Biomechanical comparisons of the power clean and power hang clean exercises at different relative intensities

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Biomechanical Comparisons of the Power Clean and Power Hang Clean Exercises at Different Relative Intensities

By

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Thesis

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Abstract

The purpose of this study was to compare normalized peak power (PP) and peak barbell acceleration (BA) between the power clean (PC) and power hang clean (PHC) exercises among eight male weightlifters (25.5 ± 2.86 yr; 85.25 ± 11 kg). Biomechanical comparisons were made between both exercises at 60%, 70%, and 80% of each subject’s one repetition maximum (1RM). When comparing both exercises for normalized PP, there was no significant difference at 60% and 70% of 1RM. At 80% 1RM, the PHC demonstrated significance (p = 0.016) with higher normalized PP when compared to the PC. When comparing both exercises for peak BA, results demonstrate greater BA for the PHC when compared to the PC at 60% (p = 0.036) and 70% (p = 0.041) of 1RM, but no significance at 80%. Results offer strength and conditioning coaches greater insight with regard to exercise selection and relative resistance when designing resistance-training programs for athletic populations.
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Chapter I: Introduction

Developing an athlete’s ability to produce high levels of muscular power and increase their rate of force production and acceleration is an important component during anaerobic sport (Comfort, Allen, & Graham-Smith, 2011a; Kilduff et al., 2007). Research suggests that the more specific a training exercise is to the actual athletic event, the greater potential for the exercise to transfer to improve athletic performance (Baker, 1996; Stone, Plisk, & Collins, 2002). Weightlifting is a sport associated with several important performance variables, and the proper selection of weightlifting exercises or their variants during training becomes an important consideration for the performance coach when trying to enhance athletic performance (Hori et al., 2007; Kawamori et al., 2005).

Recent investigations have been initiated to establish to what extent these various exercises have on physical performance, namely peak power output and rapid changes in direction (Comfort et al., 2011a; Comfort, Allen, & Graham-Smith, 2011b; Comfort, Udall, & Jones, 2012; Cormie, McBride, & McCaulley, 2007; Cormie, McCaulley, Triplett, & McBride, 2007; Cormie, McGuigan, & Newton, 2011a, 2011b; Kilduff et al., 2007; Sato, Sands, & Stone, 2012). Several of these investigations offer insight for the performance coach on potential improvements in peak power outputs, rapid rates of force production, and peak barbell accelerations when weightlifting exercises like the power clean and power hang clean are utilized. The performance coach can use these investigations to determine the appropriate selection of exercises that will best enhance anaerobic athletic movement, chiefly muscular power output and force production (Comfort, Fletcher, & McMahon, 2012; Kilduff et al., 2007).
Previous investigations support the use of weightlifting exercises to address the production of high rates of force into the ground during anaerobic sport (Baker, 1996; Cormie et al., 2011b; Hori, Newton, Nosaka, & Stone, 2005; Hori et al., 2008; Kirby, McBride, Haines, & Dayne, 2011; Kraemer & Newton, 2000). The high force production during Olympic weightlifting style exercises can aid in the athletes power production and acceleration, which are highly desirable from a training standpoint (Hori et al., 2005). These high rates of force production are beneficial for athletes that compete in various sports such as 100 meter sprinters, who require maximal power to accelerate their bodies as quickly as possible, or elite volleyball players, who require rapid changes in direction, acceleration, and vertical power for driving the ball over the net, and finally, professional football linemen, who need high levels of power and acceleration to drive an opposing player off the ball (Hori et al., 2005). Weightlifting exercises and their variants allow athletes to produce the high rates of force needed because these movements engage full, simultaneous extension of the hip, knee, and ankle joints, which demonstrate similarities to the action-reaction movements observed in sprinting, vertical jumping, and agility-type movements (Hori et al., 2005).

The sequential “triple extension” of the hip, knee, and ankle contribute to the maximal power output an athlete is able to produce during athletic movements and is commonly reported as a desirable component for strength and conditioning coaches to enhance through the introduction of various training protocols (Cormie et al., 2011a, 2011b; Kawamori et al., 2005; Kraemer & Newton, 2000). The triple extension during Olympic style weightlifting has been shown to produce high rates of force that create high barbell velocity, and as a result, greater power is produced as the product of the instantaneous ground reaction
force coupled with the resultant barbell velocity (Comfort, Fletcher, et al., 2012; Cormie et al., 2011b).

While muscular power output measurements are of primary concern, the measurement of barbell acceleration can provide additional feedback regarding training adaptations for rate of force development (Sato et al., 2012). Barbell acceleration is derived from the resultant changes in velocity of the barbell over a selected displacement (Flanagan, 2014). The application of tracking peak accelerations of the barbell can be used as an assessment to observe the barbell’s acceleration and progression of muscle force generating capabilities. Tracking barbell accelerations during weightlifting style movements allow performance coaches to quantify and observe athletic status when lifting with higher loads, especially when an athlete is not producing adequate force and barbell acceleration due to various factors such as incorrect technique, improper coaching, and possibly using a mass beyond the athletes lifting ability (Sato et al., 2012).

To induce changes in power and acceleration, performance coaches need to focus on the rapid force generating capability of the athlete (Sato et al., 2012). The clean exercise is reported to optimize the force generating capability for an athlete, which in turn may enhance sport-specific abilities during competition (Cormie et al., 2011b; Sato, Fleschler, & Sands, 2011). Performance coaches often teach weightlifting exercises because they share kinetic and kinematic characteristics (e.g., peak power output, rapid force development, movement velocity, and changes in acceleration) that can potentially elicit improvements in athletic performance (Comfort, Fletcher et al., 2012; Stone et al., 2003). Because these exercises are often selected and utilized during training, the performance coach should be able to
confidently coach and have an awareness of the key biomechanical variables that influence the effectiveness of certain weightlifting exercises.

The power clean and power hang clean are two training variations of the clean exercise in the sport of weightlifting that performance coaches might select when creating performance programming for athletes. Thus, for the power clean and power hang clean exercises, it should be considered which exercise offers superior benefit because they differ in starting position, which in turn leads to different instruction, unique movement patterns, and potentially different biomechanical output parameters (Hendrick, 2004; Hori et al., 2005).

During the initial phases of teaching the technical aspects of weightlifting, performance coaches have the difficult chore of teaching exercises from these various positions dependent upon physical abilities, experience, technique, time constraints, and the athlete’s interpretation of feedback during instruction (Hendrick, 2004; Hori et al., 2005; Hori et al., 2007). To ensure proper body mechanics and technique, the performance coach must make necessary adjustments accordingly to alter barbell travel patterns with an effective feedback approach (Winchester, Porter, & McBride, 2009). The quantity and quality of feedback can potentially translate into improved force, velocity, and muscular power production during the clean exercise (Winchester et al., 2009).

The feedback and application of weightlifting exercises performance coaches use does come with certain constraints. Performance coaches are limited with the amount of contact time they are permitted to spend with athletes during the year. The determination of which exercise, load, intensity, and optimal instructional approach becomes very valuable to the performance enhancement coach because of these restraints. Therefore, if less time can
be spent teaching a slightly less technically demanding and coaching intensive movement without dramatic changes in the biomechanical aspects of the exercise, perhaps the instruction of this variant exercise should be pursued (Comfort, Fletcher et al., 2012; Comfort, Udall et al., 2012; Kawamori et al., 2006).

Having an awareness of the changing kinetics and kinematics during weightlifting exercises are important because starting positions between them differ (Hori et al., 2005). Yet another concern for the performance coach associated with previous weightlifting studies is how muscular power output and barbell acceleration have been reported. The power clean and power hang clean have been presented using absolute comparisons (i.e., compared without mass) or compared with simple relative values (i.e., watts/kg) and may provide performance coaches with incorrect assumptions (Comfort et al., 2011a, 2011b; Comfort, Fletcher et al., 2012; Comfort, Udall et al., 2012; Cormie, McCaulley et al., 2007; McBride, Haines, & Kirby, 2011). The comparisons of absolute/relative values may skew data sets that use participants among various athletic populations with different anthropometric features such as mass. The use of allometric scaling has been suggested when strength is compared between dissimilar subjects and may be a useful approach when comparing relative intensities between subjects and studies (Jaric, 2002).

The use of proper normalization may also aid in standardizing comparisons among sample populations of differing masses. For example, significantly larger subjects may introduce statistical error when being compared with smaller subjects or compared as an average between total subjects. This error may be created from anthropometric differences in fat free mass as differences in fat free mass can differentiate power outputs among subjects.
of the same mass and in particular, among weightlifters of greater total mass (Cormie et al., 2011b; Jaric, 2002).

For subjects of varying mass and ability, differences in relative intensity for each lifter may alter force production, power output, and barbell acceleration because the load lifted is either increased or decreased from subject to subject. Because of potential differences in fat free mass and ability, technically sound subjects have the potential to increase power outputs above the capacity of untrained or inexperienced subjects from previous investigations (Bevan et al., 2010; Cormie et al., 2011a, 2011b; Gabriel, Kamen, & Frost, 2006; Hori et al., 2005; Kraemer & Newton, 2000). Thus, normalizing for subject differences in fat free mass and accounting for training experience should be considered when weightlifting exercises are involved.

There is previous work on the influence of relative loading among key biomechanical variables such as power output, rate of force development, and magnitude of force production in the power clean and power hang clean (Comfort, Fletcher et al., 2012; Cormie, McCaulley et al., 2007). Many of these papers engage participants of various sports and activities, and it must be considered that most of these data sets do not consider potential variability for both exercise and technical experience or potential anthropometric differences, especially with regard to lean muscle tissue (Bevan et al., 2010; Comfort, Fletcher et al., 2012; Haff et al., 2003).

