Sands, & Stone 2006; Suarez et al. 2019; & Taber et al. 2018). The DS and NDS configurations are described in Table 2 and Table 3, respectively. In the NDS condition, the Down Set was performed as an additional warm-up set (60% of working-set target) instead. Lastly, the subjects were instructed to perform the eccentric portion of the squat at a self-selected pace and to move the bar as fast as possible during the concentric phase.

Table 2: Down Set Condition

Set	Load
Warm-up set 1	Ten repetitions with 20 kg barbell
Warm-up set 2	Five repetitions at 40% of target for working-set
Warm-up set 3	Five repetitions at 60% of target for working-set
Working-set 1	Five repetitions at 85% of 5RM
Working-set 2	Five repetitions at 85% of 5RM
Working-set 3	Five repetitions at 85% of 5RM
Down Set*	Five repetitions at 60% of target for working-set

* Signifies different set placement compared to Traditional Set condition

Table 3: No Down Set Condition

Set	Load
Warm-up set 1	Ten repetitions with 20 kg barbell
Warm-up set 2	Five repetitions at 40% of target for working-set
Warm-up set 3	Five repetitions at 60% of target for working-set
Warm-up set 4*	Five repetitions at 60% of target for working-set
Working-set 1	Five repetitions at 85% of 5RM
Working-set 2	Five repetitions at 85% of 5RM
Working-set 3	Five repetitions at 85% of 5RM

*Signifies different set placement compared to Down Set condition

Velocity Measurement.

A Speed4Lift (Speed4Lift; Madrid, Spain) linear position transducer (LPT) was attached to each side of the barbell to collect acceleration derived metrics via integration with a tablet Apple iPad Air; iOS 11.4.1; Apple, Cupertino, CA, USA) and smartphone (Apple iPhone XR; iOS 13.3.1; Apple, Cupertino, CA, USA). Four total sets from both experimental conditions were analyzed; in the DS Condition, the warm-up set of 60% of the working-set (DWU60) and the Down Set of the same load (DS60) were used. In the NDS Condition, both warm-up sets with 60% of the working-set (WU60 and 2WU60) were analyzed. To determine mean concentric velocities (MCVs), the MCV of all five repetitions from a set was first calculated from the left and right LPT data sets. Then, the left and right LPT MCVs for these sets were averaged together for the statistical analysis. For the working-sets, the MCV of each working-set was determined, and then the three MCVs were averaged into one MCV representing all working-sets. The coefficient of variation of velocity measurements between the right and left linear position encoders was 3.19%.

Statistical Analysis

All data was collected and stored in the Speed4Lift iOS application software and then exported as a CSV file. Data was analyzed using the statistical software JASP (JASP Version 0.11.0.0) and expressed as means and standard deviations. A paired sample t-test was used to compare the MCVs of the working-sets of both conditions and normality was assessed using the Shapiro-Wilk test. A repeated-measures ANOVA was used to assess differences in MCV between DWU60, DS60, WU60, and 2WU60. Sphericity was assessed via Maulchy's test of sphericity ($p \leq 0.05$) and a Greenhouse-Gesser adjustment was used if the assumption of sphericity was violated. Cohen's d effect sizes were reported for all comparisons and were classified as trivial (< 0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99) and very-large (≥ 2.0). (Hopkins 2002). The critical alpha was set at $p \leq 0.05$.

Results

There was no statistical difference ($t(11) = 0.852$, $p = 0.412$, Cohen's $d = 0.246$) for working-set MCVs between the DS condition (0.621 ± 0.116 m/s) and the NDS condition (0.636 ± 0.129 m/s). Additionally, there was no significant difference for MVCs between DWU60, DS60, 1WU60, and 2WU60 ($F(1.712, 18.836) = 1.251$; $p = 0.303$). Effect sizes for comparisons between DWU60, DS60, 1WU60, and 2WU60 are found in Table 4. Tables 5 and 6 display MVCs for DWU60, DS60, 1WU60, 2WU60, and all working-sets from the DS condition and NDS condition, respectively.

