THE EFFECTS OF INTER-REPETITION REST ON ACUTE SNATCH PULL PERFORMANCE

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Rick Bond Davis

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by

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Department of Kinesiology

Abstract

of

THE EFFECTS OF INTER-REPETITION REST ON ACUTE SNATCH PULL PERFORMANCE

by

Rick Bond Davis

Introduction

Decrements in performance with resistance training and performance variables such as power, force, and velocity has been noted in a variety of exercises. Implementation of Inter-Repetition Rest (IRR) treatments has been shown to negate the effects of neuromuscular fatigue and performance decrements.

Purpose

To investigate the effects of Inter-Repetition Rest on the snatch pull exercise in regard to performance variables of power, force, and velocity.

Methods

Nine recreationally resistance trained men (Age: 28.125 ± 3.99 years, Height: 181.92 ± 4.88 CM, Weight: 87.155 ± 8.99 KG, One Repetition Snatch Maximum/BW: 1.17 ± .100) volunteered for this study. This study used a randomized single blind experimental design, and subjects were randomly assigned to treatment order. Treatments included (P0), (P10), and (P20), representing seconds of IRR per treatment. Each subject completed one session of each randomly assigned treatment, with three sets of five repetitions in the snatch pull exercise. Velocity and force were measured using the VICON Real-Time Motion Analysis and AMTI Force plate, respectively. Power output was calculated from force and velocity measures. A One Way Repeated ANOVA was utilized on mean peak values for power, force, and velocity to determine the within-subject treatment effects with repetitions and sets. A One Way Repeated ANOVA was utilized on peak mean values between treatment groups of IRR. Main effect differences were then further analyzed at 95% Confidence Intervals. An Alpha level of 0.05 was used to determine significance.

Results

Overall mean peak values between treatment groups showed statistical significance between all groups (P0), (P10), and (P20), for power, force, and velocity measures (P<.05). Mean peak force values between protocols were 1892 ± 140.87 N, 1824 ± 175.53 N, 1744 ± 262.68 N for P20, P10, and P0 respectively. Mean peak velocity values between protocols were 1.69 ± .15 m/s, 1.63 ± .14 m/s, 1.59 ± .14 m/s for P20, P10, and P0 respectively. Mean peak power values between protocols were 2821 ± 347 W, 2638 ± 435.77 W, 2497 ± 486.37 W for P20, P10, and P0 respectively. Decrements in performance percentage between treatments and force values were taken as a percentage of P20 being 100%. P10 and P0 were lower than P20 treatment by 3.9%, and 8.11%, respectively. P10 and P0 were lower than P20 treatment by 3.5%, and 5.92%, respectively. P10 and P0 were lower than P20 treatment by 6.48%, and 11.48%, respectively.

Conclusion

IRR treatment of P10 and P20 elicited overall higher mean peak values in comparison to P0. IRR treatment of P20 was significantly higher than all other treatments. Based on this study, implementation of IRR can help to maintain performance variables often that are affected by neuromuscular fatigue seen with continuous repetitions.

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Date

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Chapter 1

INTRODUCTION

Utilizing velocity based training for athletes has become more relevant in the strength and conditioning field. Velocity decrements has been shown to occur in conjunction with neuromuscular fatigue (Enoka, & Duchateau, 2008). In comparison to traditional strength exercise, velocity or ballistic exercises are characteristic of high velocity, higher forces, and power outputs. The ability to generate high levels of velocity, power, and force is crucial in almost any sport. Practitioners in the strength and conditioning field continue to seek out the most efficient strength-power exercises to elicit superior adaptations of force and power outputs.

The importance of muscular power can be seen across a wide variety of sport including weight lifting, strength training, and athletics in general (Cormie, Mcguigan, & Newton, 2010; Cormie, Mcguigan, & Newton, 2011; Hardee, Lawrence, Utter, Triplett, Zwetsloot, & Mcbride, 2012; Oliver, Kreutzer, Jenke, Phillips, Mitchell, & Jones, 2016). Work done by athletes in a short explosive duration is characterized by both kinetic and potential energy of the total system. Power output, which is basically work done per unit of time, has been utilized for performance measurement for decades. Power output (PO) can be described as the relationship between maximal force and velocity where *POWER= FORCE X VELOCITY* (Cormie et al., 2010; Cormie et al., 2011). Since the ability to generate maximal muscular power is crucial in sport, training methods increasing and maintaining PO have begun to give rise to new research design and literature. Maximal power has been shown to occur at different intensities based on exercise selection and sport (Bevan et al., 2010; Cormie et al., 2010; Cormie et al., 2011). Specifically, regarding Olympic weightlifting, external loads around 80-100% of 1-Repetition maximum (1RM) have been shown to induce maximal PO (Bevan et al., 2010; Ho et al., 2014).

Optimal PO is determined by maximizing force-velocity relationship to induce a maximal stimulus for adaptation. Since force and velocity are present on opposite sides of the force-velocity curve, the point at which optimal PO occurs is somewhere in between high forces and high velocity parameters. Applying this, maximal power represents the maximal instantaneous power during a single movement performed when the end goal is producing maximal velocity at take-off, release, or impact (Cormie et al., 2011; Hardee et al., 2012). Furthermore, neurological adaptations from appropriate training stimulus has been shown to contribute to maximal power production (Bevan et al., 2010; Cormie et al., 2010; Cormie et al., 2011). Neurological adaptation increasing PO is heavily determined by the stimulus placed upon the body. Since maximal PO depends on both force and velocity components, ballistic exercises involving high force and high velocities are the most appropriate stimuli for neurological and physiological adaptations (Bevan et al., 2010; Cormie et al., 2010; Cormie et al., 2011). Past literature furthermore supports an athlete's ability to generate maximal power to help improve athletic performance (Ho et al., 2014). In theory, being able to optimize power output while engaging in appropriate training stimulus should maximize one's ability in athletic bouts (Cormie et al., 2010).

Olympic weightlifting requires strength, technique, skill, and power synergistically to complete successful lifts (Ho et al., 2011; Ho et al., 2014). Olympic weightlifting consists of two lifts the snatch, and clean & jerk. The snatch and clean & jerk both can be described by pulling the bar from the floor position successfully followed by triple extension of the ankle, knee, and hip joints with a “violent” shrug to facilitate barbell displacement and velocity (Ho et al., 2014). The snatch can be described into 5 different positions: first pull, transition phase, second pull, turnover, and recovery. Biomechanical analysis has shown the importance and direct relationship between force and velocity during these phases (Ho et al., 2011, Ho et al., 2014). Almost all mechanical work during the snatch is achieved as the center of mass of the barbell achieves slightly above waist height (Garhammer, 1993). The point of maximum velocity during Olympic movements occur when the body is fully extended (ankle, knee, hip), thus inversely at this moment in time concentric muscle force would be near minimum. Therefore, maximum power output is reached at a time overlap between the first and second pull of the snatch but before the barbell is caught and received over head. Strength exercises are implemented into Olympic weightlifting training often including snatch and clean pulls, which reap majority of the stimulus from mechanical work and power without the risk of injury in the catch. The snatch pull exercise is ballistic involving only the concentric actions of the lower extremities (Garhammer, 1993). By removing the catch phase of the snatch athletes reduce eccentric muscle actions, which allows the movement to be performed at maximal speeds without the neurological muscular recruitment to decelerate the load (Ho et al., 2011, Ho et al., 2014).

The Olympic derivative snatch pull also allows for the principle of neurological overload because it is generally performed at high intensity loads ranging from 80-120% of 1RM. Based on the SAID principle (specific adaptations to induced demands) training at exercises higher than 1RM will allow for increasing neurological adaptation to take place (Cormie et al., 2011; Suchomel, Wright, Kernozek, & Kline, 2014; Suchomel, Comfort, & Stone, 2015). However, increasing intensities or loads during barbell exercise has been shown to increase fatigue and be detrimental on technique, power output, and rate of perceived effort (Hardee et al., 2012; Hardee et al 2013; Oliver et al., 2016; Valverde-Esteve et al., 2013). In combination with increasing intensity of lifts, consecutive repetitions and sets have also shown to influence performance (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Valverde-Esteve et al., 2013). Since Snatch pull implementation usually consists of multiple and consecutive repetitions and sets, it is important to consider all factors to reduce neuromuscular fatigue.

The maintenance of barbell kinematic values such as displacement and velocity during explosive movements has been shown to be indicative of fatigue reduction (Hardee et al., 2012; Hardee et al., 2013). Neuromuscular fatigue across a variety of exercises reduces muscular power output (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Haff et al 2003). Likewise, barbell measurements of power, force, and velocity have all been shown to reduce with increasing fatigue (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Haff et al 2003). Therefore, maintenance of fatigue will improve barbell mechanics ultimately optimizing performance stimuli inducing maximal adaptation (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Haff et al 2003).

Training methods maintaining performance and reducing fatigue have recently become more relevant. One training protocol implementing inter-repetition rest (IRR) has been shown attenuate fatigue, maintain power output, and maintain optimal barbell kinematics during multiple set and repetition exercise bouts (Hardee et al., 2012; Hardee et al., 2013). Inter-repetition rest consists of small resting intervals ranging from 10-40s between consecutive repetitions (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Haff et al 2003). Physiologically, the benefits of implementing short rest intervals is for partial re-phosphorylation of phosphocreatine stores (PCr) (Oliver et al., 2016; Haff et al., 2003). Creatine phosphate is a molecule utilized for high-energy demand in skeletal muscle and the brain (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Haff et al 2003) Partial rephosphorylation of PCr, which has been shown to occur around ~20 seconds, may elicit stronger voluntary contractions. IRR may improve performance in other aspects by maintaining adenosine tri-phosphate stores (ATP) and achieving less overall metabolic stress.

Inter-repetition rest, sometimes called cluster sets (CS), has been shown to benefit power and strength training alike (Oliver et al., 2016; Haff et al 2003). Haff et al. (2003) found that using a cluster set configuration led to higher barbell velocities at 90-120% in the clean pull versus traditional continuous repetitions. Hardee et al. (2012-2013) found when using IRR protocols, technique, power output, and rate of perceived effort were all preserved when compared to traditional sets in the power clean exercise. IRR also seems to elicit similar findings in strength exercises such as the bench press and the squat (Oliver et al., 2016; Valverde-Esteve et al., 2013). Valverde et al. (2013) found that IRR of 15 seconds maintained power output significantly in comparison to 0, 5 and 10 second IRR treatments. Oliver et al. (2016) study showed significant maintenance of power output and barbell velocity when comparing cluster set inter repetition with traditional continuous repetitions in the barbell squat exercise. Collectively, it appears that IRR has shown to be significantly beneficial for performance maintenance in barbell strength training exercises,

Purpose

The effects of inter-repetition rest on the snatch pull exercise is unknown. Although previous exercise literature involving IRR has been produced, none to this date focus on the snatch pull or snatch exercise. Since the snatch pull is one of the most technical exercise variations involving high barbell velocities, technique, power, and intensity with 1RM, the benefits of IRR could be significant. To date research is lacking between the relationship of IRR treatments and the snatch pull exercise with continuous repetitions and sets. Therefore, the purpose of this investigation was to analyze the effects of IRR on the biomechanical parameters of power, force, and velocity in the snatch pull exercise during a multiple set configuration.