As a result, the determination and role of relative loading combined with the use of consistent normalization techniques to report accurate comparisons among subjects are also sparse. This lack of information can present confusion when the performance coach is concerned with selecting optimal training exercises among various athletic populations and
events. Because of these limitations, comparisons between variations of the clean exercise at various intensities may be of more utility when considering appropriate normalization techniques and experienced subjects.

**Purpose of the Study**

In order to help performance coaches determine the appropriate exercise and relative intensity to improve athletic attributes, the purpose of this study was to compare relative peak power output and peak barbell acceleration between the power clean and power hang clean exercises, at three submaximal loads of 60%, 70%, and 80% of one repetition maximum (1RM).

**Significance of the Study**

The significance of this study lies in the basis that weightlifting is used as a training tool for collegiate strength and conditioning programs. Due to the limited time coaches are permitted to spend with athletes throughout the training year, it is vital to maximize the efficiency and effectiveness of physical training. Understanding the impact of different modalities at different relative intensities could greatly assist the performance coach with the exercise selection and prescription process. Because instruction and program design can be a timely process for strength and conditioning coaches, this study may provide greater insight regarding biomechanical differences between the power clean and power hang clean exercise. This in turn can potentially lead to more efficient use of time with regard to instruction and the selection of those exercises that can have the greatest impact on athletic performance.
Research Questions

1. Is there a significant difference in normalized peak power output when comparing the power clean to the hang power clean at three relative intensities of 60%, 70%, and 80% of one repetition maximum?

2. Is there a significant difference in normalized peak barbell acceleration when comparing the power clean to the hang power clean at three relative intensities of 60%, 70%, and 80% of one repetition maximum?

Delimitations

1. Participants were United States of America Weightlifting club-level weightlifters and have a minimum four years of state level competition experience and practice.

2. Participants were all male subjects.

Assumptions

During the investigation, the following assumptions were made:

1. Participants provided a maximal volitional effort during each trial.

2. Participants provided accurate up-to-date 1RM information for the power clean and power hang clean exercises.

Limitations

1. Technical skill may be different among subjects with more or less experience, which in turn may have some influence on biomechanical variables tested.

2. Subject data is limited to club-level weightlifters, previous athletic experiences may have had an impact on the variables tested.
Definitions

*Acceleration:* The rate at which the velocity changes with time. \( a = \frac{\Delta v}{t} \).

*Allometric scaling:* (i.e., Normalization) used to account for tested movement performance and body size to improve subject validity of muscle force \( S_n = \frac{S}{m_b} \); Jaric, 2011).

*Force:* Any influence that causes an object to undergo a certain change in acceleration \( F = ma \).

*Force platform:* A complex force transducer that measures all three orthogonal forces (i.e., vertical, medial-lateral, anterior-posterior) and moments applied to the surface.

*Force velocity curve:* The relationship between muscular force and velocity during contraction of a muscle fiber.

*Impulse:* A force acting briefly on a body and producing a fixed change of momentum \( \text{Impulse} = F \Delta t \).

*Kinematics:* An aspect of motion separate from considerations in mass and force.

*Kinetics:* The relationship of forces in producing or changing the motion of masses.

*Momentum:* The quantity of motion from a moving body, measured as a product of its mass and velocity \( p = mv \).

*Performance coach:* An individual with the educational background and professional skill to enhance human physiological and mechanical factors associated with sport performance.

*Power:* Rate of work per time of a human \( \text{Power} = \frac{\text{work}}{\text{time}} \text{ or } F \times \text{velocity} \).

*Power clean:* A variation of the “clean” exercise. The athlete begins with the weight on the ground in a set position, pulls the weight to just above the knee, and explosively drives the feet into the ground driving the body under the bar. The athlete will finally
catch the barbell on the shoulders in a semi-squat position.

**Power hang clean:** A variation of the “clean” exercise. The athlete begins with the weight sitting just above the knee and explosively drives the feet into the ground driving the body under the bar. The athlete will finally catch the barbell on the shoulders in a semi-squat position.

**Power output:** The amount of “power” output calculated from doing work in a prescribed manner.

**Rate of force development:** The rate in which force can be applied to an object during a specific time frame.

**Strength:** The maximal amount of force a muscle or muscle group can produce.

**Velocity:** The rate of change in the position of an object \( (v = \frac{d}{t}) \).

**Work (mechanical):** Work is preformed when a force moves an object in the direction of the force.

**Weightlifting:** The sport of lifting barbells in a prescribed manner (e.g., clean and jerk, snatch).
Chapter II: Review of Literature

During competition, competitive weightlifters must demonstrate effective technique, while maximizing power output and barbell acceleration throughout each exercise to achieve peak performance (Comfort, Udall et al., 2012; Hori et al., 2007, 2008; Sato et al., 2012). Performance coaches and strength and conditioning professionals utilize the training methods in weightlifting to help assist in the enhancement of athletic performance in sports that require high-power output and rapid rates of force development such as football, basketball, and track and field events (Hori et al., 2008).

The training methods utilized in weightlifting are beneficial to many athletes because of similarity in biomechanical profiles, primarily during the triple extension at the hip, knee, and ankle during the second pull of these exercises (Hoffman, Cooper, Wendell, & Kang, 2004). The triple extension during weightlifting is one of the fundamental movement requirements for developing high force and power output during short time frames (Hoffman et al., 2004). In addition, weightlifting exercises allow the segments of the body to accelerate the barbell through large ranges of motion during the second pull of the power clean or power hang clean (Hori et al., 2008).

Athletes utilizing training movements that are biomechanically similar to sport (i.e., “training specificity”) are potentially more capable of inducing desirable transfer of training effects to enhance sport performance (Hori et al., 2005). Competitive weightlifting exercises, such as the clean and jerk, the snatch, and their derivatives, are regularly incorporated into power training programs of many athletes who compete in various anaerobic sports (Comfort et al., 2011b).

The power clean and power hang clean are derivatives of the full clean exercise.
Similar to the full clean, both require the exertion of high forces against the ground instantaneously (Hori et al., 2008). These clean exercises involve exerting high forces against the ground rapidly, and because of this, they appear to be ideal training exercises to exhibit performance adaptations among anaerobic athletes (Hori et al., 2008).

Weightlifting exercises have also been shown to demonstrate high muscular power outputs with methods where power is expressed as the product of a ground reaction force and barbell velocity; thus, peak power output during weightlifting is achieved at a specific level of force and barbell velocity (Comfort, 2013; Comfort et al., 2011b; Cormie et al., 2011b; Hori et al., 2005). Hypothetically, the athlete and performance coach will find training with proper technique and optimal intensity during weightlifting exercises like the clean and jerk as a method to increase peak power output (Hori et al., 2005).

Clean exercises may increase force generation and muscular power output beyond that of regular resistance style training (Cormie et al., 2011b; Hori et al., 2005). These changes stem from neuromuscular adaptations that drive the improvement in athletic performance following power training (Cormie et al., 2011b). These neuromuscular adaptations are commonly derived from increased motor unit recruitment, preferential recruitment of high-threshold motor units, and/or lowering the threshold of motor unit recruitment (Gabriel et al., 2006).

In utilizing these exercises, it becomes important for coaches to introduce the appropriate variant exercise. It should be considered that the power clean and power hang clean differ in starting position; thus, starting position may become a consideration in the exercise selection process when there is limited time to teach technical aspects of each exercise, especially with unfavorable coach-to-athlete ratios (Hori et al., 2005).
Similar to the full clean, the power clean starts with the athlete in a “set” position (Figure 1) with the weight resting on the floor, but this is unique to each athlete due to anthropometric and fitness differences among each individual (e.g., flexibility, range of motion, height, limb length, and mass; Favre & Peterson, 2012). The first phase during the power clean begins in a set position when the athlete’s upper body is positioned with the chest up, scapula retracted, and spine tight or slightly lordotic (Favre & Peterson, 2012). The moment of separation from the floor is known as the first pull and occurs when the athlete applies force into the ground and lifts the barbell upward (Favre & Peterson, 2012). After the moment of separation, the lifter extends the legs, having the knees move slightly backwards until the shins are almost vertical. This extension helps keep the athlete’s weight in the heel and body weight balanced during the first pull (Favre & Peterson, 2012).

The transition phase includes a shift in the athlete’s position to keep the body in line with the bar to progress into the second pull phase. The second pull phase begins as the barbell reaches near mid-thigh position. The lifter then has a brief moment of deceleration, also known as the “double knee bend” and rapidly drives the feet into the ground (Figure 2). During the final phase, the athlete drives the hips in a vertical direction while accelerating the barbell to a certain height and transitions the body under the barbell in the catch position (Hori et al., 2005).
Figure 1: Set Position for the Power Clean Exercise.
Figure 2: Power Clean Sequence.

1 — Set ground position
2 — First pull
3 — Transition
4 — Second pull
5 — Catch
The power hang clean differs from the power clean because it begins with the athlete in the “hang” position (Figure 3). The athlete starts the exercise with the barbell just above the knee with his chest up and spine “tight” or slightly lordotic (Favre & Peterson, 2012). The athlete then transitions the barbell in line with the body, keeping weight in the heel, and then drives the feet rapidly into the ground, entering into the second pull phase from this style of the clean much quicker (Figure 4). The athlete will catch the bar on the shoulders exactly like the power clean; however, performance coaches may consider teaching from the hang position first because the first pull from the “set” position is completely eliminated. Teaching this technique first ensures technique simplicity, with previous investigations indicating the acquisition of high-power outputs during the second pull phase (Hori et al., 2005).