Table 4: Effect Sizes for Comparisons Between DWU60, DS60, 1WU60, and 2WU60

Comparison		Cohen's d
DWU60 (0.944 ± 0.175)	DS60 (0.942 ± 0.175)	0.031
	1WU60 (0.976 ± 0.167)	0.407
	2WU60 (0.971 ± 0.151)	0.347
DS60 (0.942 ± 0.175)	1WU60 (0.976 ± 0.167)	0.438
	2WU60 (0.971 ± 0.151)	0.378
1WU60 (0.976 ± 0.167)	2WU60 (0.971 ± 0.151)	0.060

Table 5: Down Set Condition

Set Number	Load (% of Working-Set)	Repetitions	MCV ± SD
1	20 kg Bar	10	Not measured
2	40%	5	Not measured
3	60% (DWU60)	5	0.944 ± 0.175
4	100%	5	0.63 ± 0.119
5	100%	5	0.612 ± 0.121
6	100%	5	0.647 ± 0.14
7	60% (DS60)	5	0.942 ± 0.175

Table 6: No Down Set Condition

Set Number	Load (% of Working-Set)	Repetitions	MCV ± SD
1	20 kg Bar	10	Not measured
2	40%	5	Not measured
3	60% (WU60)	5	0.976 ± 0.167
4	60% (2WU60)	5	0.971 ± 0.151
5	100%	5	0.64 ± 0.129
6	100%	5	0.621 ± 0.143
7	100%	5	0.622 ± 0.104

Discussion

This study is the first study to the authors' knowledge that has specifically investigated whether a Down Set can be performed with greater movement velocities due to postactivation potentiation from the heavier working-sets. It has been suggested by Stone et al. (2008) and Haff & Bompa (2009) that the Down Sets are potentiated by target working-sets and thus can be moved with greater concentric velocities. Stone et al. (2008) observed this potentiation effect through manipulating the load sequencing in the mid-thigh pull. In many training programs and studies performed to determine the physiological and performance outcomes of training interventions, Down Sets have also been included in many strength exercises such as barbell back squats, barbell press variations, and weightlifting derivatives. Given that such exercises vary in their kinetic and kinematic profiles, this study was done to determine if the Down Set loading pattern could produce the intended potentiation effect in the barbell back squat.

The results of this study support the hypothesis that accumulation of fatigue from performing working-sets before the Down Sets would mask the expression of postactivation potentiation. Concentric velocities in the Down Set were similar, if not slightly reduced. Additionally, the repeated measures ANOVA did not find a significant difference in velocities between the DS condition and the NDS Condition when the Down Set load was performed as a third warm-up set.

The fitness-fatigue paradigm has been established as a theoretical foundation for postactivation potentiation. In any protocol intended to utilize postactivation potentiation, the conditioning acticity conceptually increases an athlete's level of "fitness" through stimulation of specific underlying neuromuscular mechanisms (Stone et al. 2008). Once the conditioning activity has been performed, fitness and fatigue are simultaneously increased; the rate at which fatigue decays is a critical component determining whether potentiation manifests or not. This difference between fitness and fatigue is known as "preparedness" and is theoretically elevated when in a potentiated state. The data suggests that the set-repetition scheme used for the barbell back squat did not allow fatigue to fatigue to decay enough, resulting in no potentiation manifesting. While this scheme has been previously used in training programs and studies, other repetition schemes using fewer sets and repetitions per set along with higher intensities (3x3, 4x2, 3x2, etc.) have been coupled with Down Sets and may be better suited for potentiation purposes since the volume of conditioning activity is lower (Stone et al. 2006; Suarez et al. 2019). The inherently greater range-of-motion along with eccentric and concentric portions in the barbell back squat may have contributed to the accumulation of peripheral fatigue over the course of three sets of five repetitions. In contrast, the dynamic mid-thigh pull Stone et al. tested is moved with a limited range of motion and only consists of a concentric portion (DeWeese et al. 2013). Since only the back squat was used for this study, there remains a possibility that potentiation within a training set can be utilized with different exercises that are similar in nature.