Hypotheses

Hypothesis 1: Increasing IRR treatment quantity will have no effect on mean peak power

Hypothesis 2: Increasing IRR treatment quantity will have no effect on mean peak ground reaction force

Hypothesis 3: Increasing IRR treatment quantity will have no effect on mean peak barbell velocity

Limitations

- Dietary intake not controlled for
- Variability in day to day training
- Not all factors affecting performance controlled for (psychological & physiological)

Delimitations

- All subjects were males
- All subjects had 3 years of weight training experience
- All subjects had 1 year of weightlifting experience
- All subjects had a snatch 1RM of at least bodyweight
- All subjects were healthy and injury free
- All testing done at the same time of day
- All subjects were currently training on a weightlifting program

Assumptions

- All the subjects performed maximally
- All the subjects adhered to training, rest, and recovery protocols
- All subjects performed the best to their abilities

Definition of Terms

Power output: force multiplied by velocity of movement national strength conditioning association

Inter-Repetition Rest: rest between each repetition

“1RM” 1 Repetition maximum: The maximum amount of force that can be generated in one maximum contraction

Velocity - Rate of change of position, commonly referred to as “speed with a direction”

Fatigue - Reversible decline in muscle performance associated with muscle activity that is marked by a progressive reduction in force developed by a muscle

Force - “mass multiplied by acceleration” of movement. The ability to generate contractions against a load by actions of muscles.

Rate of force development - “change in force with time”

Traditional sets - “continuous repetitions with no rest”

Chapter 2

REVIEW OF LITERATURE

Past literature on Olympic weightlifting indicates that derivatives of pulls such as the snatch pull are a beneficial stimulus to improve performance (Storey, & Smith, 2012; Suchomel et al., 2014; Suchomel et al., 2015). The snatch pull derivative involves the four consecutive phases of the movement up to triple extension of the ankle, knee, and hip joints, and scapular elevation (shrug), while eliminating the catch phase of the snatch (Comfort, Allen, & Graham-Smith, 2011). Lower body power development is one of the most critical components for athletic performance in sports that require any type of triple extension at the hip, knee, and ankle joints. Triple extension is often used in a variety of sports that involve specific explosive movements as it pertains to sprinting, jumping, and change of direction (Cormie et al., 2010). Power output, force, and velocity production during movement are physiological markers for human performance in sport. Furthermore, a training stimulus with high force, and power production are optimal for neurological adaptation and sport performance (Cormie et al., 2010). Continuous repetitions, increasing quantity of sets, increasing load, and increasing fatigue have been shown to be detrimental on performance variables in traditional strength and power exercises. To combat the regression of power output, force, and velocity in barbell exercises, strength and conditioning practitioners have begun to implement Inter-Repetition Rest(IRR) protocols. IRR treatments have been shown to likely assist with acute performance variable regression.

Weightlifting Derivatives

Weightlifting derivatives such as the snatch pull have been implemented into strength and conditioning programs for decades (Comfort et al., 2011, Cormie et al 2010, Suchomel et al., 2014, Suchomel et al., 2015). Weightlifting derivatives can be explained by a variation or derivative of the main movement in relation to the snatch or clean. Derivatives allow for different training stimulus to occur which may elicit greater movement variation and physiological adaptation. Weightlifting pulling derivatives can vary from different starting positions, to partial movements in relation to full movements of the snatch and clean & jerk (Comfort et al., 2011; Suchomel et al., 2014; Suchomel et al., 2015). Examples of pulling derivatives include: snatch pulls, clean pulls, hang power cleans, hang power snatches, and hang snatch pulls.

While lower body triple extension occurs, the intrinsic properties and synergistic muscular, skeletal, and neurological systems coordinate movement that dictate power production in humans (Comfort et al., 2011; Cormie et al 2010; Suchomel et al., 2014, Suchomel et al., 2015). Although triple extension can be achieved from sprinting and jumping, loaded (weighted) triple extension may provide a greater stimulus for neurological feedback to improve rate of force production and power output (Cormie et al., 2011; Suchomel et al., 2015). Neurological feedback such as neuromuscular unit recruitment, increased rate coding, efficient muscular synchronization, and neural inhibition have been related to generating force production involved during ballistic exercise (Haff et al., 2001).

Weightlifting Application and Stimulus

Past literature has shown that weightlifting derivatives may influence a training stimulus that is as effective or more, in contrast to the complete weightlifting movements (Comfort et al., 2011; Suchomel et al., 2014). Weight Lifting pulling derivatives are often used for technique work, and building strength-power characteristics when maximally done (Suchomel et al., 2014; Suchomel et al., 2015). It has been noted that pulling derivatives may induce greater velocity, power, and rate of force development. Implementation of the snatch pull derivative assists in reducing the complexity of movement while avoiding technical errors occurring in the catch phase (Suchomel et al., 2014, Suchomel et al., 2015). Implementing the pulling derivative of the snatch also encourages acceleration throughout the entire movement without a reduction in power during the catch phase. By avoiding the catch phase in the full snatch movement, technique errors related to barbell displacement may also be avoided (Gourgoulis, Anggelousis, Garas & Mavromatis, 2009; Ho et al., 2011). Another benefit during the snatch pull is a reduction in impact from the catch phase which may cause overuse injuries to athletes over time (Suchomel et al., 2014; Suchomel et al., 2015). Decreasing impact stress on the lower body when training for power-strength could potentially avoid overuse injuries while athletes still receive adequate stimulus for overload (Gourgoulis et al., 2009).

Overload can be defined as applying a greater stressor load on the body to force adaptation from the prescribed stimulus or load (intensity) used. When regarding the full

Olympic weightlifting movement of the snatch, athletes are limited greatly by the catch phase and their 1RM (Gourgoulis et al., 2009; Ho et al., 2011, Suchomel et al., 2015). The snatch pull derivative is included into program design at exceedingly higher intensities than one's maximum repetition ability in the snatch. Physiologically, training at higher loads with snatch pulls induces overload that can transition in improved performance in the full weightlifting movementS (Suchomel et al., 2014; Suchomel et al., 2015). Overload in the snatch pull exercise allows for translational improvements in peak velocity, peak force, and peak power production (Cormie et al., 2011; Suchomel et al., 2014). Pulling derivatives have been shown to be programmed anywhere from intensities ranging from 60-140% of 1RM (Suchomel et al., 2014; Suchomel et al., 2015). Implementation of sets and repetition schemes should be applied scientifically to provide an efficient stimulus for the desired adaptation to occur. Higher intensities during strength-power phases have been shown to increase power production, however as intensity of exercise increases performance variables such as peak velocity and peak power decrease (Hardee et al., 2012; Hardee et al., 2013; Oliver et al., 2016; Suchomel et al., 2014; Suchomel et al., 2015). Literature has shown peak force was highest as intensity increased in the snatch pull (Wicki, Culici, DeMarco, Moran, & Miller, 2014) and the mid-thigh pull (Comfort et al., 2012), both being pulling derivatives. Loading scheme range is based on desired stimulus for pulling derivatives. However, during strength phases heavier loads > 100% 1RM are typically common for the snatch pull exercise (Storey, & Smith 2012; Suchomel et al., 2015). The concept of overload is the main criteria for load intensities reaching >100% 1RM (Storey, & Smith 2012; Suchomel et al., 2015). Heavier loads are used to develop greater peak force, rate of force development, and high power (Storey, & Smith 2012; Suchomel et al., 2015). Variations such as pulling derivatives allow for overload stimuli to be applied for physiological adaptations to take place based on the SAID (specific adaptation to imposed demands) principles (Suchomel et al., 2015). By overloading the triple extension movement via pulling derivatives, neurological stimuli adaptations are thought to carry over into full snatch movement progressions as well. (Storey, & Smith 2012).

Weightlifting and Muscular Power

Explosive power output is characteristic of athletic performance in various activities and sport that involve high velocity movements. The ability of the muscular and neurological systems to explosively and efficiently coordinate contraction is critical in settings involving throwing, jumping, and striking (Newton & Kraemer 1994). In sport and athletics, the ability to rapidly change direction, accelerate, sprint, and jump are all critical for performance (Newton & Kraemer 1994). Since power output drives these adaptations for athletic parameters, training to optimize the power-velocity relationship should be at the top priority for strength and conditioning for power athletes. Human biomechanical analysis has shown greater power output values with high velocity weightlifting movements in comparison to regular strength training exercises (Garhammer, 1993; Hydock, 2001). In the complex high velocity weightlifting movements, the pull is responsible for majority of the power production in athletes (Garhammer, 1993; Hydock, 2001; Newton, & Kraemer 1994). The top pull position can be described as full extension of the ankle, knee, and hip joints, with the addition of scapular elevation or shrugging (Garhammer, 1993; Hydock, 2001; Newton & Kraemer, 1994). Garhammer (1993) was able to find that 86-94% of the work done by athletes in lifting the barbell vertically was completed by the time the bar reached maximum velocity. Maximum velocity is generally reached at the top position of the pull, however force placed on the barbell drops to low magnitudes in the top pull position (Hydock., 2001). Pennington, Laubach, De Marco, & Linderman (2010) identified maximal power output to occur for both the power clean and power snatch at intensities of >80% 1RM. Haff et al. (2003) showed increasing power output levels with clean pulls >100% 1RM. Identifying maximal power output occurs at higher intensities, suggesting that training for increasing power should occur around 80-100% 1RM with weightlifting exercises.

Neural Adaptations and Ballistic Training

Neurological adaptation to developing maximal neuromuscular power encompasses not only morphological muscle architecture, but physiological neurological adaptation. Neural factors related to the development of muscular power include motor unit recruitment, firing frequency, synchronization, and inter-muscular coordination (Cormie et al., 2011). Motor unit recruitment follows the size principle in the rule that slow graded low threshold type muscle fibers are recruited before high-threshold fibers (Cormie et al., 2011). During ballistic exercise, high threshold motor unit recruitment is typically lowered due to rapid increasing force production (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). High-threshold motor units play a critical part in force production and rate of force development, which in turn is highly influential for neuromuscular power production. Since motor unit recruitment is heavily dependent on the imposed stimulus demand, it is important to incorporate exercises that induce high-threshold recruitment to improve performance (Aagaard et al., 2002). Another neural factor related to improving neuromuscular power is motor unit firing frequency. Firing frequency can be described as the rate of neural impulses transmitted from alpha-motor neuron to muscle fibers (Cormie et al., 2010). Motor unit firing frequency influences magnitude of force generated and the rate of force production of voluntary muscular contractions (Aagaard et al., 2002). Ballistic exercises represent high levels of firing frequencies, which in result increases rate of force production in muscular contractions (Cormie et al., 2010). Ballistic exercise inducing high levels of firing frequency has been suggested to be a component to having an overall impact on performance (Aagaard et al., 2002). Motor unit synchronization or co-activation of numerous motor units has been hypothesized as an adaptation to ballistic exercise (Cormie et al., 2011). Essentially, coordination of the muscular system to control complex movements would elicit greater muscular power output with co-activation. Lastly, inter-muscular coordination represents co-activation of the musculoskeletal system (Cormie et al., 2010). Efficient co-activation of muscular agonist, synergists, and antagonist muscle groups occurring during complex movements elicits maximal power transmission (Cormie et al., 2011). Triple extension of the ankle, knee, and hip complex is a prime example of efficient neuromuscular inter-muscular coordination occurring to produce maximal power at an instantaneous moment in time. The process of efficient triple extension can only occur with efficient neuromuscular inter-muscular coordination. The benefits of neurological adaptation from ballistic exercise represents the neurological and muscular systems working to maximally generate high forces and power outputs during coordinated complex movements.

Kinetic Variables and Performance

Kinetic variables that are related to performance include power, force, and rate of force development. Power is defined as the rate at which work is done. Work can be defined as the force done to an object that moves that object. Therefore, power is derived from the relationship product of force and velocity (*Power = Force x Velocity*). Since power is characteristically reliant on force and velocity, maximal power is seen with high forces and velocities, respectively. Power has been well documented in a variety of sports that require high forces over short periods of time. In general, majority of athletic bouts require optimal power production to elicit peak performance (Hardee et al., 2013). The power output variable is a general marker for performance, strength, and adaptation across the sport of weightlifting (Cormie et al., 2010). Maximal power output levels have also been shown to be highest in Olympic lifting exercises. Olympic lifts in nature are ballistic, multi-joint dependent, and characteristic of high force and power stimuli. Peak power production shares a positive relationship with force and velocity. Identifying with the force-time continuum curve when prescribing exercise for power development is crucial to success to induce desired physiological adaptation (Haff et al., 2001).