Biomechanical similarities of the triple extension may influence the rapid rates of force development produced during the clean exercise and its variations, which have been shown to play an important role in training adaptations for the vertical jump (Mackenzie, Lavers, & Wallace, 2014). Rapid rates of force production and power capability in the vertical direction during weightlifting movements have also been found to be related to performance in sprinting and jumping because of the similarities in force production (Kirby et al., 2011).
Figure 3: Set Position for the Power Hang Clean Exercise.
Figure 4: Power Hang Clean.

1 — Set position
2 — Hang transition
3 — Second pull initiation

4 — Second pull
5 — Catch
Kinematic and kinetic comparisons have been made between the vertical jump, power cleans, and jump squats (Mackenzie et al., 2014). On average, maximal power output ranged from 4384 Watts (W), 3772 W, and 3532 W in the vertical jump, jump squat, and power clean, respectively (Mackenzie et al., 2014). Maximal power was significantly greater during the vertical jump when compared to the power clean and jump squat (Mackenzie et al., 2014). Conversely, maximal force production during these exercises was significantly greater for the power clean when compared to either exercises with 1770 Newtons (N), 2234 N, and 2411 N for the vertical jump, jump squat, and power clean, respectively (Mackenzie et al., 2014).

Another factor that could play a role in power output is the rate of force development because the rate at which force is applied may dictate increased or decreased power output at various relative intensities. Mackenzie et al. (2014) compared the rate of force development among ten university-aged female volleyball players and ten male football players and when comparing means, the power clean was significantly greater at 70% 1RM (17245 Newtons per second) when compared to the vertical jump (9465 Newtons per second), and the jump squat (7920 Newtons per second). The authors concluded that the power clean may enhance jumping performance because of the increased force generated during the power clean exercise when compared to the vertical jump and jump squat (Mackenzie et al., 2014).

In another study comparing the power clean and power hang clean among eleven elite rugby players, the power hang clean demonstrated a trend to elicit higher rates of force development (10314 ± 4238 Newtons per second at 60% 1RM) when compared to the power clean (8675 ± 2746 Newtons per second at 60% 1RM) (Comfort et al., 2011b). The higher rates of force development by subjects in the power hang clean over the power clean may be
partly due to the different starting positions of each exercise (Comfort et al., 2011b). Because starting from the top of the knee is different than starting from the ground like that of the power clean, the power hang clean has less distance to generate linear momentum on the barbell, and thus, rate of force development must be increased (Comfort et al., 2011b). This positional difference should potentially increase force and rate of force development, which may prove useful for the performance coach if the power hang clean does provide higher peak power outputs and barbell accelerations based upon the higher rate of force development (Cormie et al., 2011b).

Current literature on rates of force production during the power hang clean generally show increased peak power output when compared to the power clean, which may be from increased rate of force production and subsequent barbell velocities (Comfort et al., 2011a, 2011b; Mackenzie et al., 2014). However, there may be a point when loads become too heavy, requiring higher force values but leading to lower power outputs because the barbell velocity is significantly reduced (Comfort et al., 2011b).

Comfort et al. (2011b) described variations in force when multiple weightlifting exercise derivatives (e.g., power hang clean, power clean, and mid-thigh clean pull) were used. The authors found a significant difference in peak force during the power hang clean (2442 ± 293 N at 60% 1RM) when compared to the power clean (2306 ± 240 N at 60% 1RM); thus, the shorter barbell path during the power hang clean is associated with increased peak force production (Comfort et al., 2011b). Although comparisons of force generation for the power hang clean and power clean can be useful, previous investigations have not collected and compared force production changes during a sport training study, which may offer ideas on how these exercises may influence or enhance athletic ability (Comfort et al.,
Increases in barbell accelerations at high loads can be used as an indicator of increased force production for athletes in anaerobic sport (Sato et al., 2012). These increases coincide with Newton’s second law of motion, where the acceleration of an object is proportional to the force causing the acceleration and inversely proportional to the mass of that object. These relationships are represented by the equation below, where $F = \text{force}$, $m = \text{mass}$, and $a = \text{acceleration}$; Sato et al., 2011:

$$F = ma.$$ 

If the power hang clean or power clean can increase peak force and rate of force development, barbell acceleration will be inherently increased. Thus, force and acceleration outputs are helpful for performance coaches in determining exercises that are most beneficial to enhance performance or the use of implements associated with performance.
Biomechanical Variables

Peak Power Output

Peak power output represents the ability to produce muscular force in a rapid manner while producing maximal velocity during the second pull in Olympic weightlifting movements, and signifies the maximum instantaneous muscular power output (Cormie et al., 2011a, 2011b). In general, muscular power is a desirable athletic quality and is expressed as the rate of doing “work” where the work accomplished is then defined as applying a force to the barbell for a given displacement (Flanagan, 2014). Where \( W = \text{work}, \ F = \text{force}, \) and \( d = \text{(distance) displacement}; \)

\[ W = F \times d. \]

The ability to increase an athlete’s peak power output is attributed to modifying the constraints of the force-velocity curve (Kraemer & Newton, 2000). Observations of power have expressed the force-velocity curve as a delicate mix between maximal concentric shortening velocity and the associated muscular force production (McBride et al., 2011). Peak power may be thought of as a maximal amount of force produced that coincides with low velocity movements or high velocity movements (Kraemer & Newton, 2000). Thus, the ability to modify parameters of weightlifting exercises that are associated with force and/or velocity can manipulate an athlete’s power output and potentially increase performance (Cormie et al., 2011a).

Training with the clean exercise variations have shown improvements in maximal power output and are shown to be kinetically similar to jumping, sprinting, and agility testing (Cormie, McBride et al., 2007; Cormie, McCaulley et al., 2007; Kilduff et al., 2007; Mackenzie et al., 2014). Performance coaches designing training programs featuring...
variations of the clean exercises may be able to use these exercises to enhance peak power output and explosive performance during sport (Hori et al., 2005). However, when training to improve power, utilizing exercises that provide the highest power output at optimal relative intensities should be used to enhance adaptation. The correct relative loading (e.g., percentage of maximal weight lifted) may be one of the most effective stimuli for increasing muscle power capabilities (Comfort, Fletcher et al., 2012; Cormie, McCaulley et al., 2007; Kilduff et al., 2007).

Power outputs during weightlifting have been collected for multiple athletic and non-athletic populations from elite rugby players to recreationally active individuals (Comfort, 2013; Comfort, Fletcher et al., 2012; Comfort, McMahon, & Fletcher, 2013; Cormie, McCaulley et al., 2007; Kilduff et al., 2007; McBride et al., 2011). Clean variations investigated previously (Table 1) have shown a wide range of power outputs between populations and weightlifting exercises while also providing different optimal loads that enhance power output.

Power output assessments for weightlifting exercises are quite variable in literature. This variability during weightlifting exercises has been attributed to different measurements among research groups (Cormie, McBride et al., 2007; Hori et al., 2007). Values among anaerobic athletes have been found to range from 2918 W during the second pull phase of the power clean (Comfort, Fletcher et al., 2012), to 4925 W during the second pull phase of the power hang clean (Cormie, McCaulley et al., 2007). Peak power outputs are of value to coaches because of their association with anaerobic sport. Determining kinematic and kinetic factors (e.g., rate of force production, barbell velocity, and barbell acceleration) can be useful in determining potential performance enhancements from the clean exercise variations (Hori
et al., 2005). What must be considered, however, are the various technical aspects to collecting these parameters.

Performance coaches need to select proper exercises that are desirable for the enhancement of performance. Determining which exercise provides a higher power output and is technically easier to teach should be the top priority (Hori et al., 2008). However, multiple biomechanical assessment techniques have been used to determine power output using various weightlifting exercise variations, bringing reliability into question because the calculation of power outputs have been derived from these various biomechanical methods (Comfort et al., 2011b; Cormie, McBride et al., 2007; Kawamori et al., 2006).
Table 1: Power Outputs and Data Collection Methods Reported at 70% and 80% 1RM.

<table>
<thead>
<tr>
<th>Author</th>
<th>Exercise</th>
<th>70% 1RM (W)</th>
<th>80% 1RM (W)</th>
<th>Data Collection Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilduff et al. (2007)</td>
<td>Power hang clean</td>
<td>$4346 \pm 600$</td>
<td>$4467 \pm 477$</td>
<td>Force platform</td>
</tr>
<tr>
<td>McBride et al. (2011)</td>
<td>Power clean</td>
<td>$1476 \pm 592$</td>
<td>$1611 \pm 505$</td>
<td>Barbell + body (force plate + barbell displacement)</td>
</tr>
<tr>
<td>Comfort et al. (2012)</td>
<td>Power clean</td>
<td>$2951 \pm 931$</td>
<td>$2918 \pm 102$</td>
<td>Force platform</td>
</tr>
<tr>
<td>Comfort et al. (2013)</td>
<td>Power clean</td>
<td>$4610 \pm 939$</td>
<td>$4925 \pm 919$</td>
<td>Force platform, linear position transducer</td>
</tr>
<tr>
<td>Cormie et al. (2013)</td>
<td>Power clean</td>
<td>$1846 \pm 325$</td>
<td>$1875 \pm 285$</td>
<td>Force platform</td>
</tr>
</tbody>
</table>
Power Output and Sport

Performance and power have been studied extensively (Cormie, McCaulley et al., 2007; Hori et al., 2005; Kawamori et al., 2005; Kilduff et al., 2007). Analyses by Kawamori et al. (2005) examined the effects of peak rate of force development (i.e., rate of force produced over a set time frame) and peak force during different relative intensities of the mid-thigh clean pull. The authors concluded that strong positive correlations (r = 0.65 – 0.74) exist between dynamic peak forces produced during the mid-thigh clean pull and vertical jump performances (Kawamori et al., 2005). This supports the notion that peak rate of force development can be regarded as a fundamental factor in sport. The increased rate of force development may increase power generated by these large rates of force development over short periods of time and may lead to increases in movement velocity and performance of the athlete (Comfort et al., 2011a; Cormie et al., 2011b).