However, while other set-repetition configurations have been paired with Down Sets, the unpublished data from Carter et al.'s dissertation indicates that it is unlikely postactivation potentiation manifests during inter-set conditions. One of the protocols used three sets of single repetitions with 85% of a determined 1RM in the normal, dead-stop squat. The volume and intensity in this protocol is in line with the protocols found to induce potentiation by Seitz and Haff (2015) and likely does not induce significant fatigue, considering that the subjects' average back squat 1RM to body mass ratio was 1.91 ± 0.36. Since no postactivation potentiation was observed in this protocol, it is unlikely that the other set-repetition configurations coupled with Down Sets would greatly differ since more repetitions are performed with similar intensities.

One potential limitation to this study is that the participants were allowed to continue their routine training in addition to the testing procedures. While the procedures were clearly outlined and all participants were instructed to temporarily cease training 1-2 days prior, their training was not monitored beyond specific questions asked about their recent training. However, many participants had many years of experience training for weightlifting or for general strength development and had a general understanding of resistance training principles. When asked about their training before each session, most participants kept their training as minimal as possible so that the effect of training-induced fatigue on the testing outcomes was minimized.

Additionally, since there was no standardized period of training cessation prior to participation, participants were within varying stages of fitness upon participation. It has been established that previous training resulting in increased maximum strength may augment power development when power-specific training is emphasized (Baker 1996; Behm et al. 2017; Harris et al. 2000; James et al. 2018; and Stone et al. 2003a). As reported by their coach, several of the weightlifters who participated had recently completed a strength-endurance block and were in the initial phases of a maximal strength block. Suarez et al. (2019) found slight depressions in the rate of force development measured from isometric mid-thigh pulls after a high-volume, strength-endurance phase. Rate of force development rebounded above previous values as the training emphasis shifted from maximal strength to strength-power over the course of several weeks (Suarez et al. 2019). Other subjects were in the midst of general strength training programs to increase back squat, bench press, and deadlift strength and were likely training at lower volumes than the weightlifters prior to participation, resulting in less accumulated fatigue that may have influenced their performance capacity. Future studies investigating the kinematic and kinetic characteristics of programming strategies could implement a standardized period of general strength-training before splitting participants into experimental conditions to obviate this limitation.

Another important factor to note is that the average back squat to body mass ratio (1.61 ± 0.25) of the participants was measured through estimated one-repetition maximums based on the Bryczki formula. For the purposes of assigning working-set loads for sets of five repetitions, a 5RM was assessed since strength is specific to repetition ranges trained. The average back squat to body mass ratio would most likely be higher if a true one-repetition maximum were to be tested, providing a better indication of strength levels and thus potentiation capabilities. As shown by Seitz et al. (2014a), an athletes' strength levels greatly influence rest durations required to express potentiation. Given that the working-set MCVs in both conditions did not differ greatly, it is likely that a longer rest duration may have been needed in order for the Down Set to be moved with greater velocities.

It would have been preferable to include a third warm-up set at 80% of the working-set load with at least 2-3 repetitions in both conditions to ensure that all subjects were adequately prepared and warmed-up for their working-sets. While both participants performed the same exact sets, repetitions, and loads in both conditions, the additional warm-up set in the NDS condition may have positively influenced working-set performance, which was most likely a product of simply performing more total warm-up repetitions prior to working-sets. Bodyweight, strength training experience, and maximal muscular strength levels varied from subject to subject. The stronger, more experienced subjects would most likely benefit the most from an additional warm-up set since they inherently warm-up with more loads for their working-sets in their own training.