Maximal force generated in sport and athletic bouts is also crucial to success (Cormie et al., 2010, Haff et al., 2001, Hardee et al., 2013, Kipp, Harris, & Sabbick., 2013). Force can be defined as the product of mass and acceleration (*F=MA*). Internal neuro-musculo-skeletal force production occurs to externally produce movement.

Regarding weightlifting movements external forces placed on the barbell are calculated from the mass and acceleration of the external load of the barbell (Kipp et al., 2013). External load kinetics numerical variables give feedback to allow for physiological internal inferences to occur (Kipp et al., 2013). Research shows that with relatively higher loads (>85%) internal and external means for calculating forces and power are correlated. Kipp et al. (2013) showed that when using the impulse-momentum method correlations from internal joint powers and external power outputs to be correlated between 75-85% 1RM in the clean exercise. Applying this, external power outputs values may give reasonable insight into intrinsic physiological parameters during the pull portion of Olympic lifts.

Ground reaction force (GRF) is another core principle for athletic performance. GRF can be defined as the relationship of the forces placed onto the ground and thus exerted back. Newton’s laws of motion dictate that every force has an equal and opposite reaction force, therefore GRF is the force exerted by an individual onto the ground. Furthermore, maximizing GRF and sustaining GRF over maximal bouts of exercise is critical for performance. High maximal forces occur during running, sprinting, jumping, and Olympic ballistic lifting (Cormie et al., 2011). Collectively, being able to sustain high forces over maximal effort exercise bouts is critical for performance and power output generation.

Lastly, rate of force production (RFD) is essential for maximizing performance. Rate of force development is the rate of change of force applied in a movement over time (Comfort, Allen, & Graham-Smith 2011; Cormie et al 2010; Suchomel et al., 2014;

Suchomel et al., 2015). RFD can be calculated by the change in force with time. Lower body RFD is generally correlated to faster sprint times and greater jump heights (Aagaard et al., 2002). This implies that maximizing RFD may be critical for athletic bouts, as sprinting and jumping are core characteristics to majority of sport (Aagaard et al., 2002). RFD can be improved via multiple mechanisms including ballistic exercise training and Olympic lifting, which elicit the overall greatest stimulus for adaptation (Haff et al., 2001). In summary, these kinetic variables are related to human performance and are critical to maintain during weightlifting exercise to induce optimal physiological adaptations in response to athletic bouts.

Kinematic Variable and Performance

The main kinematic determinants during weightlifting are barbell displacement and velocity. Barbell displacement and velocity are the biomechanical external variables related to success and performance in weightlifting. Maximum barbell velocity is characteristic of being efficient in weightlifting (Ho et al., 2011; Ho et al., 2014; Storey & Smith 2012). The practical application of velocity in biomechanics is the rate of change in displacement often thought of as “speed”. Practitioners, coaches, and athletes alike seek maximum velocity by visual and verbal feedback of being told to “move fast” or “move the bar fast”. Based on previous literature, maximum barbell velocity is reached during the second pull, but increased mechanical work was done during the first pull (Ho et al., 2014; Suchomel et al., 2014; Suchomel et al., 2015). Mechanical work done in the first pull phase has been characterized by force, whereas the second pull with power. Higher maximum barbell velocity with a shorter duration of the second pull is thought to be the resultant factor for increasing power output (Ho et al., 2014). Success and failure of full weightlifting movements are the combined kinetic and kinematic factors of the barbell and body variables. Since internal joint feedback is hard to identify, the major key factor in visually determining performance is often characterized by barbell velocity. Peak barbell velocity occurs in the power position of the snatch at the end of the second pull (Ho et al., 2014; Suchomel et al., 2014; Suchomel et al., 2015). The snatch pull exercise includes the phases up to the second pull which allows for peak velocity to occur. Recent literature has shown peak barbell velocity (>80% 1RM) to not be correlated with successful lifts (Gourgoulis et al., 2009). However, peak barbell velocity is still considered a key element to performance amongst practitioners, coaches, and strength athletes alike (Ho et al., 2014; Suchomel et al., 2014; Suchomel et al., 2015).

Maximizing vertical bar displacement is characteristic of good technique in weightlifting (Ho et al., 2014). Having a larger vertical bar displacement allows the weightlifter to “get under” the bar in preparation for the catch phase in the snatch and or clean and jerk (Suchomel et al., 2014). Previous literature discussed the second pull being primarily responsible for optimal barbell displacement (Ho et al., 2014; Suchomel et al., 2014; Suchomel et al., 2015). Optimal peak vertical bar displacement is sought out by weightlifters and various experience levels because of its relationship with successful lifts (Suchomel et al., 2014). Increasing peak vertical bar displacement in the field of strength and conditioning has been thought to increase the chances of successful lifts (Ho et al., (2014). Theoretically greater vertical displacement or travel permits more time and distance for lifters to be able to brace and get stable in the catch phase.

Muscular Fatigue Mechanisms and Performance

Research show that muscular fatigue has been shown to negatively affect performance during physical activity (Izquierdo, Ibanez, Calbet, Gonzales, Navarro-Amezqueta, Grandados, Malanda, Idoate, Gonzales-Ballido, Hakkinen, Kraemer, Tirapu, & Gorostiaga, 2009). Muscular fatigue can be described as the transient decrease in the capacity of muscle to perform physical actions. Muscular fatigue often refers to impaired intellectual performance, impaired motor performance, impaired force generation, increased EMG activity for given performance, and a shift of EMG power-spectrum to low frequencies (Enoka, & Duchateau 2008). Research shows that multiple mechanisms for causing fatigue exist and that there is no single cause of muscular fatigue. Fatigue has been thought to occur when one, or more specifically, several physiological processes that allow contractile proteins to generate muscular force become impaired (Enoka, & Duchateau 2008).

Briefly, energy metabolism may contribute to muscular fatigue via an increase in energy requirements of Adenosine-tri-phosphate (ATP) seen with increasing contraction forces (Izquierdo et al., 2009). The rate at which energy is supplied from anaerobic glycolysis is highly influenced by the glycolytic enzyme phosphofructokinase (PFK) (Izquierdo et al., 2009). Inhibition of PFK usually occurs from the accumulation of metabolic metabolites such as hydrogen ions and lactate, which can severely limit the rate which energy is supplied via anaerobic glycolysis. Inhibition of PFK has been shown with increasing muscle temperature and fatigue.

Fatigue furthermore can be explained and understood with peripheral and central mechanisms. Fatigue in general can occur at various points involving multiple mechanisms. Central fatigue is characteristic of failure with voluntary or involuntary neural drive (Enoka, & Duchateau 2008). Impairments in neural drive result in reductions in motor unit firing frequencies and reductions of number of functioning motor units (Cormie et al., 2011). Peripheral fatigue is characteristic of force generation impairments of the whole muscle. Impaired-excitation contraction coupling elicits failure of muscle actions and impaired neuromuscular transmissions (Enoka, & Duchateau 2008).

In summary, muscular fatigue can negatively affect performance by both central and peripheral mechanisms. Muscular fatigue would lead to reductions in performance by impairments in muscular force and the ability to perform physical activity in an efficient manner.

Rest Interval Configurations

Based on the notion to preserve and maximize training stimuli, cluster sets and or inter-repetition rest (IRR) has been shown to attenuate the regression of performance characteristics such as power, velocity, and force (Haff et al., 2003; Hardee et al., 2013; Moreno et al., 2014; Oliver et al., 2016). Cluster sets, sometimes called intra-set rest intervals, consist of grouping repetitions together within the prescribed set and repetition scheme. IRR is defined by taking small-moderate rest between each repetition in the prescribed volume scheme. Lastly, inter-set rest is described as the rest interval length between each set of the prescribed volume scheme. Variance in acute performance variables such as velocity, power, and force have shown to fluctuate with different prescribed intra-and inter repetition rest intervals. Furthermore, variance in chronic performance variables such as anabolic hormones testosterone, growth hormone, and IGF-1 have shown fluctuations with different prescribed rest intervals as well (Rahimi, Rohani, & Ebrahimi, 2011).

Although past literature regarding IRR exists for strength, and explosive movements, literature focusing on the snatch pull derivative is lacking. In relation to optimal acute performance variables such as force, velocity, and power, the optimal inter-repetition rest is relatively unexplored and unknown. To date, majority of studies existing manipulating rest intervals mostly are characterized by cluster or intra rest sets. Limited research for IRR has been done, especially in relation to ballistic exercises such as Olympic weightlifting. Minimal research does strongly show that significant values can be achieved while manipulating rest schemes involving 20-90 seconds between rest. However, to date limited or no research as looked at implementation of smaller rest intervals such as the difference between 10-20 second rest treatments during resistance training exercise. Shorter IRR intervals may allow for time efficiency while still achieving the benefits of implementing rest in relation to values greater than 20 seconds. Furthermore, with shorter IRR being prescribed athletes or individuals performing may achieve a more superior endocrine response while maintaining internal and external efficiency during their lifts.

Effects of Rest Interval Length on Endocrine Response

Proper prescription of rest intervals during resistance exercise training is important to induce maximal stimulus and adaptations. Different rest interval lengths have been shown to induce varying neuroendocrine responses in previous literature (Schoenfeld., 2013). It has been established that the proper amount of rest time in between sets is about 3-5 minutes for maximal phosphagen system resynthesis (Cormie et al., 2010). Overall, rest intervals ranging from 3-5 minutes seem to induce the greatest maximal strength adaptations (Ahtiainen, Pakarinen, Alen, Kraemer, & Häkkinen, 2005). Maximal strength gains observed with increasing rest intervals duration have also shown to increase serum testosterone levels (Schoenfield, 2013). Rahimi et al. (2011) found that rest intervals under 1.5 minutes reduced acute testosterone response. Rahimi et al. (2011) also found increasing cortisol and decreasing testosterone ratios immediately post exercise with 1 and 1.5-minute rest intervals in comparison to 2 minutes. However, Ahtiainen et al. (2005) found no acute or chronic endocrine variance between 2 and 5-minute rest intervals in response to levels of free testosterone, total testosterone, cortisol, and growth hormone levels.

In comparison, decreasing rest intervals in duration may elicit a greater overall hypertrophic response. Schoenfield, (2013) supports overall decreases in rest interval durations induces an increased hormonal response. The increased hormonal response is indicated by a more anabolic response seen with increasing levels of growth hormone, and IGF-1 (Rahimi et al., (2011). With an overall more anabolic environment, maximal hypertrophic responses have been thought to be induced via the increasing levels of anabolic hormones (Ahtiainen et al., (2005). Research indicates that post-exercise elevations of anabolic hormones in relation to shorter rest intervals, is related to increased metabolic stress. (Schoenfield, 2013). With a reduction of rest interval lengths, metabolic stress increases in relation to the accumulation of metabolites such as inorganic phosphate, hydrogen ions, and lactate (Schoenfield, 2013). In summary, varying total inter, and intra rest intervals per set may elicit and overall different stimulus for the neuroendocrine response.