Haff et al. (1997) proposed that peak power output during the power hang clean and vertical jump share structural and functional neuromuscular organization. Force-time curve analysis was used to determine relationships for the mid-thigh clean pull, counter movement jump, and static vertical jump. Significant positive correlation in force production during the mid-thigh clean pull and force produced during the counter movement jump was found at 80% 1RM (r = .80). Investigators also found significant correlation at 90% 1RM for peak force production and force produced during the counter movement jump (r = 0.78).

Peak power output was maximized at 80% 1RM (4466 ± 477 W) during the hang power clean among a group of professional rugby players (Kilduff et al., 2007), although peak power output was not found to be significantly different from 50%, 60%, 70%, and 90% 1RM. Research by Haff et al. (2007) indicate peak power output occurred at 80% 1RM with
values from 2440 ± 236 W at 80%, 2422 ± 251 W at 90%, and 2404 ± 251 W at 100% 1RM. While the peak power outputs were not significantly different from one another, it should be considered that only three relative resistances were used (80%, 90% and 100% 1RM) and may lead to inaccurate results as the peak power output might be achieved at relative loads less than 80% 1RM.

Current research of Comfort, Fletcher et al. (2012) found significantly greater peak power output during the power clean at 70% 1RM 2951 ± 931 W when compared to power outputs of 2149 ± 406 W at 30% 1RM, 2201 ± 438 W at 40% 1RM, and 2231 ± 501 W at 50% 1RM, although no significant differences were found when compared at 60% and 80% conditions. Nineteen subjects who were regularly engaged in physical activity with limited experience to weightlifting exercises were used in this study. Consequently, peak power in this study may have been compromised because large variations in mass could increase mean peak power across all subjects (e.g., eight kilogram standard deviation). Further, subjects may have less skill, thus limiting the efficiency of movement and limited experience in the power clean when compared to stronger heavier more experienced lifters shown in other studies (Comfort, Fletcher et al., 2012).

Upon review of previous projects, a general consensus exists among these various investigations that suggest 80% 1RM for the power clean and power hang clean is that approximate relative intensity that elicits peak power output among experienced subject populations (Cormie, McCaulley et al., 2007; Haff et al., 1997; Kilduff et al., 2007; Kraemer & Newton, 2000; McBride et al., 2011). The use of 80% 1RM may provide the performance coach with a basic marker of optimal relative intensity that should be utilized during weightlifting exercises to enhance muscular force and subsequent barbell accelerations.
Although it should be recognized that there still exists the potential for error in interpreting the results of these studies due to the variance in anthropometry, weightlifting experience among the subject populations, and the reliability limitations among the various biomechanical assessment techniques (Comfort, Udall et al., 2012; Hori et al., 2008; Kawamori et al., 2005).

**Peak Barbell Acceleration**

Barbell acceleration is a rate at which barbell velocity is altered during a specific time frame while performing a given weightlifting exercise (Flanagan, 2014). Tracking peak barbell accelerations during weightlifting tasks has been used to observe changes in velocity at various relative intensities (Sato et al., 2012). Barbell accelerations are reported to be proportional to the force applied to the barbell, and performance coaches can use barbell accelerations to assess rapid force progressions due to forces generated during athletic movements (Sato et al., 2011; 2012).

**Peak Acceleration and Sport**

Although the assessment of peak barbell acceleration is sparse, tracking barbell velocities for weightlifting exercises have been frequently reported (Comfort, Udall et al., 2012; Haff et al., 2003; Hori et al., 2007; Kilduff et al., 2007; Sato et al., 2012; Sato, Smith, & Sands, 2009; Suchomel, Wright, Kernozek, & Kline, 2014). Peak velocity data collected during previous weightlifting protocols have ranged from 2.08 m·s⁻¹ at 30% 1RM (Suchomel et al., 2014), 1.69 m·s⁻¹ at 40% 1RM (Kilduff et al., 2007), and 1.61 ± 0.21 m·s⁻¹ at 50% 1RM (Comfort, Fletcher et al., 2012).

The assessment of barbell velocity is important when investigating specificity and training adaptation (Cormie et al., 2011b). However, because many sporting movements rely
upon rapid changes of direction and are not performed with constant velocity, barbell acceleration should not be overlooked as it can give the performance coach information on velocity changes and force generation, whether these are whole body actions or movements that use implements. Accelerations of inertial resistance from variant force generations are proportional in accordance with Newton’s Law of Acceleration. Further, because barbell acceleration is proportional to the force applied by the athlete, recording barbell accelerations give the performance coach a detailed look at the force generating capacity of the athlete (Sato et al., 2011).

Although existing studies are sparse, the most recent work by Sato et al. (2011) found significant differences in acceleration patterns when utilizing a tri-axial accelerometer during assessment of barbell accelerations. The investigators found significant decreases in barbell accelerations as the mass of the bar increased. For example, peak barbell acceleration at 80% 1RM (19.63 ± 3.04 m/s²) was significantly higher than barbell acceleration at 85% 1RM (16.78 ± 3.56 m/s²). Barbell acceleration was also significantly different when 80% 1RM was compared to 90% 1RM (13.65 ± 3.50 m/s²). However, no significant differences were found from 85% to 90% 1RM. The investigators proposed that the increased load was a primary factor in decreasing the barbell’s acceleration (Sato et al., 2011). These results indicate that the collection of barbell acceleration data may offer a general determination of those relative intensities that will enhance peak power output.

It should be noted that there appears to be no research to date that compares acceleration patterns of the power hang clean and power clean during the second pull. An interesting observation made by Sato et al. (2011) indicated barbell accelerations during the second pull of the power clean remained relatively stable from 50% to 80% 1RM. The stable
acceleration patterns up to 80% 1RM could be due to either a “rate of force” generating threshold for decreasing acceleration of the barbell or related to the athletes maximal ability to exert force onto the barbell (Sato et al., 2011). Tracking barbell accelerations allows the performance coach to observe an athlete’s acceleration patterns and the progression of force generation due to physical training (Sato et al., 2012; 2009). In addition to the lack of studies that investigate barbell acceleration comparisons among weightlifting exercises, there is limited data that exists comparing this parameter for the power clean and power hang clean exercises at different relative intensities.

**Normalization Considerations**

Interpretation and reports on muscular power output and acceleration are in need of review with regard to weightlifting research, primarily because many studies have used assorted populations with diverse activity backgrounds and considerably different training experiences in relation to the technical aspects of performing the variant weightlifting exercises that were studied (Comfort et al., 2011b; Hori et al., 2007; Lake, Mundy, & Comfort, 2014). Also worthy of consideration is the fact that multiple investigations have presented data with standard deviations in mass greater than ten kilograms, indicating large deviations in anthropometric measures (e.g., larger athletes with more fat free mass versus smaller athletes with less fat free mass). This broad range of measures may affect outcomes for the generated muscular power output when making comparisons between individuals or a group (Jaric, 2002; Suchomel et al., 2014).

Variance in fat free mass could impact data because larger technically advanced athletes (assuming they have greater fat free mass) should produce higher power outputs and barbell accelerations when compared to the smaller athletes (Cormie et al., 2011a, 2011b;
Hori et al., 2007; Jaric, 2002; Kraemer & Newton, 2000; McBride, Triplett-McBride, Davie, & Newton, 2002). Because humans are not anthropometrically similar (e.g., dimension, stature, mass), weightlifting investigations making comparisons of populations with variant abilities and physical capacities should consider normalization techniques that account for these differences. Normalization techniques that utilize body mass alone do not account for differences in quantity of muscle tissue and segment length.

One recent method that accounts for variable anthropometric measures is to use a form of normalization by scaling mass to the power of 0.67 (i.e., kg^{0.67}; Jaric, 2002). This scaling method allows comparisons between subjects of difference strength levels, which can be due to variations in body shape, maturation, age, sport participation, and training experience. Thus, analysis must consider the various factors that are influential when comparing strength and force capability among various subjects or athletic populations (Jaric, 2002).