Practical Applications

The volume and intensity of back squats used in this study may not be appropriate to positively influence the velocity of a subsequent Down Set. Sequencing lighter loads after heavier loads within a training session may still be efficacious for developing power across a broad spectrum of loads, but the results of this study suggest that those loads will not be moved with greater velocities. Moreover, performing more Down Sets of the same loads may even result in depression of velocities since the Down Set MCV was slightly lower than the equivalent load performed in the warm-up period. Based on the data from the No Down Set condition, it may actually be preferable to use the warm-up period to perform the lighter loads, as MCVs were slightly, although not significantly, higher for the loads at 60% of the working set. Performing the loads in this sequence did not seem to negatively affect performance of the working sets.

The literature strongly suggests that power development can be optimized by sequencing a block of training to develop maximal-strength prior to a block centered on developing power and maximal-velocity (Baker 1996; Harris et al. 2000; Stone et al. 2003a; James et al. 2018; Behm et al., 2017). However, most strength and conditioning coaches working with team sports have limited time available for strength training due to multiple matches per week and the increase in tactical and technical training sessions (Rønnestad et al. 2011). Thus, it is crucial to implement appropriate training approaches to train multiple fitness qualities, and perhaps more importantly improve and/or maintain as much strength and power as possible during the competitive season (Gamble 2006). It has been determined that average training intensity should be maintained above 80% of 1RM in order to maintain strength capacity over the course of a competitive season for most team sports (Brito et al. 2014; Hermassi et al. 2019; Hoffman &

Kang 2003; Veliz et al. 2014). To further increase the transfer-of-training effect, training should also incorporate sport-specific power-based movements to develop power and movement skills (Silva et al. 2015).

Performing Down Sets using strength-oriented exercises such as the back squat and deadlift to develop lower body power in such a scenario may not be an optimal approach to simultaneously develop strength and power since Down Sets have been only been programmed as a single set following three to four strength exercises in a training session (Carroll et al. 2018; DeWeese et al. 2015b; Hornsby et al. 2017; Painter et al. 2012; Stone, Pierce, Sands, & Stone 2006; Taber et al. 2018). Power outputs in these exercises are inherently limited due to the deceleration of the barbell during a substantial portion of the concentric phase (Cronin et al. 2002; Elliott et al. 1989; Wilson et al. 1989). In contrast, complete acceleration is produced through a full range-of-motion in ballistic exercises and weightlifting derivatives, producing significantly higher average velocity, peak velocity, average force, average power and peak power (Canavan, Garrett, & Armstrong 1996; Carlock et al. 2004; Hori et. al 2005; Newton et al. 1996; Turner et al. 2020b). Incorporating these exercises in a strength and conditioning program as a power-development stimulus in lieu of lighter loads of strength exercises may produce superior adaptations over a longitudinal period. Recently, Suchomel et al. (2020) found that targeting force- and velocity-specific overload stimuli with weightlifting pulling derivatives may produce superior outcomes in relative strength, sprint speed, and change of direction compared to submaximally-loaded weightlifting catching and pulling derivatives.

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Chapter 4: Summary and Future Investigations

The purpose of this study was to determine if concentric velocities of lighter loads of back squat 1RM could be augmented if they performed after heavier working sets. As an experimental approach to this problem, twelve trained males with a self-reported back squat 1RM of at least 1.5 times their bodyweight volunteered to perform a 5RM and two separate squat training session conditions consisting of three sets of five repetitions with 85% of their 5RM. The DS condition involved performing a "Down Set" after their working sets that was 60% of the working set load, while a NDS condition involved performing this Down Set as an additional warm-up set to determine if mean concentric velocity was significantly different in the DS condition. Velocity was measured using a linear position transducer attached to each side of the barbell. No significant difference was observed in the working set MCVs in both conditions and amongst MCVs in the Down Set and all the loads using 60% of the working set used in the repeated-measures ANOVA. While no postactivation potentiation effect positively influenced performance of the Down Set, performing multiple Down Sets after working sets can still be an efficacious option to train across a broad power-load spectrum.