Effects of Rest Intervals on Kinetic Variables

The power output variable is characteristic of being a general marker for performance, strength, and adaptation across for weightlifting (Cormie et al., 2010). Power output has been shown to decrease with multiple repetition and set schemes as well as with increasing intensity. Reductions in power output are seen from decreases in force & velocity (Hardee et al., 2012; Hardee et al., 2013). Significant decreases ($p<.05$) in power output have been noted as sets, repetitions, and intensity increase (Haff et al., 2001; Hardee et al., 2013). The maintenance of power output in performance to keep stimulus adaptations high is appealing among practitioners and athletes alike. IRR protocols have showed significant maintenance of power output when compared to traditional sets in a variety of exercise.

Lawton, Cronin, & Linsell, (2006) showed significant difference when utilizing intra-set and inter-repetition rest in comparison to continuous repetitions in the 6RM bench press. Lawton et al. (2006) concluded that inter-repetition with (1 set of 6 repetitions) with 23 second intervals was able to maintain power output 21% higher than control groups of continuous repetitions. The Lawton study also showed a 25% higher retained power output with 2 sets of 3 repetitions in comparison to baseline continuous repetitions. This implies that even with traditional non-ballistic exercise IRR, and Intra-set rest (rest within sets) benefit the maintenance of power output in comparison to traditional continuous repetition sets.

Hardee et al. (2013) showed that peak power significantly decreased by approximately 14.94% in comparison of the first repetition to the sixth repetition in the power clean exercise with minimal rest between repetitions. In comparison Hardee et al. (2013) showed that with treatment groups of 20 and 40 second IRR subjects peak power decreased by only by 5.76% and 4.08% respectively. Based on this research, IRR may successfully maintain peak power in ballistic Olympic exercises.

Moreno et al. (2014) further strengthens the application of manipulating rest volumes in between a set. Moreno et al. (2014) showed variance among power output in the squat jump between 3 different protocols (2x10, 4x5, 10x2) sets x repetitions respectively. Significant interactions ($p<.05$) between groups were found, with 10x2 preserving power output the greatest. This study demonstrates that cluster sets could maintain plyometric jumps power output greater in comparison to traditional sets.

Oliver et al. (2013) showed large increases in power output when comparing traditional set schemes with intra-set rest schemes in the bench press, squat, and vertical jump. The treatment groups were 4x10 repetitions with 120 seconds rest in comparison to 8x5 repetitions with 60 rest conditions. With total rest conditions being equated, Oliver et al. (2016) research concluded that the ISR group produced greater power output in bench ($p=.0020$), vertical jump ($p=0.036$), and the squat power approaching significance at ($p=0.053$).

Oliver et al. (2016) study reported that cluster sets produced greater power output for increasing number of repetitions in each set in the back squat. Set configurations consisted of either traditional 4x10 repetitions with 120 seconds between sets, or a cluster of 4 sets of 2 clusters of 5 repetitions (4x(2x5) with 30 seconds between clusters and 90 seconds between sets. Subjects produced greater average power when performing clusters in 5 repetitions (1,7-10) during set 1, 6 repetitions (1,6-10) during sets 2 and 3, and 8 repetitions (1-3,6-10) during set 4. Differences in average power output in repetitions 6-10 between the cluster and traditional were increasingly larger from set to set as well. The study implies that cluster sets importance may be more relevant in the later repetitions. The research also suggests that with increasing sets, cluster sets impact becomes more significant.

In relation to kinetics, force is another variable that is highly regarded as being crucial related to performance. Force has been shown to decrease with increasing repetitions and sets. For maintaining optimal force outputs, manipulation of rest intervals has been shown to assist with maintenance.

Hardee et al. (2013) study showed that peak force significantly (p<.05)

decreased by approximately 7.15% from repetitions 1 to 6 in the power clean exercise with minimal to no rest. In comparison, treatment groups of 20 seconds and 40 seconds significantly decreased peak force production by 2.88% and 0.04 % respectively.

Oliver et al., (2016) identified significant difference average force in comparison of cluster sets with traditional set schemes during the back-squat exercise. Cluster sets resulted in significantly (P<.05) greater average force in isolated repetitions during those sets. Statistical significance increased with sets and repetitions, implying that cluster sets effectiveness increased with continuous repetitions and sets.

In summary, manipulation of inter-repetition and intra-set rest intervals show maintenance of kinetic variables during a variety of exercises. This implies that IRR and ISR may elicit overall greater physiological adaptations to resistance exercise in comparison to traditional set schemes.

Effects of Rest Intervals on Kinematic Variables

Peak velocity has been shown to decrease with increasing fatigue, intensity, and duration (Hadi, Akkus, & Harbili, 2012, Hardee et al., 2012, Hardee et al., 2013, Moreno et al., 2014, Valverde-Esteve et al., 2013). Therefore, the maintenance of barbell velocity whenever possible is crucial for performance strength-power development. Implementation of inter-repetition rest has been shown to help attenuate the effects of diminishing barbell velocities and displacement in both a variety of strength and ballistic exercises (Hadi et al., 2012, Hardee et al., 2012).

Haff et al. (2003) showed significantly higher peak displacement values when comparing IRR vs traditional set configurations in the clean pull exercise. Haff et al. (2003) also found barbell displacement to be significantly ($p= .001$) different at 90%, and 120% 1RM with cluster set configurations (IRR) vs traditional and undulating repetition schemes. Furthermore, the research showed that a significantly ($p<0.016$) higher peak velocity occurred during the cluster set when compared with the traditional sets at both intensities of 90% and 120%.

Hardee et al. (2013) found mean horizontal displacement to be significantly different ($p>.05$) when comparing IRR intervals of 20 and 40 seconds, to a control group. This would be indicative of form breaking down as mean horizontal displacement is unwanted with efficiency of lifts. Hardee et al. (2013) also showed decreases in peak velocity by approximately 9.07% from repetitions 1 in relation to 6 with the power clean exercise in the control group. In comparison, implementing IRR treatments with 20 seconds' peak velocity only decreased by 3.86%, and 40 second IRR by 1.89%.

Another study Oliver et al. (2016) demonstrated velocity maintenance in back squat exercises implementing cluster sets & IRR vs. traditional continuous repetition configurations ($p<0.05$). The study found significantly higher back squat velocities when comparing cluster set protocols to continuous repetitions ($p=.010$). Another finding in this study was that velocity maintenance was observed mostly between sets 2-4. This suggests that inter-set rest becomes more significant as multiple set configurations increase over time.

Moreno et al. (2014) showed significantly ($p<0.5$) greater take off velocities involving cluster sets with the plyometric jump squat exercise in relation to traditional set schemes. Specifically, the study found cluster sets with 10 sets and 2 repetitions at 10 seconds of rest between sets to elicit superior power output and take off velocities in the jump squat in comparison to traditional continuous repetitions

In summary, the kinematic variables of displacement and velocity may be maintained in a variety of exercises. Maintenance of acute kinematic variables may induce superior physiological adaptations to resistance exercise stimulus.

Long term physiological effects of IRR

Although implementing IRR has been postulated to maintain fatigue with acute kinetic and & kinematic variables, long term research is still needed. The implementation of IRR with strength and power exercises alike may prove to benefit other physiological adaptations with long term use. Hansen, Cronin, Pickering, & Newton, (2011) showed similar increases in back squat 1RM between traditional and cluster set protocols. The study also showed large training effect sizes in both training interventions (1.0-2.2). Although the effect sizes were large, traditional in comparison to cluster training in Hansen’s research showed a superior percent change in strength than cluster interventions (TT % change 18.3± 10.1 vs CS 14.6±18.0). In comparison, the cluster training protocol showed likely a positive effect on peak power at 40 kg (6.5% positive difference) (Hansen et al., 2011). Hansen et al. (2011) also showed cluster interventions also showed possible effects and peak velocity at 0 and 40 kg loads (3.3 & 4.7% positive difference). Lastly Hansen et al. (2011) also showed peak force in relation to cluster intervention postulates possible positive difference with 1.8% increases in comparison to the traditional intervention. With the rise of cluster set training and IRR, new research is being done to manipulate rest variables to induce superior gains. One protocol, called intraset rest intervals is characteristic of IRR and cluster sets, but IRS incorporates rest between groups of repetitions (Oliver et al., 2013). Although there is variance between IRR and IRS, physiologically the principles are alike in hopes of maintenance of fatigue by implementing rest. Oliver et al. (2013) showed that ISR produced greater power output in bench press (p= 0.020), and vertical jump (p = 0.036). The same study was also able to demonstrate greater strength gains in bench p= 0.010), and squat (p = 0.002) when comparing traditional vs ISR protocols. This study demonstrated no significant differences between groups in lean body mass. This implies that IRR and ISR may be beneficial for strength and power gains in comparison to TRD without compromising hypertrophic gains over a long period of adaptation.

Rationale

While numerous studies have analyzed the snatch technique and the variables of importance to successfully complete lifts, no literature has identified the pulling derivative and how set configuration should be approached. Since the pulling derivative is a critical variation for overloading stimuli and inducing adaptation (Suchomel et al., 2014, Suchomel et al., 2015), the need for power & velocity analysis on varying set configuration is required. Previous literature has shown attenuation of undesirable effects of fatigue on performance implementing IRR protocols. However, to this date, literature and empirical data optimizing the snatch pull derivative with different IRR protocols is lacking.

In conclusion, further research is needed to identify proper set configurations in the snatch pull derivative to maximize power, velocity, and force performance variables. The benefits of IRR influence on peak mean values for power, velocity, and force in the snatch pull is needed to quantify these appropriate set configurations for maximal stimulus and adaptation.

Chapter 3

METHODOLOGY

Introduction

The purpose of this study was to determine the effects of inter-repetition rest intervals on the biomechanics of the snatch pull exercise. The protocol consisted of 4 sessions over 2-week period with at least 72 hours between treatment sessions. The first session was characterized by familiarization of lab equipment, technique, and assessment of a 1-Repetition Max (1RM) of the snatch. The later 3 sessions consisted of randomized protocols with subjects performing 3 sets of 5 repetitions at 100% 1RM (snatch) in the snatch pull. Randomized treatments of inter-repetition rest were prescribed for each testing session by the practitioner of either (P0) seconds, (P10), and (P20) seconds. Five minutes of rest was given between sets as recommended by National Strength Conditioning Association guidelines for optimal recovery for power and strength performance. Biomechanical parameters consisting of force, power output, and velocity were measured throughout the protocol.

Subjects

Nine healthy male (24-33 years old) recreationally trained weightlifters participated in this study. Subjects had to meet criteria of weight training for at least 3 years, 1 year of weightlifting experience, and show competence in technique with the snatch technique as well as snatching their own bodyweight relative to load on the barbell. Proper technique criteria were assessed by a certified strength and conditioning specialist (CSCS) and USA Weightlifting sports performance coach. To verify proper testing procedures with human subjects, the study was reviewed by Institutional Review Board at California State University Sacramento (CSUS). All subjects signed an informed consent form and completed a health medical screening. For subjects to be included in the study based off the medical screening and ACSM guidelines, candidates had to be classified as “low” health risk. Subjects were healthy, currently involved in recreational weightlifting and training, and to the investigator's knowledge had no lower or upper extremity injuries.

Testing Protocol (Session 1)

All subjects reported to the biomechanics lab at CSUS for session 1. Session 1 was used for familiarization of equipment, descriptive data, and 1RM testing. Descriptive data of participants included height, weight, and 1RM in the snatch exercise. All participants had refrained from exercise for 24 hours prior to testing. Gradual increases in intensities were used when working up to the maximal loads with 2 minutes of rest between efforts. Proper technique was observed by the USA weightlifting certified sport performance coach when loads reached maximal.