Previous investigations have neglected the use of allometric scaling or have used the method incorrectly when applying it to subjects tested (Comfort et al., 2011b; Kawamori et al., 2005; Kawamori et al., 2006; Kilduff et al., 2007; Suchomel et al., 2014). This inconsistency is a primary limitation if comparisons cannot be made between studies when methodology has no standard protocol to track power or acceleration. Consequently, when performance coaches are comparing data among studies that have vastly different methodology, it becomes a questionable comparison for their athletes because of these fluctuations in kinetic and kinematic variables. Thus, it is proposed to implement a model of force that is independent from body shape and size. Jaric (2002) has proposed one such approach using the scaling equation:
\[ S_n = s/m^b. \]

where \( S_n \) is normalized strength, \( S \) is muscle strength, \( m^b \) is the allometric parameter used combined with mass, and the allometric parameter \( (b) \) should be noted as \( b = 0.67 \) when normalizing force among subjects. The aforementioned scale to the power of 0.67 is used not only to obtain an index of muscular force that is independent of body size, but also because it is suggested that muscular strength increases at a lower rate than body mass. So, the augmented fat free mass or fat mass may increase or decrease muscular force production, ultimately changing mean power output and must be accounted for with proper normalization techniques (Jaric, 2002).
Chapter III: Research Design and Methodology

Study Design

Upon approval from the College of Health and Human Services Human Subjects Review Board, eight male weightlifters aged 25 ± 2 years old volunteered to participate in the study. Subjects were recruited from emails and in-person meetings to nearby weightlifting clubs, coaches, and athletes in southeast Michigan. All subjects were USA Weightlifting sanctioned club-level weightlifters with at least four years competitive experience. Athletes recruited for this study trained regularly for at least 1.5 hours or more a day, with at least four days of training per week. To provide consistent measurements all subjects were asked to refrain from consuming alcohol or completing any form of resistance training three days prior to testing.

Once recruited, subjects came in for their scheduled visit, informed consent, and permission to collect anthropometric, video, and biomechanical data for the entire study were signed. Subjects then provided relevant one repetition maximum (1RM) for each exercise (Table 2). All 1RM information was used to calculate relative lifting intensities for each subject in the power hang clean and power clean. The 1RM for the power clean and power hang clean for each subject was taken from the most recent practice session or sanctioned USA weightlifting competition, where maximal performance should have been attained. Finally, subject’s height and weight were measured using a stadiometer/scale (Detecto, Webb City, Missouri) prior to the lifting protocol. To maintain testing reliability, a National Strength and Conditioning Association certified strength and conditioning specialist was present to ensure adequate technique, correct barbell loading, and proper testing procedures.
Table 2: Participant Anthropometric and Performance Characteristics for Age, Weight, 1RM Power Clean, and 1RM Power Hang Clean.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Experience (Years)</th>
<th>Age (Years)</th>
<th>Mass (kg)</th>
<th>Normalized Body Mass (kg$^{0.67}$)</th>
<th>1RM PC (kg)</th>
<th>1RM PHC (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>28</td>
<td>82.72</td>
<td>19.26</td>
<td>120</td>
<td>110</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>20</td>
<td>81.81</td>
<td>19.12</td>
<td>127</td>
<td>112</td>
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<tr>
<td>3</td>
<td>5</td>
<td>27</td>
<td>86</td>
<td>19.77</td>
<td>130</td>
<td>115</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>24</td>
<td>77.27</td>
<td>18.40</td>
<td>129</td>
<td>113</td>
</tr>
<tr>
<td>5</td>
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<td>25</td>
<td>98.18</td>
<td>21.61</td>
<td>126</td>
<td>111</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>26</td>
<td>111.36</td>
<td>23.51</td>
<td>155</td>
<td>140</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>21</td>
<td>85.45</td>
<td>19.69</td>
<td>130</td>
<td>115</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>28</td>
<td>85</td>
<td>19.62</td>
<td>127</td>
<td>115</td>
</tr>
<tr>
<td><strong>Mean ± SD</strong></td>
<td></td>
<td></td>
<td><strong>85.25 ± 11</strong></td>
<td><strong>19.65 ± 1.54</strong></td>
<td><strong>128 ± 10.4</strong></td>
<td><strong>114 ± 9.47</strong></td>
</tr>
</tbody>
</table>
Data Collection Procedures

Data was collected within a two-week window, with each subject only participating in a single day of testing (i.e., all paper work, 1RM information, review of procedures, warm-up, testing protocol finished in one day). Subjects were randomized prior to testing and placed in either group A or group B. Group A consisted of the power clean testing first then the power hang clean testing second. Group B was assigned the power hang clean testing initially and then the power clean testing. Lifting intensities were presented in randomized order for each subject in each group. Exercises were performed in a randomized order because this procedure produces groups that are fairly similar on average and ensures no patterns exist between subjects or testing protocols (Comfort et al., 2011a; Cormie, McBride et al., 2007).

Based on each subject’s 1RM for both the power clean and power hang clean, resistances used during the testing protocol and warm-up session could be determined. During each self-paced warm-up set, subjects performed 4 sets of 3 repetitions up to 90% 1RM for the power clean and power hang clean (Comfort et al., 2011b). Subjects started all self-paced, warm-up sets on an Olympic weightlifting platform, using a 20-kilogram Olympic bar (Werksan USA, Moorestown, NJ). The warm-up sets were used to ensure the athlete was ready to perform all submaximal sets while accumulating minimal fatigue. Once all warm-up sets were completed, a minimum of five to ten minutes were given before the testing protocol. Twelve individual attempts were assessed in a randomized order at 60%, 70%, and 80% of 1RM. Each subject completed two lifts per relative maximum intensity (e.g., two at 60%, two at 70%, and two at 80% 1RM), and combined the two lifts for an average raw output. Subjects were able to rest at a minimum of one minute between
repetitions and two minutes between intensities to minimize the development of fatigue (Comfort et al., 2013).

Kinetic Data Collection

Calculation of peak power and barbell acceleration began with all force plates and camera systems being calibrated according to proprietary biomechanical software specifications (Nexus 1.8.5 software, Vicon, Los Angeles, CA). Ground reaction force data was captured in the vertical axis on two OR6-6-2000 force platforms (Advanced Medical Technology Inc., Watertown, MA) set at 1000 hertz (Hz) for each foot position of the lifter (Figure 5). All data were filtered using a fourth-order digital low-pass filter with a cut off frequency of 16 Hz (Comfort, Udall et al., 2012). Proprietary software (Nexus 1.8.5 software, Vicon, Los Angeles, CA) processed all force plate data once trials were complete.

Subjects were asked to assume the set lifting position prior to all trials, with data collection commencing as soon as the lifter gave a verbal indication they were prepared to perform a repetition for the selected exercise. Data from the sum of both the right and left foot positions on the force platforms were used to acquire total force application for each attempt. Ground reaction forces were collected for each individual trial until the lift was considered complete, and kinetic data was synchronized with the kinematic parameters collected for each testing session.

Kinematic Data Collection

Eight Vicon MX T-40 & T40-S infrared cameras (Vicon, Los Angeles, CA) placed around the lifting platform (Figure 6) were used to capture barbell displacement, which allowed the calculation of velocity and acceleration. Reflective markers were placed on the ends of the barbell to capture all barbell data for each trial (Figure 7). The MX T-40 & T 40-
S cameras captured data at 100 Hz based on studies that have shown this to be an appropriate sampling rate to capture weightlifting motions (Sato et al., 2009; 2012). Acceleration data collection began as the verbal signal was given from the subject to allow for less movement restriction and error. All data was filtered using a fourth-order digital low-pass filter with a cut off frequency of 16 Hz (Comfort, Udall et al., 2012). Proprietary software (Nexus 1.8.5 software, Vicon, Los Angeles, CA) processed all barbell displacement, velocity, and acceleration data once trials were complete.

To visually confirm that adequate technique was maintained throughout the lifting protocol and to inspect if force and acceleration peaks matched with the second pull of each exercise, high definition and digital high-speed video cameras were used. One high definition digital high-speed video camera was used to capture the perpendicular view of the sagittal plane during all trials and collected at 100 Hz (Bonita 720c Vicon, Exton, CA), while one standard definition high-speed camera was used to capture the frontal plane of the lifter during each trial and collected at 100 Hz (piA640-210gc, Basler, Exton, PA).

**Peak Power Analysis**

To calculate peak power during all trials, ground reaction force data obtained from the force platforms were synchronized with kinematic data collected from the motion capture system (Cormie, McBride et al., 2007; Hori et al., 2007). Because kinetic and kinematic data were collected at different frequencies, the ground reaction force data (1000 Hz) was averaged and calculated for every frame of kinematic data (100 Hz). This procedure was used to synchronize the data set to calculate peak power for every attempt. Barbell velocity was calculated from displacement and multiplied with the same frame of ground reaction force data. To make comparisons among subjects with variable body mass, peak power
output was normalized using a method as proposed by Jaric (2002). The normalization technique used has been previously reported to appropriately index muscular force while making body mass independent. Normalized peak power was calculated with the following equation below, where $W = \text{watts}$, and $Kg = \text{body mass in kilograms to the power 0.67}$:

$$\frac{W}{([kg]^{0.67})}.$$

**Peak Acceleration Analysis**

To calculate peak acceleration, barbell displacement was collected from the motion capture system at 100 Hz over the span of each exercise attempt. Accelerations were processed with the Vicon-Nexus 1.8.5 proprietary software. Once all data was processed and peak acceleration was found, accelerations were normalized in accordance to the force generation of each subject (Jaric, 2002). This was implemented according to Newton’s Law of Acceleration in that the acceleration of the barbell is proportional to the force applied to the barbell (as measured by the ground reaction force) causing that acceleration and inversely proportional to the mass of the barbell (Mackenzie et al., 2014). Normalized peak acceleration was calculated with the following equation below, where $m/s^2 = \text{meters per second squared}$, and $Kg = \text{body mass in kilograms to the power 0.67}$:

$$\frac{m/s^2}{([kg]^{0.67})}.$$
Figure 5: Two AMTI OR6-6-2000 Force Plates.
Figure 6: Placement of the Vicon Infrared Cameras and Force Plates.
Figure 7: Reflective Marker Barbell Setup.
**Statistical Analysis**