Programming methodologies intended to simultaneously develop strength and power by contrasting heavy and light loads within a resistance training session commonly rationalize that postactivation potentiation may allow the lighter loads to be moved with greater velocities (Carter & Greenwood 2014; Cormier et al. 2020; Lim & Barley 2016). Practitioners typically aim to induce potentiation by prescribing a high-force or high-power movement to augment the performance of a subsequent high power or high velocity movement in a training session (Seitz and Haff 2015 & Stone et al. 2008). Theoretically, postactivation potentiation could result in an augmentation in power output of the subsequent exercise due to phosphorylation of the myosin light chains and an increase neuromuscular activation (Gullich & Schmidtbleicher 1996; Hodgson et al. 2005; Robins 2005; Sale 2002; Seitz & Haff 2015; Tillin & Bishop 2009; Vandenboom, Grange, & Houston 1995 & Weber et al. 2008). In many cases, the conditioning activity is a heavy-strength oriented exercise such as the barbell back squat (Chiu et al. 2013; Jo et al. 2010; Young et al. 1998). Stronger individuals are likely able to harness postactivation potentiation to a greater extent than weaker individuals (Seitz & Haff 2015). Seitz et al. (2014a) found that athletes with a back squat 1RM greater than twice their bodyweight expressed a postactivation potentiation effect as early as 3-minutes after a conditioning activity, whereas that effect was delayed in weaker individuals with a back squat 1RM less than twice their bodyweight.

Down Sets have been programmed as a single reduced-load set of five repetitions performed after a series of working sets with 50-60% of the working-set load (Carroll et al. 2018; DeWeese et al. 2015b; Hornsby et al. 2017; Painter et al. 2012; Stone, Pierce, Sands, & Stone 2006; Taber et al. 2018). They have been used to provide additional work at loads that maximize power outputs with the potential benefit of performing them with greater velocities due to possible postactivation potentiation from the heavier working sets (Bompa & Haff 2009 and Stone, Pierce, Sands, & Stone 2006). In the training programs they're used in, Down Sets were introduced during the strength- and power-oriented blocks and were paired with strength-oriented exercises such as: back squats, push press, push jerk, incline bench press, and mid-thigh pulls (Carroll et al. 2018; Hornsby et al. 2017; Painter et al. 2012; Suarez et al. 2019; Stone et al. 2003a; Stone et al. 2006; & Taber et al. 2018). While no studies have investigated the proposed benefits of Down Sets for power development, unpublished data from Carter et al. (2013)

showed no significant differences in peak power and peak velocity when a Down Set was compared to an equivalent warm-up set.

The results of this study are in agreement with the findings Carter et al. (2013); no significant changes in velocity were observed in the Down Set, nor when the Down Set was performed as an additional warm-up set in a second condition. Additionally, the additional warm-up set did not seem to negatively affect the velocities of the working-sets. Since no significant changes in velocities were observed in both conditions, lighter loads can still be used within a training session to train across a power-load spectrum that heavy-loading alone cannot achieve.

While this thesis provided answers to some questions, it also raised more questions for future research. Down Sets have only been programmed as a single set of five repetitions, which is minimal volume and likely results in a negligible stimulus for power development. Future investigations could use similar protocols as this study to examine the changes in velocity over the course of a training session when performing multiple Down Sets or submaximal warm-up sets in conjunction with heavy working sets. Wave-loading is another commonly used protocol that contrasts heavy and light loads between sets and has not been studied before. An example of a wave-loading protocol would be performing the first working set of a barbell snatch with 80% of an athlete's 1RM and performing that for three repetitions. In the subsequent sets, loads at 85%, 75%, 80%, and 85% are performed for two, three, three, and two repetitions, respectively. Since loads and reps are inversely undulated on a set-per-set basis, there is a possibility for inter-set potentiation since the heaviest loads are not performed at once as in the Down Set protocol. This could potentially result in less fatigue from performing more total work that would otherwise mitigate a potentiation response. As with much of the postactivation potentiation literature, this study was acute in nature, and long-term training studies are needed to determine if these programming strategies can result in any longitudinal changes in strength-power characteristics.

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