Testing Protocol (Sessions 2-4)

In a randomized order, each participant was involved in three different treatment sessions. Treatment sessions were conducted at the same time of day with at least 48 hours in between. Dietary intake was not monitored. All subjects were instructed not to take any form of stimulants or supplements that might skew data. Subjects worked up to treatment intensity loads by making 10% increase in load starting at 50% 1RM. Warm up sets included 1x5 50%1RM, 1x5 65% 1RM, 1x3 80% 1RM, 1x3 90% 1RM. Prior to being filmed subjects were told 1 set before the working treatment that they would be filmed next. The treatment sessions included 3 sets of 5 repetitions at 100% 1RM. The independent variable was inter-repetition rest (IRR) at 0, 10, or 20 seconds. The order of IRR was also randomized by the investigators. Intensities of 90-105% for pulling derivatives for Olympic weightlifting have been shown to be commonly prescribed for various stages in programming. Intensities of around 80-90% have been shown to be optimal for peak power and velocity output for pulling derivatives. Intensities >100% have been shown to decrease in power, velocity, and displacement. Therefore, the intensity used was selected to show significance of IRR configurations on power and velocity.

Instrumentation

Three-Dimensional Kinematic data were collected using 6 infrared cameras (Bonita b3; 240 Hz) and the VICON Real-time Motion Analysis system (Vicon Motion Systems Ltd UK, West Way, Oxford). Reflective markers were placed on both sides of the barbell for data collection. Peak Vertical bar displacement (m), and peak vertical bar velocity, were measured through VICON analysis system. Peak vertical ground reaction force (GRF) was analyzed via force plate data (Advanced Mechanical Technology, Inc, Watertown, MA) Peak power output was calculated by the equation "*POWER = FORCE (from vertical GRF) x VELOCITY (from vertical barbell velocity)* or "*P= F X V*". This methodology of power output determination has been shown to be valid and reliable (Cormie et al., 2007). Data were collected for each repetition and the peak mean values of force, velocity, and power were determined for each treatment protocol among subjects.

Statistical Analysis

Mean peak values of force, velocity, and power were analyzed using a One-Way Repeated Measures Analysis of Variance (ANOVA). The within-subjects effect of treatment (IRR) was examined by repetitions and grouped sets. A one-way ANOVA was used to compare overall mean peak values between treatment groups. Main effect differences (significant F statistic) were further analyzed by examination of the 95% confidence intervals. Alpha level was set at ($p \leq .05$) for all analyses. All data were analyzed using STATA®, release 14 (StataCorp LLC, College Station, TX).

Chapter 4

RESULTS

The purpose of this study was to analyze the effects of IRR treatment groups during multiple set and repetition configuration in the snatch pull exercise. It was hypothesized that increasing the quantity of IRR would maintain peak power, force, and velocity over continuous repetitions and sets. A One-way Repeated Measured ANOVA was used to analyze sets and repetitions with IRR treatment to determine statistical significance. The overall statistical significance between treatment IRR protocols is represented in table 2. Significance ($p< 0.5$) was found between all treatment protocols. The overall mean peak values for all sets and repetitions of power, force, and velocity between P0, P10, and P20 are represented in figures 1-3. Sets and IRR treatment interactions are represented by figures 3-6. Significant interactions occurred between sets and treatment between all P20 and P0 treatments. Significant values were seen between Set 3 P10 treatments and Set 3 P0 treatments for all variables. Mean peak values for all treatments were then compared to identify percentage decrements between treatment protocols. Percentage decrement graphs are represented by figures 6-9 for mean peak power, force, and velocity for all treatment groups P0, P10, and P20.

Mean peak force varied significantly between protocols. Peak mean force values were 3.9% lower in P10 than P20, and 8.11% lower in P0 than P20 across all subjects (P20 = 1892 ± 140.87 N, P10 = 1824 ± 175.53 N, and P0 = 1744 ± 262.68 N respectively). Peak mean velocity values were 3.55% lower in P10 than P20, and 5.92%

lower in P0 than P20 across all subjects (P20 = 1.69 ± .15 m/s, P10 = 1.63 ± .14 m/s, P0 = 1.59 ± .14 m/s). Peak mean power values were 6.48% lower in P10 than P20, and 11.48% lower in P0 than P20 across all subjects (P20 = 2821 ± 347 W, P10 = 2638 ± 435.77 W, P0 = 2497 ± 486.37 W)

Table 1:
Subject Descriptive Statistics

Age	**28.125 ± 3.39 years**
Height	**181.92 ± 4.88 CM**
Weight	**87.155 ± 8.99 KG**
One Repetition Maximum / Relative to Body Weight	**1.17 ± .100**

*Means ± Standard Deviation

Table 2:
Overall Treatment Effect Significance

Measure	**Treatment**	**Treatment**	**Significance**
FORCE	P0	P10	.001
	P10	P20	.003
	P20	P0	0
VELOCITY	P0	P10	.023
	P10	P20	0
	P20	P0	.001
POWER	P0	P10	.008
	P10	P20	.001
	P20	P0	0

*Overall statistical significance between all treatment groups P<.05

The overall mean peak values for all subjects, sets, and repetitions related to force values were analyzed and compared to determine statistical significance between IRR protocols of P20, P10, and P0; (20, 10 and 0 seconds) respectively.

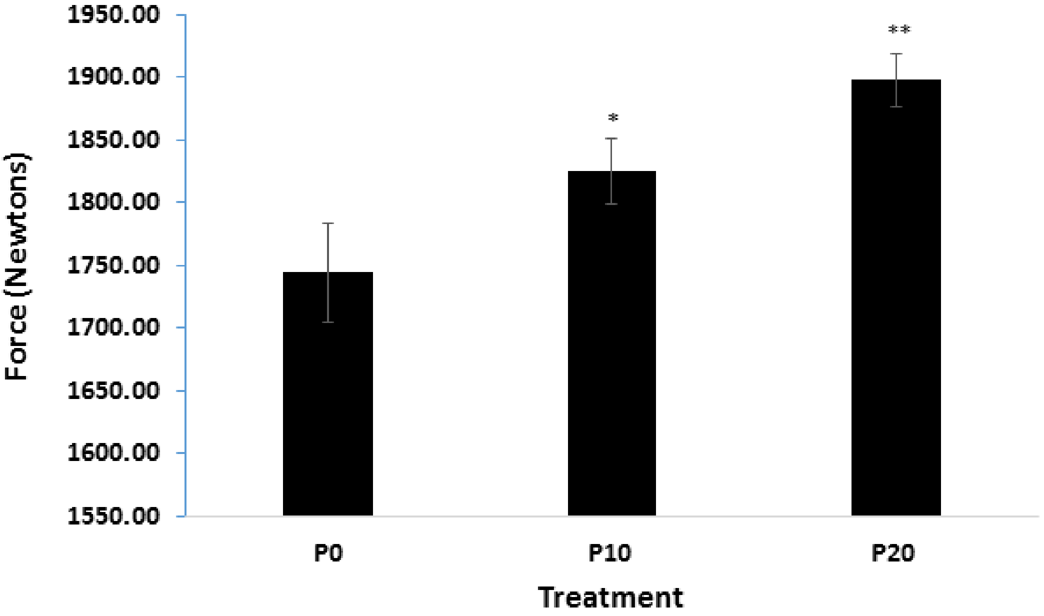


Figure 1: Mean peak force values (Newtons) between treatment protocols.

Error bars are reported means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. Reported as means ± SEM. All significant values represented at $P \leq 0.05$ **P20 treatment significantly different from P0, and P10. *P10 treatment significantly different than P0.

The overall mean peak values for all subjects, sets, and repetitions related to velocity values were analyzed and compared to determine statistical significance between IRR protocols of P20, P10, and P0; (20, 10 and 0 seconds) respectively.

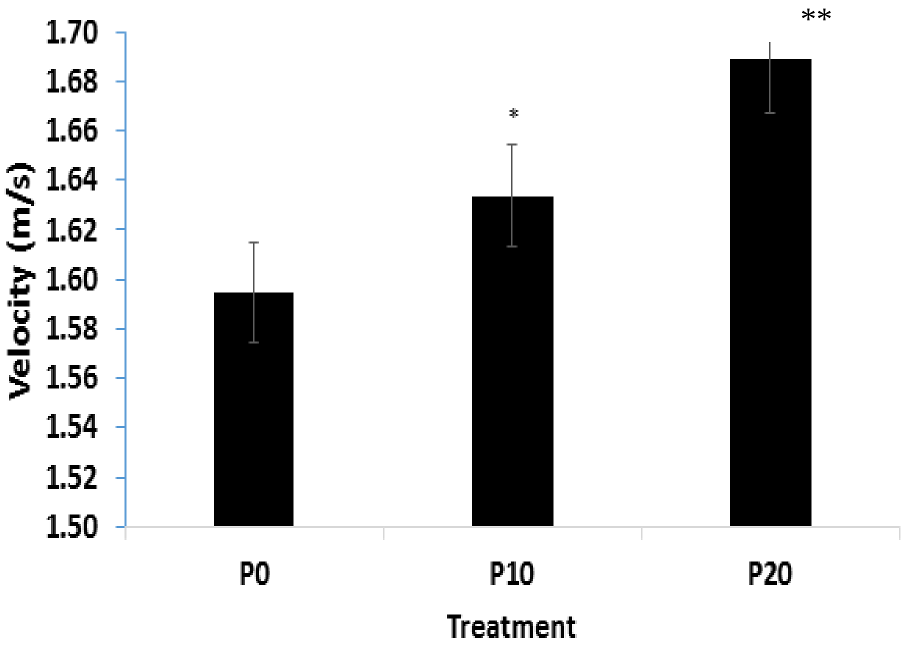


Figure 2: Mean peak velocity values (m/s) between treatment protocols.

Error bars are reported means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. All significant values represented at P ≤ 0.05 **P20 treatment significantly different from P0, and P10. *P10 treatment significantly different than P0.

The overall mean peak values for all subjects, sets, and repetitions related to power values were analyzed and compared to determine statistical significance between IRR protocols of P20, P10, and P0; (20, 10 and 0 seconds) respectively.

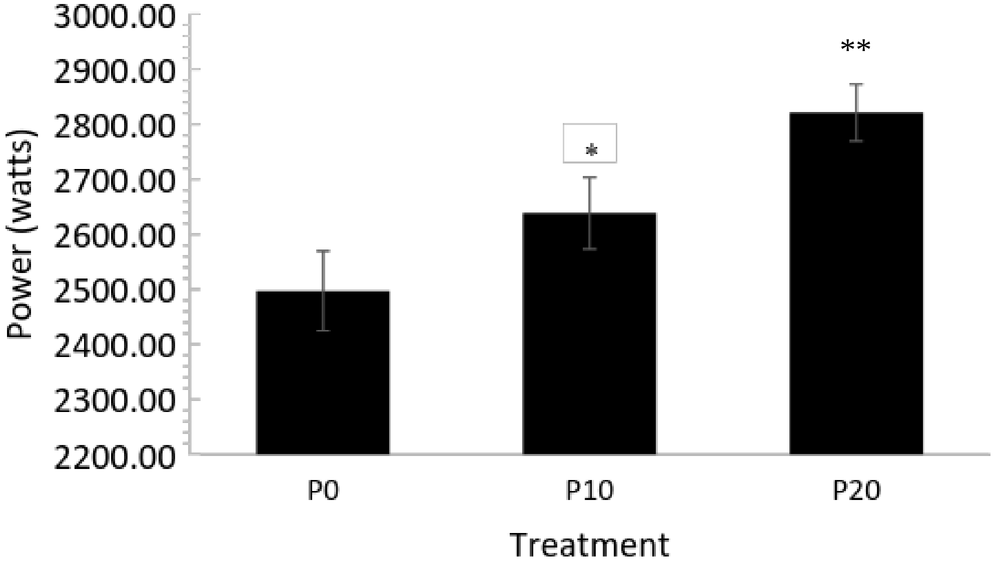


Figure 3: Mean peak power (watts) between treatment protocols.