To determine if any significant differences existed within subjects at a given relative intensity between the power clean and power hang clean, a two-way repeated measures analysis of variance (ANOVA) was performed using SPSS 22.0 (IBM, NY). Further, to determine the differences within exercises at 60%, 70%, and 80% a Bonferroni post hoc test was performed. The repeated measures ANOVA was used to determine if significant differences were evident during all peak power and peak acceleration trials between the power clean and power hang clean exercises at each relative intensity of 60%, 70%, and 80% 1RM of each respective exercise. The Bonferroni post hoc test compared both exercise conditions at 60% to 70%, 60 to 80%, and 70 to 80% 1RM. The level of significance was set at (p < 0.05) for all statistical analyses.
Chapter IV: Results

Peak Power Output

Clean exercise variations were used to evaluate potential differences in mean peak normalized power output (Table 3). A significant difference was found at 80% of 1RM for the main effect of exercise $F(1,7) = 11.66, p = 0.011$, wherein normalized values for the power hang clean ($254.92 \pm 41.65 \text{ watts/kg}^{0.67}$) was greater than the power clean ($221.26 \pm 29.56 \text{ watts/kg}^{0.67}$). A significant difference was not found at 60% of 1RM for the main effect of exercise $F(1,7) = 3.12, p = 0.120$, in that the normalized power hang clean ($252.28 \pm 42.06 \text{ watts/kg}^{0.67}$) was not greater than the normalized power clean ($230.91 \pm 41.24 \text{ watts/kg}^{0.67}$) (Table 4). Similarly, no significant difference was found at 70% of 1RM for the main effect of exercise $F(1,7) = 4.81, p = 0.064$, when comparing normalized peak power output for the power hang clean ($252.08 \pm 35.96 \text{ watts/kg}^{0.67}$) and power clean ($227.73 \pm 41.06 \text{ watts/kg}^{0.67}$) respectively.

Bonferroni post hoc analysis revealed no significant difference ($p = 0.323$) within the power clean for peak normalized power output during 60% 1RM when compared to the 80% 1RM condition. No significant difference ($p = 0.395$) was found for peak normalized power output within the power clean at 70% 1RM when compared to 80% 1RM condition. Similarly, no significant difference ($p = 0.578$) was found for peak normalized power output within the power clean at 60% 1RM when compared to 70% 1RM condition. Additionally, Bonferroni post hoc analysis revealed no significant difference ($p = 0.578$) within the power hang clean at 60% 1RM when compared to 80% 1RM condition. No significant difference ($p = 0.323$) was found within the power hang clean at 60% 1RM when compared to 70% 1RM condition. Finally, no significant difference ($p = 0.395$) was found for peak normalized
power output within the power hang clean at 70% 1RM when compared to 80% 1RM condition.
Table 3: Mean Peak Normalized Power for all Participants at All Three Relative Intensities.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mass (kg)</th>
<th>Power clean (W/kg$^{0.67}$) 60% 1RM</th>
<th>Power clean (W/kg$^{0.67}$) 70% 1RM</th>
<th>Power clean (W/kg$^{0.67}$) 80% 1RM</th>
<th>Power hang clean (W/kg$^{0.67}$) 60% 1RM</th>
<th>Power hang clean (W/kg$^{0.67}$) 70% 1RM</th>
<th>Power hang clean (W/kg$^{0.67}$) 80% 1RM</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>82.72</td>
<td>236.99</td>
<td>211.04</td>
<td>196.01</td>
<td>273.78</td>
<td>250.56</td>
<td>245.75</td>
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<td>81.81</td>
<td>207.94</td>
<td>197.88</td>
<td>185.04</td>
<td>219.75</td>
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<td>259.68</td>
<td>234.24</td>
<td>305.83</td>
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<td>301.31</td>
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<td>77.27</td>
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<td>186.26</td>
<td>208.48</td>
<td>242.36</td>
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<td>210.41</td>
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<td>244.56</td>
<td>221.68</td>
<td>231.32</td>
</tr>
<tr>
<td>6</td>
<td>111.36</td>
<td>267.45</td>
<td>274.92</td>
<td>256.13</td>
<td>243.49</td>
<td>259.53</td>
<td>312.08</td>
</tr>
<tr>
<td>7</td>
<td>85.45</td>
<td>195.40</td>
<td>190.68</td>
<td>217.21</td>
<td>182.43</td>
<td>195.80</td>
<td>194.59</td>
</tr>
<tr>
<td>8</td>
<td>85</td>
<td>307.29</td>
<td>290.94</td>
<td>269.41</td>
<td>306.00</td>
<td>277.81</td>
<td>291.41</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>85.25 ± 11</td>
<td>230 ± 41</td>
<td>227 ± 41</td>
<td>221 ± 29</td>
<td>252 ± 42</td>
<td>252 ± 35</td>
<td>254 ± 41</td>
</tr>
</tbody>
</table>
Table 4: Mean Peak Normalized Power Output Comparisons at 60%, 70%, and 80% 1RM.
*Denotes Significance Between Exercise at p<0.05.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>60% 1RM (watts/kg^{0.67})</th>
<th>70% 1RM (watts/kg^{0.67})</th>
<th>80% 1RM (watts/kg^{0.67})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power hang clean</td>
<td>252.28 ± 42.06</td>
<td>252.08 ± 35.96</td>
<td>254.92 ± 41.65*</td>
</tr>
<tr>
<td>Power clean</td>
<td>230.91 ± 41.24</td>
<td>227.73 ± 41.06</td>
<td>221.26 ± 29.56*</td>
</tr>
</tbody>
</table>
Figure 8: Comparison of Normalized Peak Power Output Between Exercises.
*Denotes Significance Between Exercise at p<0.05.
Barbell Acceleration

Clean exercise variations were used to evaluate potential differences in mean peak normalized barbell accelerations (Table 5). There was a significant difference at 60% 1RM for the main effect of exercise $F(1, 7) = 6.94$, $p = 0.034$, in that greater normalized peak barbell acceleration was achieved with the power hang clean ($0.91 \pm 0.36$ m/s$^2$/kg$^{0.67}$) when compared to the power clean ($0.73 \pm 0.26$ m/s$^2$/kg$^{0.67}$) (Table 6). A significant difference was also found at 70% 1RM for the main effect of exercise $F(1, 7) = 6.23$, $p = 0.041$, wherein the power hang clean normalized peak acceleration was higher ($0.85 \pm 0.36$ m/s$^2$/kg$^{0.67}$) when compared with the power clean ($0.63 \pm 0.17$ [m/s$^2$]/kg$^{0.67}$). No significant difference was found at 80% 1RM for the main effect of exercise $F(1, 7) = 3.74$, $p = 0.094$, in that the power hang clean ($0.69 \pm 0.22$ m/s$^2$/kg$^{0.67}$) was not significantly different to the power clean ($0.59 \pm 0.18$ m/s$^2$/kg$^{0.67}$) for normalized peak barbell acceleration. Bonferroni post hoc analysis revealed a significant ($p = 0.03$) difference for peak normalized barbell acceleration within the power clean at 60% 1RM, such that significantly greater normalized peak barbell acceleration was found during 60% 1RM when compared to 80% 1RM condition. However, no significant difference was found within the 70% ($p = 0.92$) and 80% 1RM ($p = 0.169$) comparison during the power clean. No significance ($p = 0.092$) was found within the power clean when 60% and 70% 1RM were compared. Bonferroni post hoc analysis also revealed significantly greater ($p = 0.005$) normalized barbell acceleration within the power hang clean at 60% 1RM when compared to the 80% 1RM. No significant differences ($p = 0.351$) were found within the power hang clean when 60% 1RM was compared to 70% 1RM. Lastly, post hoc analysis revealed a significantly greater normalized peak barbell acceleration at 70%
1RM (p = 0.047) in the power hang clean when compared to the power hang clean at 80% 1RM.
Table 5: Mean Peak Normalized Acceleration for All Participants at All Three Relative Intensities.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mass (kg)</th>
<th>Power clean (m/s^2/kg^{0.67}) 60% 1RM</th>
<th>Power clean (m/s^2/kg^{0.67}) 70% 1RM</th>
<th>Power clean (m/s^2/kg^{0.67}) 80% 1RM</th>
<th>Power hang clean (m/s^2/kg^{0.67}) 60% 1RM</th>
<th>Power hang clean (m/s^2/kg^{0.67}) 70% 1RM</th>
<th>Power hang clean (m/s^2/kg^{0.67}) 80% 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>82</td>
<td>0.77</td>
<td>0.58</td>
<td>0.48</td>
<td>0.63</td>
<td>0.51</td>
<td>0.61</td>
</tr>
<tr>
<td>2</td>
<td>81</td>
<td>0.83</td>
<td>0.73</td>
<td>0.66</td>
<td>0.97</td>
<td>1.28</td>
<td>0.81</td>
</tr>
<tr>
<td>3</td>
<td>86</td>
<td>0.43</td>
<td>0.39</td>
<td>0.43</td>
<td>0.55</td>
<td>0.51</td>
<td>0.40</td>
</tr>
<tr>
<td>4</td>
<td>77</td>
<td>1.13</td>
<td>0.86</td>
<td>0.87</td>
<td>1.41</td>
<td>1.40</td>
<td>1.02</td>
</tr>
<tr>
<td>5</td>
<td>98</td>
<td>0.90</td>
<td>0.84</td>
<td>0.77</td>
<td>1.27</td>
<td>1.00</td>
<td>0.89</td>
</tr>
<tr>
<td>6</td>
<td>111</td>
<td>0.89</td>
<td>0.66</td>
<td>0.69</td>
<td>1.07</td>
<td>0.91</td>
<td>0.74</td>
</tr>
<tr>
<td>7</td>
<td>85</td>
<td>0.36</td>
<td>0.48</td>
<td>0.49</td>
<td>0.38</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>8</td>
<td>85</td>
<td>0.51</td>
<td>0.52</td>
<td>0.33</td>
<td>0.99</td>
<td>0.79</td>
<td>0.69</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>85.25 ± 11</td>
<td>0.72 ± 0.26</td>
<td>0.63 ± 0.17</td>
<td>0.59 ± 0.18</td>
<td>0.90 ± 0.35</td>
<td>0.84 ± 0.37</td>
<td>0.69 ± 0.22</td>
</tr>
</tbody>
</table>
Table 6: Mean Peak Normalized Barbell Acceleration at 60%, 70%, and 80% 1RM.  
*Denotes Significance Between Exercises at p<0.05.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>60% 1RM (m/s²/kg^{0.67})</th>
<th>70% 1RM (m/s²/kg^{0.67})</th>
<th>80% 1RM (m/s²/kg^{0.67})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power hang clean</td>
<td>.91 ± .36*</td>
<td>.85 ± .36*</td>
<td>.69 ± .22</td>
</tr>
<tr>
<td>Power clean</td>
<td>.73 ± .26*</td>
<td>.63 ± .17*</td>
<td>.59 ± .18</td>
</tr>
</tbody>
</table>
Figure 9: Comparison of Normalized Peak Barbell Acceleration Between Exercises. *Denotes Significance Between Exercise at $p<0.05$. 

![Graph showing comparison of peak barbell acceleration between exercises at different relative loads. The x-axis represents relative load (% 1RM) with three categories: 60%, 70%, and 80%. The y-axis represents peak barbell acceleration ($m/s^2/kg^{0.67}$). The graph includes bars for Power hang clean and Power clean with error bars indicating variability. Significant differences are denoted with an asterisk (*).]
Chapter V: Discussion

The purpose of this study was to compare kinetic and kinematic parameters of the power hang clean and power clean exercises at various relative intensities among local club-level weightlifters. Normalized peak power output in the power hang clean was found to be significantly different than the power clean at 80% 1RM (p = 0.011), while normalized peak barbell acceleration was found to be significantly different at 60% (p = 0.034) and 70% (p = 0.041) 1RM between exercises. Additionally, no significant differences were found for normalized peak power output when comparing 60% to 70% 1RM, 70% to 80% 1RM, and 60% to 80% 1RM for each exercise; however, normalized peak barbell acceleration for both the power hang clean (p = 0.005) and power clean (p = 0.03) was significantly greater for the 60% condition when compared to the 80% condition, but no significance was found when comparing the 70% and 80% 1RM condition.

It has been previously reported that information regarding power output and barbell acceleration from these training exercises can aid the performance coach in proper exercise selection and implementation prior to the initiation of a physical training programs (Hori et al., 2005; Sato, Fleschler, & Sands, 2011). Furthermore, research has supported peak muscular power as the most important neuromuscular function to improve anaerobic performance (Cormie et al., 2011a, 2011b; Hori et al., 2005; Kraemer & Newton, 2000). Thus, designing and implementing training programs that utilize appropriate weightlifting exercises may lead to enhanced performance among those anaerobic-dominant sports that require high muscular power outputs, rapid force production, and movement acceleration.
Normalization

Throughout the past decade comparisons of muscular force and strength in research have presented two problems. First, many studies do not normalize force variables when making comparisons among dissimilar populations. Furthermore, when normalization techniques are used for force comparisons, there is still debate with regard to the most suitable methodology (Jaric, 2002; Kawamori et al., 2005). The perspective of body size has not been seriously considered when subjects were compared among different movement performances that require high force production (Cormie, McCaulley et al., 2007; Jaric, 2002). Thus, when comparing subjects of a particular data set, the use of normalization as proposed by Jaric (2002) presents a novel and appropriate approach concerning these normalization limitations from previous investigations.

Jaric (2002) has suggested that heavier athletes tend to be stronger and produce more force than lighter athletes, and this is referred to as a “body-size effect.” Body size has been stated to be a well-known factor that has the propensity to alter force production associated with tested muscular strength (Jaric, 2002). Additionally, due to the body size effect, a so-called “effect of scale” has also been brought into question when muscle force is analyzed. The assumption for “effect of scale” relies on biological similarity (i.e., humans are the same shape, so they must only differ in size). Due to this assumption, the equation where $S_n$ is normalized strength, $S$ is muscle strength, $m^b$ is the parameter of mass and the allometric parameter ($b$) is predicated as $b = 0.67$:

$$S_n = S/m^b.$$ 

This equation implies athletes to be proportional to body mass to the two-thirds power (i.e., $kg^{0.67}$) and accounts for various body-size effects (Jaric, 2002).
For this study, all muscular power outputs and barbell accelerations were allometrically normalized using this procedure as described by Jaric (2002). Jaric (2002) also proposes the use of normalization is also applicable to power testing. For example, previous research has tested power output among a group of individuals in which the differences were significant when compared from absolute data but were shown to be insignificant when normalizing for body mass (Jaric, 2002). The use of an appropriate normalization technique is vital particularly when making comparisons among subjects with varying values of fat free mass and fat mass. Previous investigations have only normalized with body mass without consideration for body composition utilizing “ratio standards” (i.e., per kilogram of body mass), and this can become problematic due to the differences in fat free mass among subjects although they may be of similar mass (Comfort, Udall et al., 2012; Kawamori et al., 2005). Furthermore, larger subjects are assumed to have higher fat free mass, thus having an effect on cross sectional area of muscle. Muscle cross sectional area may indeed influence force production (increased cross sectional area may enhance tension), thus exposing a major flaw of the ratio method. This is a strong consideration and limitation among previous investigations as the increased fat free mass affects force, and force is a primary determinant of power and limb acceleration, thus ultimately influencing athletic performance (Flanagan, 2014).

Numerous levels of technical experience with regard to weightlifting have been previously used when comparing kinetic and kinematic parameters (Comfort et al., 2011b; 2013; Cormie, McCaulley et al., 2007; Cormie et al., 2011b; Hori et al., 2005; Hori et al., 2008; Jaric, 2002; Kawamori et al., 2005; Kilduff et al., 2007). This is another factor that has not been considered a major limitation but should likely be accountable. Anthropometric
differences can induce technical alterations and when combined with differences in experience, they become key considerations when comparing weightlifting exercises.

Additionally, although it can be assumed recruited subjects train with the current exercises, the closer a population is to the skill level of a national or international athlete, the less technical variability one would expect during data interpretation. This training experience has an influence on technique, which directly affects the kinetic and kinematic parameters of the exercise. Inexperienced subjects may demonstrate and introduce poor lifting ability, thus impacting bar and body kinematics and kinetics, respectively.

To date, few investigations have considered technical ability while simultaneously accounting for body size. The present normalization methodology enabled the comparison of subjects with various masses but with similar competitive weightlifting experience because the technique needed for comparison has been lacking in previous studies (Hori et al., 2008; Kawamori et al., 2005). Larger collegiate athletes may have a greater proportion of fat free mass (i.e., greater cross sectional area) to fat mass when compared to smaller collegiate subjects (Comfort, Fletcher et al., 2012). This has the potential, if not appropriately normalized, to confound results and lead performance coaches into incorrectly thinking one exercise is superior over another due to the larger biomechanical values attributed to anthropometric advantages. Additionally, if a subject has significantly greater fat free mass but has subpar technique in the exercise, that subject may potentially affect total mean power outputs. Thus, accounting for mass, technical experience, and considerations for sports that incorporate primarily upper body movements versus primarily lower body movements must be considered when testing the power clean and power hang clean exercises (Cormie et al., 2011a, 2011b; Jaric, 2002).
For this study, the act of scaling body mass is used to account for anthropometric differences from subject to subject (e.g., fat free mass), while also accounting for subject variability that may come from technical experience in each exercise tested and compared. The current study utilized trained weightlifters with adequate technical ability and experience to enable body size to be that variable influenced by the normalization procedure as proposed by Jaric (2002). Future normalization procedures should address technical ability when muscular force production and power output are compared among subjects of similar weightlifting experience.
Normalized Peak Power Output

For the present study, comparisons of normalized peak power output resulted in significant differences between exercises at 80% 1RM (p = 0.011). Normalized peak power output analyzed at 60% (p = 0.12) and 70% (p = 0.064) 1RM between these exercises did not reveal statistical significance; however, at the 70% loading condition, there did appear a trend almost reaching statistical significance (p = 0.064) with a higher normalized peak power output in the power hang clean exercise.

The power hang clean begins with the barbell in a hang position just above the knee, while the power clean begins with the weight resting on the floor. The power hang clean will eliminate any movement of the barbell from the floor, thus making this exercise easier to teach novice lifters due to less movement being performed while still providing higher peak power outputs that are desirable from performance coaches to enhance abilities among anaerobic athletes (Hori et al., 2005). As a result, the power hang clean at designated relative intensity is suggested as an exercise that will more closely relate to the high force and power production an athlete will produce during an athletic event (Hori et al., 2005).