Error bars are reported means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. Reported as means ± SEM. All significant values represented at P ≤ 0.05

**Significantly different from P0, and P10. *Significantly different than P0.

The interactions between sets 1, 2, and 3, were further analyzed to determine statistical significance between set interactions and IRR treatment protocols of (P20, P10, and P0). Force values were analyzed to determine statistical significance between sets and treatment protocols.

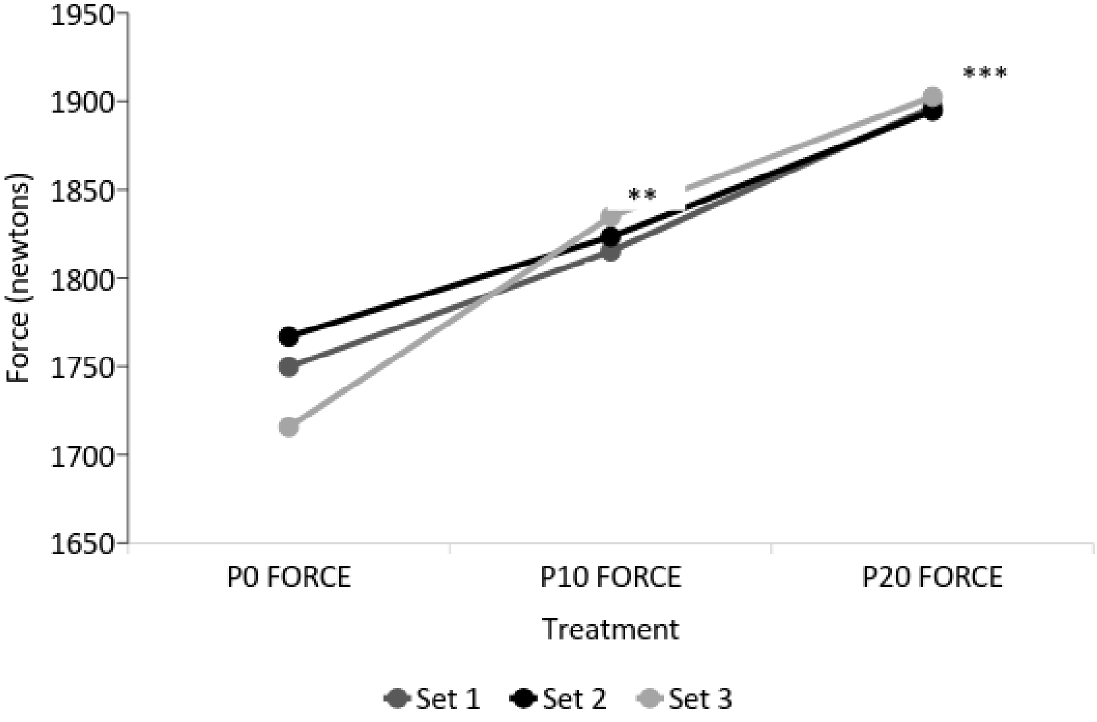


Figure 4: Set Interactions of force and treatment protocols.

P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. Reported as means ± SEM. All significant values represented at P ≤ 0.05. ***P20 treatment significantly different from all P0 treatment trials. **Set 1 P10 treatment significantly different than Set 3 P0 and Set 3 P20. *P10 set 3 significantly different from Set 1 P0, and Set 3 P0

The interactions between sets 1, 2, and 3, were further analyzed to determine statistical significance between set interactions and IRR treatment protocols of (P20, P10, and P0). Velocity values were further analyzed to determine statistical significance between sets and treatment protocols.

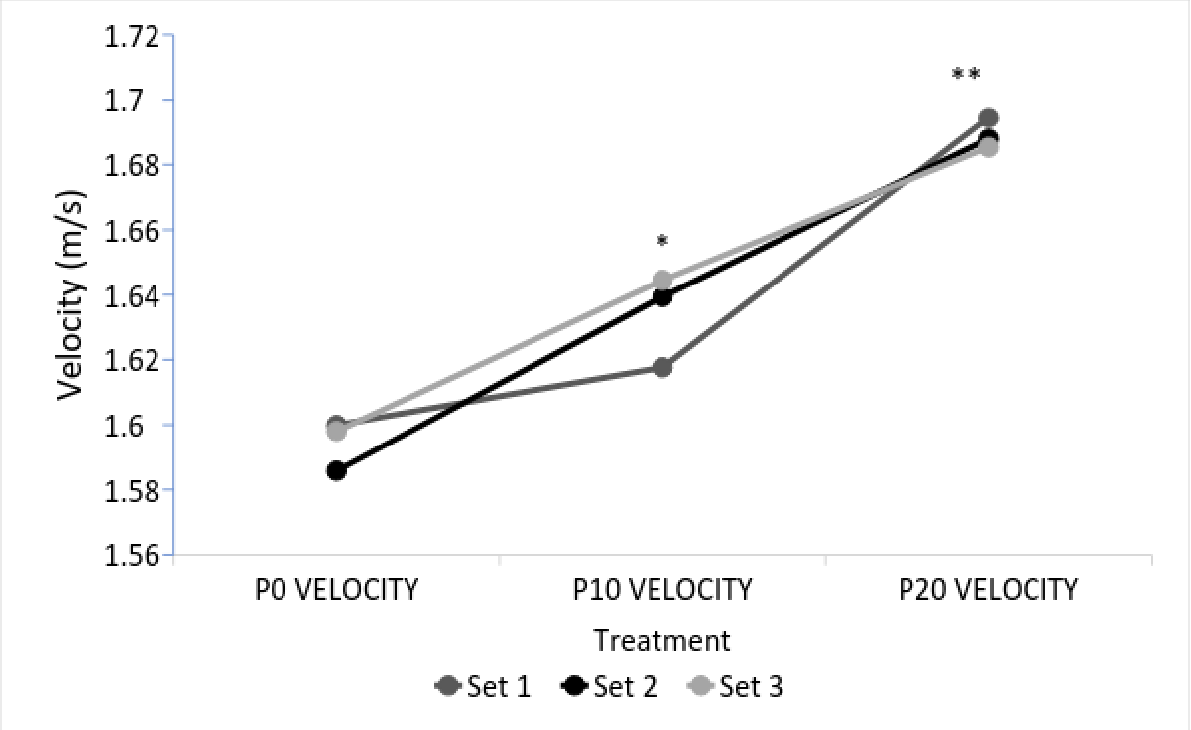


Figure 5: Set Interactions of velocity and treatment protocols.

P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. Reported as means ± SEM. All significant values represented at $P \leq 0.05$. **P20 all sets significantly different from all P0 Sets, and Set 1 P10. *P10 Set 3 significantly different from Set 2 P0.

The interactions between sets 1, 2, and 3, were further analyzed to determine statistical significance between set interactions and IRR treatment protocols of (P20, P10, and P0). Power values were further analyzed to determine statistical significance between sets and treatment protocols.

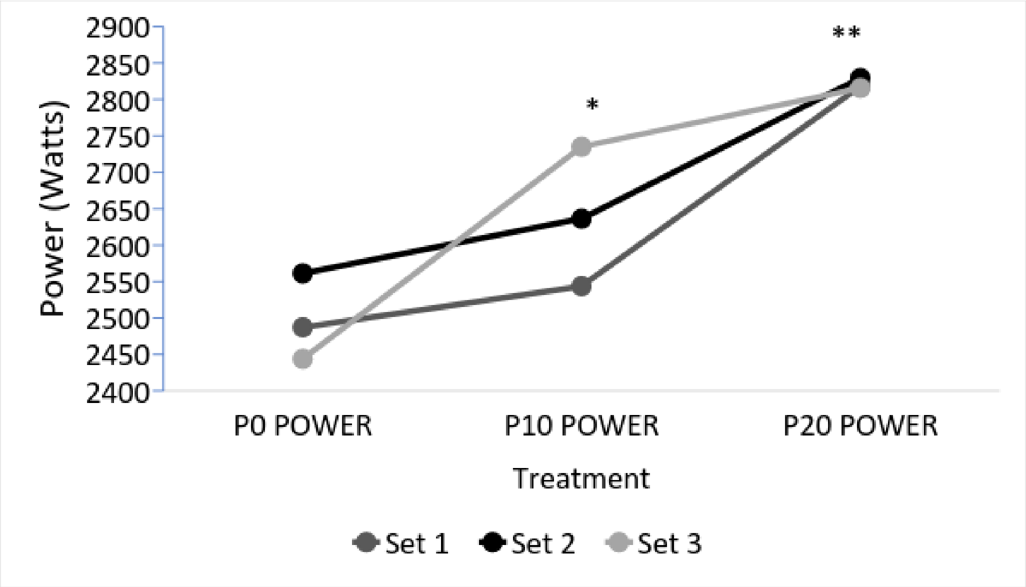


Figure 6: Set Interactions of power and treatment protocols.

Reported as means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. All significant values represented at $P \leq 0.05$. **All P20 sets significantly different from all P0 trials, and Sets 1-2 with P10 treatments. *Set 3 P10 significantly different from all P0 trials, and Set 1 P10 trial.

Mean peak force percentages between protocols were further analyzed to determine percentage differences between protocols. IRR of P20 was represented as 100% of maximal values. IRR P10, and P0 were then analyzed to determine percentage drop off in relation to P20.

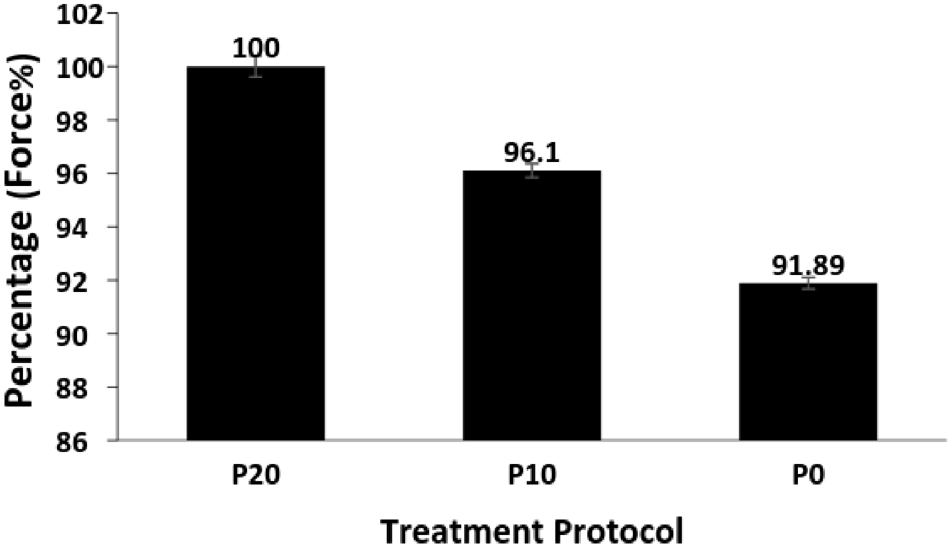


Figure 7: Mean peak force percentage difference between protocols.

Error bars are reported means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR.

Mean peak velocity percentages between protocols were further analyzed to determine percentage differences between protocols. IRR of P20 was represented as 100% of maximal values. IRR P10, and P0 were then analyzed to determine percentage drop off in relation to P20.

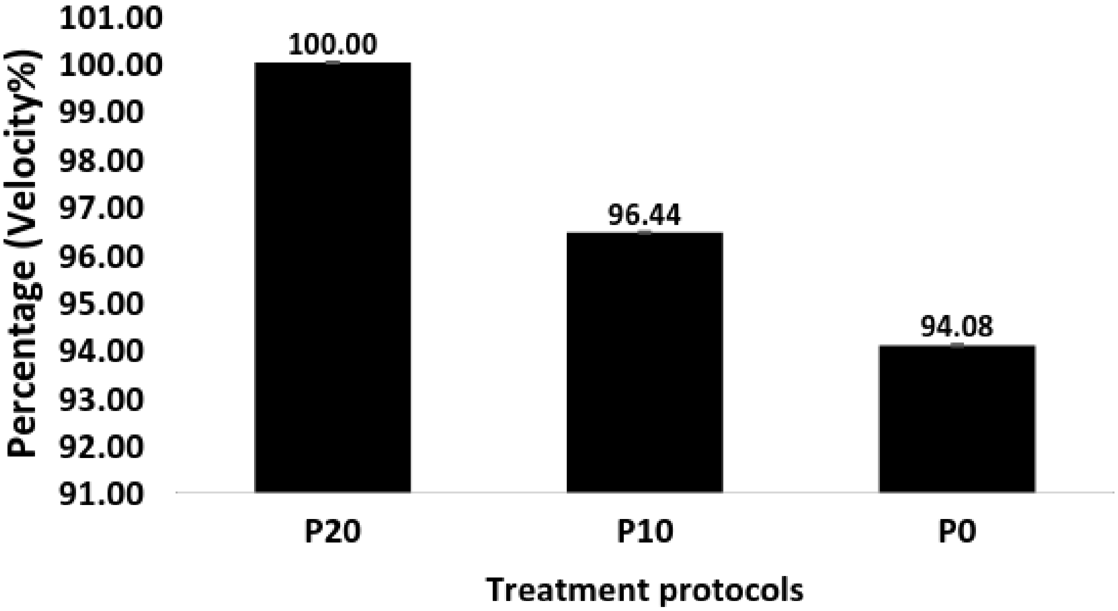


Figure 8: Mean peak velocity percentage difference between protocols.

Error bars are reported means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR.

Mean peak power percentages between protocols were further analyzed to determine percentage differences between protocols. IRR of P20 was represented as 100% of maximal values. IRR P10, and P0 were then analyzed to determine percentage drop off in relation to P20.

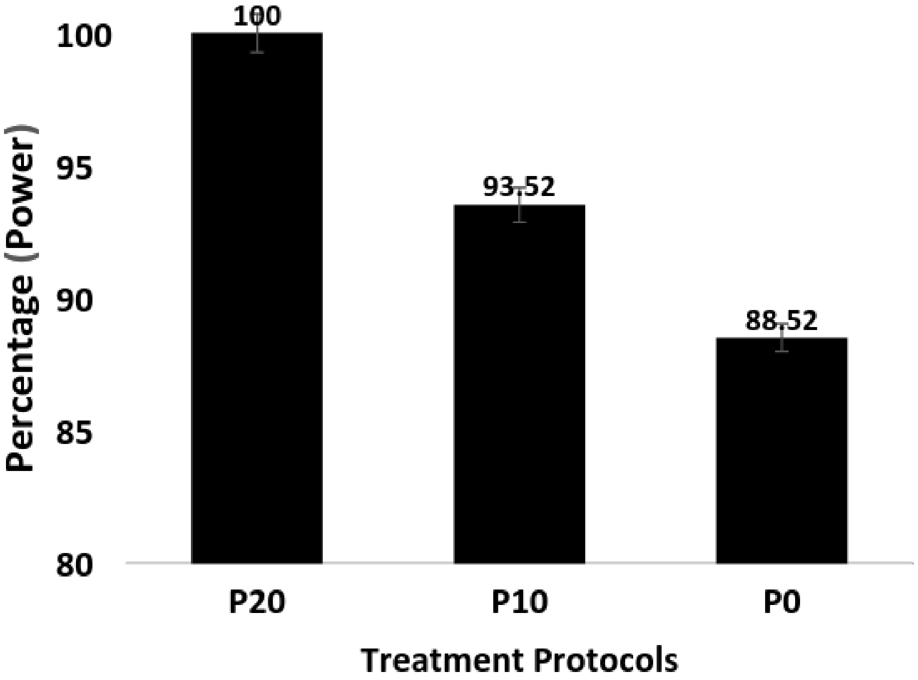


Figure 9: Mean peak power percentage difference between protocols.

Error bars are reported means ± SEM. P0= 0 seconds IRR. P10= 10 seconds IRR. P20= 20 seconds IRR. Reported as means ± SEM.

Chapter 5

DISCUSSION

Previous literature has explained the relationship between continuous repetitions, sets, and neuromuscular fatigue (Enoka & Duchateau, 2008). The ability to maintain power, force, and velocity throughout exercise bouts is ideal for maximizing the appropriate stimulus, thus in turn causing optimal adaptation to exercise. Power output is viewed as one of the most valid markers for performance in weightlifters and athletes alike. Weightlifting maneuvers are characteristic for improving performance and power output by influencing ballistic neurological adaptations (Cormie et al., 2011). However, since weightlifting movements are complex and ballistic in nature, proper exercise prescription is essential to success. Previous literature has shown decrements in performance variables involving weightlifting maneuvers and basic strength exercises with continuous repetition bouts. Therefore, training methodologies to maximize stimulus and adaptation during weightlifting bouts is of high interest in the strength and conditioning field. The current study aimed to investigate the effects of varying Inter-Repetition Rest (IRR) on the acute snatch pull performance variables of power output, force, and velocity.

This investigation showed a strong relationship between longer bouts of IRR treatments and production of power output, force, and velocity. This investigation showed an overall statistical significance between all-time treatment (time) groups and the dependent performance variables of power, force, and velocity. Specifically, there were differences between P0, P10, and P20 treatments for power, force, and velocity. The treatment effect was strongest between P0 treatments and P20 (p = 0.000) indicating the relationship between P0 and P20 to be most critical. This is in conjunction with the P20 treatment group being highest in all dependent peak mean values for power, force, and velocity. Overall, treatment effects between P10 and P20 were significantly different for power, force, and velocity, at p = .001, p= .000, and p = .003 respectively.

The statistical significance between treatments of P10 and P20 infers the relationship between the two treatment groups to be meaningful for discussion. Although P20 treatments elicited superior data in power, force, and velocity, the P10 treatment group decrements were minimal relative to P20 treatment group. Specifically, the P10 treatment group had decrements of force, velocity, and power of 3.9%, 3.56%, and 6.48% respectively. Although these values are significant, in comparison, the P0 treatment group had decrements of force, velocity, and power of 8.11%, 5.92%, and 11.48% respectively in comparison to the P20 treatment. Based on the observed biomechanical parameters, P20 elicited the most consistent and superior values. However, the P10 treatment group was also statistically effective when compared to the P0 treatment.

No statistical significance was found between sets (group). This data suggests that rest intervals had more of a distinct relationship effect on overall within set group values, and not within set repetition differences. However, post hoc analysis indicated significant interactions between select sets and treatment effects. Specifically, there were significant interaction effects between all sets for P20 treatment and P0 treatments. The set and time interaction infer that the relationship between the P0 treatment and P20 treatment group is repeatable within all sets 1-3 for every variable measured. In comparison, fewer set and treatment interactions occurred between the P0 treatment and P10 treatment. Set interactions between treatment P10 Set 3 and Set 3 for P0 treatment for both force and power were significant P<.05. Based on these data, set interactions appear to be occurring in the later sets (set 3) between treatment P10 and treatment P0. This suggests that the treatment of P10 is eliciting better force and power as the quantity of sets increases compared to the P0 treatment. It can be speculated that the importance of IRR increases as set quantity increases, which is seen in the relationship of the P0 treatment and P10 treatment becoming significant in the last set of the experiment.

The results agree with previous studies showing IRR and cluster sets to have influential effects on performance maintenance in continuous repetitious bouts of exercise (Haff et al., 2001; Hardee et al., 2013; Lawton et al., 2006; Moreno et al., 2014). Haff et al., (2001) showed higher barbell velocities utilizing cluster sets with multiple repetition bouts in the clean pull exercise. Hardee et al. (2013) showed significantly higher power, force, and velocity values with increasing IRR treatments during the power clean exercise. Lawton et al. (2006) showed significant differences when implementing IRR and cluster sets compared to traditional continuous repetition bouts in the bench press exercise. The study showed 23 second IRR elicited a 21% higher power output than control groups with continuous groups. Hardee et al. (2013) showed that mean peak power dropped 14.94% throughout the set with continuous repetition bouts in comparison to only 5.76% decreases with 20 second IRR treatment groups. This study agrees with these previous studies by showing significantly higher values in power, velocity, and force with increasing IRR in the snatch pull exercise. The data reported shows peak mean values for power output during the control group of P0 seconds IRR to be 11.97% lower than P20 treatment group and P10 seconds IRR to be 6.48% lower than the P20 treatment group. Based on the results found in this study and previously published literature, the relationship between IRR, especially ≥ 20 seconds seem to elicit superior values for power, force, and velocity within multiple set and repetition schemes.

Furthermore, the current investigation only showed significant differences within IRR treatments. This study showed no statistically significant data reported between repetitions. In comparison, other studies showed statistically significant decreases in performance within sets when comparing multiple repetitions (Haff et al., 2001; Hardee et al., 2013; Lawton et al., 2006; Moreno et al., 2014). Previous literature has shown decreases in power, force, and velocity with continuous repetitious exercise bouts across a variety of exercises. Hardee et al., (2013) showed significant differences between repetitions 2-6 in a 6-repetition bout of power cleans. The study showed significantly decreasing power output, velocity, and force after the 1st repetition and continuing until the 6th repetition. Generally, repeated bouts of intense exercise are characteristic of decrements in performance (Enoka & Duchateau, 2008). The decrements in performance can be quantifiable by power, force, and velocity measurements with strength training (Haff et al., 2001; Hardee et al., 2013; Lawton et al., 2006; Moreno et al., 2014). However, this study did not find a significant difference within or between repetitions and IRR treatments. Reasons why the lack of statistical relationship between each repetition and IRR treatments in this study occurred can only be speculated. It should be noted that this is the first article, to the authors knowledge, implementing IRR with any snatch variation.

Previous literature has showed IRR treatments to be significant in other Olympic lifts such as the clean and power clean. Clean variations are significantly higher in loads. Increasing intensities or loads cause for more of a reduction and decrement between repetition power, force, and velocity values (Haff et al., 2001; Hardee et al., 2013; Lawton et al., 2006; Moreno et al., 2014). The subject population all performed exercise derived from a maximal effort lift. However, the nature of the snatch pull exercise could be a submaximal stimulus and not a true maximal effort lift due to various reasons. One reason being that Olympic weightlifting movements are complex, ballistic, and most of all require efficient technique. Since the prescribed exercise is based off a 1RM in the snatch, lifters could be inhibited by strength and not technique in their 1RM. Snatch pull exercise is essentially a ballistic deadlift with triple extension of the ankle, knee, and hips. Meaning, athletes generally snatch pull significantly higher intensity loads than their 1RM in the snatch. Potentially, the load of 100% 1RM in the snatch may not have been a high enough intensity to induce decreases within each repetition.

Collectively this study, and previous literature have demonstrated utilizing IRR and cluster set interventions to maintain performance in a variety of aerobic and anaerobic exercise bouts. The main principle behind the improving maintenance of performance is the reduction of neuromuscular fatigue (Enoka & Duchateau, 2008). The process of reducing muscular fatigue can be accomplished by positively affecting energy metabolism, peripheral, and central fatigue factors (fatigue). Furthermore, the theory behind performance maintenance implementing IRR and cluster sets, is the physiological process of partial synthetization of phosphocreatine stores between exercise bouts (Enoka & Duchateau, 2008). Mendez-Villaneuva, Edge, Suriano, Hamer, & Bishpop et al. (2012) compared repeated bouts of sprint exercise with phosphocreatine resynthesis to determine the physiological equivalents of power output maintenance. The investigation showed a strong correlation (r= 0.67) between re-synthesis of phosphocreatine and power output maintenance. Mendes Villanueva et al., (2012) suggests that intramuscular phosphocreatine content is an important physiological determinant of performance during repeated bout exercise. This implies that for anaerobic sprint work phosphocreatine content shares a strong relationship with sprint performance. Billaut, Giacomoni, & Falgairette, (2003) found significant differences between rest intervals of 15 seconds and all other groups, 30, 60, 90 seconds when comparing maximal sprint performance. This study concluded that peak power values were maintained from minimal 30 seconds of rest between 8 second bouts of maximal sprints. The study also found that the treatment of 15second rest although significant, only elicited a decrease in peak power from 7-8%. Collectively, Billaut et al., (2003) and Mendes-Villanueva et al., (2012) stated that phosphocreatine re-synthesis plays a critical part in repeated sprint bouts when muscle pH and motor unit activity may be severely depressed. Phosphocreatine re-synthesis has been shown to vary with age, gender, activity level, intensity of exercise, and recovery duration. With increasing maximal intensity phosphocreatine repletion was noted to replenish by 50% at 30 seconds' duration after complete depletion (Maughan, & Gleeson., 2010). This in somewhat in agreement with Harris, Edwards, Hultman, Nordesjo, Nylind, Sahlin, (1976) investigation that showed phosphocreatine re-synthesis half-life to be around 21-22 seconds during isometric quadriceps contraction bouts. Furthermore, phosphocreatine stores with short duration maximal anaerobic work appears to share a strong relationship. This could be one of the unmeasurable mechanistic outcomes of our study showing significance of P20 treatment groups being superior when comparing P0 treatment, and P10 treatment. Synthesizing the literature, IRR of 20 seconds may elicit an appropriate time for partial phosphocreatine resynthesis to occur. The partial phosphocreatine resynthesis may be the cause of the resultant superior power, force, and velocity measurements observed in this study. To date no research has looked at resistance training IRR and phosphocreatine resynthesis rates, indicating more future in-depth research analysis with IRR and exercise bouts.

Conclusion

The current research supports the benefit of implementing IRR treatment with previous studies (Haff et al., 2001; Hardee et al., 2013; Lawton et al., 2006; Moreno et al., 2014). Based on the results from this study implementing IRR could maintain performance in multiple set and repetition bouts during a snatch pull movement. The data demonstrates that implementing 10-20 seconds of IRR in comparison to continuous bouts will help to maintain power output, force, and velocity during full body resistance training. It appears based on Hardee et al. (2013), and our current findings, that implementing IRR of 20 seconds' intervals elicit significant maintenance of acute performance variables. Being able to perform dynamic high-intensity weight lifting while maintaining muscular power and force may elicit a stronger stimulus, in turn, allowing for maximal adaptation to exercise.

Practical Application

The ability to produce and maintain maximal power output, force, and velocity during weightlifting movements is crucial for neurological and physiological adaptations. Therefore, implementing appropriate methodologies while performing these movements may produce a more superior stimulus leading to an overall increase in adaptation. Strength coaches, athletes, researchers, and exercise practitioners can benefit alike from having the knowledge and ability to implement IRR protocols to control neuromuscular fatigue and maintain a higher stimulus during weight lifting exercises.

Appendix A
INFORMED CONSENT

THE EFFECTS OF INTER-REPETITION REST ON ACUTE SNATCH PULL PERFORMANCE

You are invited to participate in a research study which will involve a set lifting volume configuration for the snatch pull exercise. My name is Ricky Davis, and I am a Graduate Kinesiology Student at California State University, Sacramento. The purpose of this research is to identify the effects of inter-repetition rest (rest intervals) during a compound velocity based olympic weightlifting pulling derivative (snatch pull) in relation to the acute performance variables (power output, velocity, displacement).

If you decide to participate, you will be asked to fill out a health questionarre followed by 4 treatment sessions. All treatment sessions will take place in the biomechanics laboratory at california state university campus. The first treament session we will determine a 1-repetition maximum of the snatch exercise. The remainder 3 treatment sessions you will be asked to return back to the laboratory and we will randomly assign a set rest interval for the snatch pull volume configuration. This means that you will have to perform 3 sets of 5 repetitons in the snatch pull exercise and the investigator will manipulate and tell you how much time between repetitions is allowed for the current treatment session. An example of the rest intervals will be 0, 10, and 20 seconds respectively. Your participation in this study will last 4 weeks or less. The time commitment for this study will be overall less than 4 hours minus travel time from your disclosed location. A dynamic warmup will be controlled and included prior to each testing session. Assigned warm up sets and repetitions will be included up until the working volume prescribed for the treatment session.

There are some possible risks involved for participants. These risks include any injuries that can commonly or uncommonly occur during weight lifting exercises. Musculoskeletal injuries being at the top of the list, followed by strains, sprains, and bruises that may occur from weightlifting. To reduce the chance of injury a certified strength and conditioning specialist, certified personal trainer, and usa weightlifting sport performance coach (same person) will be instructing the dynamic warmup and overseeing all lifting during the treatment sessions. Also in case of emergency local university police will/can be contacted. There are some benefits to this research,particularly in understanding how performance is effected by implementing rest intervals. Other benefits include insight to acute performance in snatch pull exercise, and how continous repetitions and sets may effect your physiological performance.

Your participation in this project is voluntary. You have the right not to participate at all or to leave the study at any time without penalty or loss of benefits to which you are otherwise entitled.

Any information that is obtained about this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Measures to insure your confidentiality are the protected rights of your personal information, data and names will be kept confidential, kept on a password protected computer, and hard copies of data sheets will be kept in a locked file cabinet during and after the study. Data will be stored electronically and as paper documents. The data obtained will be maintained in a safe, locked location and will be destroyed after a period of three years after the study is completed. No names will be associated or other identifiable measures will be stored at any time during the study.

If you have any questions about the research at any time, please call me at (925-708-2375) or feel free to email me at Rickdavis@csus.edu also, feel free to contact the graduate advisor Rodney Imamura @ RImamura@csus.edu ((916) 278-7477) If you have any questions about your rights as a participant in a research project please call the Office of Research Affairs, California State University, Sacramento, (916) 278-5674, or email irb@csus.edu. In the event of a research-related injury, please contact your regular medical provider and bill through your normal insurance carrier, and then advise us. Also, in the case of emergency local university police will/ can be contacted at 278-6900 via cell phone or from any campus phone by dialing 911 *,8-6900, or 8-6000.

Your signature below indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled, that you will receive a copy of this form, and that you are not waiving any legal claims, rights or remedies. Sharing of data will be provided in the means of tables and graphs that will no depict names or any other identifiable objects. Final data can be obtained from the investigator once data collection is complete via email if the subjects are interested.

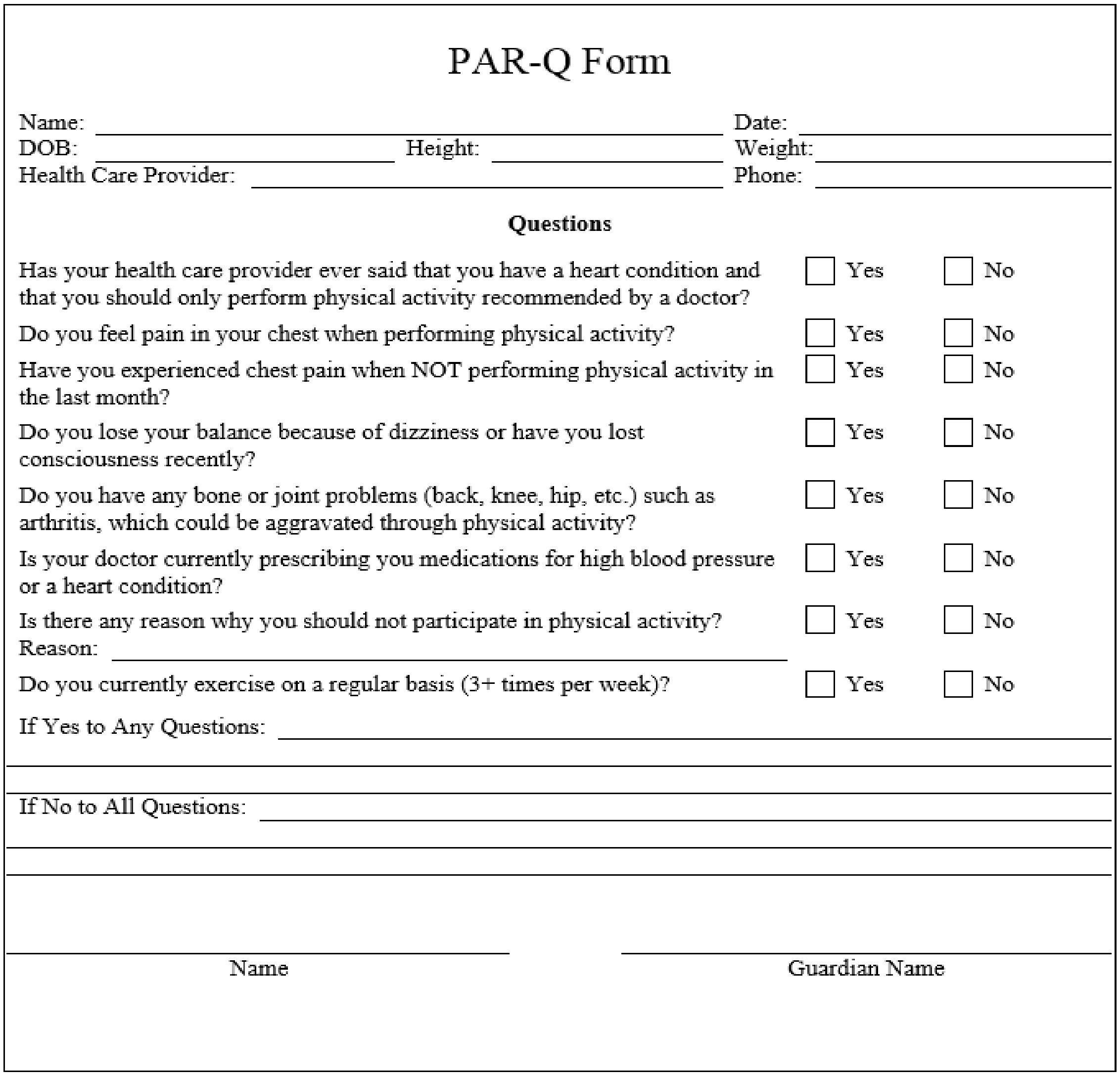
Name __________________________

Signature________________________

Date __________________________

Email __________________________

Appendix B
Health Questionnaire



PAR-Q Form

Name: ____________________ Date: ____________

DOB: ____________ Height: ____________ Weight: ____________

Health Care Provider: ____________________ Phone: ____________

Questions

Has your health care provider ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?	☐ Yes	☐ No
Do you feel pain in your chest when performing physical activity?	☐ Yes	☐ No
Have you experienced chest pain when NOT performing physical activity in the last month?	☐ Yes	☐ No
Do you lose your balance because of dizziness or have you lost consciousness recently?	☐ Yes	☐ No
Do you have any bone or joint problems (back, knee, hip, etc.) such as arthritis, which could be aggravated through physical activity?	☐ Yes	☐ No
Is your doctor currently prescribing you medications for high blood pressure or a heart condition?	☐ Yes	☐ No
Is there any reason why you should not participate in physical activity? Reason: ____________	☐ Yes	☐ No
Do you currently exercise on a regular basis (3+ times per week)?	☐ Yes	☐ No

If Yes to Any Questions: ____________________

If No to All Questions: ____________________

Name

Guardian Name

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