Normalized peak power output during the power hang clean at 60% 1RM although not significant, demonstrated higher normalized peak power output (252 ± 42 watts/kg^{0.67}) when compared to the power clean exercise (230 ± 41 watts/kg^{0.67}). These results are in agreement with those by Comfort et al. (2012) in which no significant difference was found between the power hang clean and power clean exercises at 60% 1RM. These findings are likely due to the relative exercise intensities during each exercise being too low. The lower intensity at 60% 1RM may not require any significant technical adjustments when performing the exercises, leading to similar normalized peak power outputs. Additionally, the
current subject population has ample experience in both exercises, and therefore, subjects may not have had to create a larger impulse in the power hang clean to significantly increase power of the bar; this would give another explanation in which no biomechanical adjustments are needed between exercises. Finally, because mass of the barbell may have been too light, subjects may not have recruited a majority of the larger type IIb muscle fibers or did not cause enough tension to elicit a maximal muscle spindle stretch reflex (i.e., storing and releasing mechanical stress via deformation of muscle and tendon), leading to mechanical and physiological differences in motor unit recruitment and power output (Cormie et al., 2011a; Gabriel et al., 2006).

Normalized peak power output at 70% 1RM was not significantly different between the power clean (227 ± 41 watts/kg^{0.67}) and power hang clean (252 ± 35 watts/kg^{0.67}) exercises; however, the power hang clean did provide greater normalized peak power output than the power clean. These results are in agreement with the work of Cormie et al. (2007) in that the power hang clean offers an increased power output but is not significantly different from power clean at 70% 1RM. However, the results at 70% 1RM are not in agreement with Comfort et al. (2012) and Kawamori et al. (2005) in which peak power output was found at 70% 1RM. The current finding that peak power was not found at 70% 1RM may be explained by the use of male collegiate athletes and recreationally active men during previous studies when compared to the local competitive weightlifters used in the present study (Comfort, Fletcher, et al., 2012; Kawamori et al., 2005). Thus, experience and technical ability in previous studies suggest that trained weightlifters will provide peak power output at a higher percentage of 1RM (Cormie, McCaulley et al., 2007).
While there seems to be discrepancies among various studies with regard to athletic background differences and data collection techniques, the current study utilized an experienced weightlifting population with validated methodology for capturing peak power output with an allometric scaling technique to control for differences in fat free mass (Cormie, McBride et al., 2007; Jaric, 2002). The studies of Comfort, Fletcher et al. (2012) and Kawamori et al. (2005) may have been skewed by large deviations in mass (i.e., 8.0 kilogram and 14.5 kilogram standard deviations, respectively), with no mention of the impact of potential differences in fat free mass. Additionally, Comfort et al. (2012) provided no procedure to normalize subjects due to the large deviations in mass. The lack of proper normalization further supports the idea that outcomes may have been skewed by the magnitude of fat free mass among the subjects (Jaric, 2002).

However, the work of Kawamori et al. (2005) applied a ratio standard as an allometric technique (watts/kilogram), but this type of normalization does not account for fat free mass and has been suggested by Jaric et al. (2002) to be an improper method of allometric scaling. Instead, the normalized peak power output as calculated for the current data set accounts for this type of error (Jaric, 2002). Proper normalization techniques that account for variations in fat free mass and an understanding with the knowledge of how load will affect the kinematic and kinetic outcomes are useful, so the performance coach can appropriately distinguish differences between exercises.

Finally, technical training experience (e.g., average lifting experience was 5.5 ± 1.3 years) must also be considered because subjects with another year of experience may have an advantage over less experienced subjects in that it could be assumed that the experienced weightlifter is mechanically adept and efficient at producing movements that contribute
wholly to power production rather than fixate or neutralize unwanted movements or perturbations of the exercise. Thus, utilizing a technically easier exercise such as the power hang clean would provide a substantial benefit when technical deficiencies are bound to occur in novice lifters such as a deficient first pull from the ground.

Normalized peak power during the power hang clean at 80% 1RM (254 ± 41 watts/kg^{0.67}) was significantly higher than the power clean exercise (221 ± 29 watts/kg^{0.67}). These results are in agreement with the majority of studies that have used similar methodology and show significant differences in peak power output at 80% 1 RM (Cormie, McCaulley, et al., 2007; Cormie et al., 2011b; Kilduff et al., 2007; McBride et al., 2011). However, the results at 80% 1RM are not in line with previous research suggesting peak power output is significantly different at 70% 1 RM (Comfort, Fletcher et al., 2012; Kilduff et al., 2007). Prior studies finding significance at 70% 1RM may not have truly taken technical expertise into consideration when comparing the power clean and power hang clean, which may lead to lower mechanical efficiency and a lower peak power output at a percentage of 1RM and finally, lead to inaccurate comparisons with other athletes due to the technical advancement from experience.

The current study is in support of utilizing the power hang clean over the power clean due to the production of higher normalized peak power output, while also being a technically easier exercise to teach because it excludes technical instruction from the floor. The results have also shown a trend for the power hang clean to be greater at 70% 1RM when compared to the power clean but did not show any trends at 60% 1RM. This information is in line with the current suggestion of the power hang clean being a superior exercise when peak power output is the desired training characteristic.
Based upon the results of this study, the power hang clean seems to be the superior exercise when compared to the power clean assuming ease of technical ability is a primary concern because of the limited training time athletes have with the performance coach. Furthermore, the 80% 1RM relative intensity may be the optimal intensity to produce peak power output, while 70% 1RM may also assist in the athlete’s progression of force and power generating capabilities. Loading at 60% 1RM seems to be too light of a resistance to affect technical variables during the exercises and does not appear to induce kinematic or kinetic alterations during either exercise. Thus, the power hang clean is suggested as a superior exercise over the power clean when the performance coach is focused on the athlete’s ability to produce high power output. The power hang clean is also an easier exercise to teach and perhaps more economical with the use of limited coaching exposure. The improved kinematic and kinetic output, coupled with technical ease to teach the exercise, support the use of the power hang clean, and it should be utilized over the power clean during athletic training programs for anaerobic athletes that require the high force, power, velocity, and acceleration of the body during sport.
Normalized Barbell Acceleration

For the present study, comparisons of normalized peak barbell acceleration between the power hang clean and power clean were significantly different between exercises at 60% (p = 0.034) and 70% 1RM (p = 0.041). During the 60% 1RM loading condition, post hoc analysis has shown the power hang clean providing significantly (p = 0.005) higher normalized peak barbell acceleration when compared to 80% 1RM of the power hang clean. The power hang clean also provided significantly higher normalized peak barbell acceleration at 70% (p = 0.047) when compared to 80% 1RM. Lastly, post hoc analysis revealed the power clean providing significantly higher (p = 0.033) normalized barbell acceleration at 60% 1RM when compared to the 80% 1RM condition.

A noteworthy common trend during all trials was shown, through a gradual decrease in normalized acceleration, from peak normalized acceleration at 60% 1RM in the power hang clean (0.91 m/s²/kg⁰.⁶⁷) to the lowest measured peak normalized acceleration during 80% 1RM (0.69 m/s²/kg⁰.⁶⁷). This is in opposition to the findings of Sato et al. (2011) utilizing nationally ranked weightlifters stating maintenance in accelerations from 50% to 80% 1RM. This finding further supports the implication of weightlifting experience on technical ability for these exercises.

Normalized peak barbell acceleration at 60% was significantly higher during the power hang clean (0.91 ± .36 m/s²/kg⁰.⁶⁷) than the power clean (0.73 ± .26 m/s²/kg⁰.⁶⁷), and this may be due to the power hang clean having a shorter distance to travel when compared to the power clean. Thus, decreased distance in the power hang clean may suggest a more urgent need for high barbell acceleration to get the barbell into the catch position (Cormie et al., 2011a). The increased acceleration from the power hang clean demonstrates a potential
relationship for increasing an athlete’s force development and movement velocities, while also providing these rapid implement accelerations.

At 70% 1RM, normalized peak barbell acceleration during the power hang clean at 70% 1 RM (0.85 ± 0.36 m/s²/kg⁰·⁶⁷) was significantly higher during the power clean (0.63 ± 0.17 m/s²/kg⁰·⁶⁷) at 70%. The result, as with the 60% relative intensity, are in opposition to the only previous study comparing barbell accelerations during the second pull of a weightlifting exercise (Sato et al., 2001). However, there is an agreement with the previous work of Sato at al. (2011) that there may be a “force generation threshold” where peak barbell acceleration is impacted because acceleration is inversely related to the mass of the barbell. Absolute barbell acceleration (Appendix C) was shown to be 17.9 ± 6.2 m/s² during the power hang clean at 70% 1RM, while the power clean had a peak acceleration of only 12.6 ± 2.6 m/s², meaning force had a proportional increase with acceleration. The power hang clean is further supported by a 500-watt increase in peak power output. Ultimately, the increased force, velocity, and acceleration produced at 70% 1RM may provide greater stimulus to elicit an adaptation when compared to the 60% 1RM load during the power hang clean. The use of the power hang clean at 70% 1RM is recommended as this may provide athletes with a higher stimulus (i.e., moving more mass to improve force generations when compared to 60% 1RM) to improve anaerobic performance from the increased amount of force required to accelerate the barbell into the catch phase, and this exercise also provided a higher power output than the 60% relative condition.

Finally, normalized peak barbell acceleration during the power hang clean (0.69 ± 0.22 m/s²/kg⁰·⁶⁷) was not significantly different from the power clean (0.59 ± 0.18 m/s²/kg⁰·⁶⁷) during 80% 1 RM. At the present time, only the work of Sato et al. (2011) has
compared peak barbell accelerations. The accelerations cannot be appropriately compared to the present study because the full snatch and clean exercises were used. These differences may be based on the acceleration of the barbell being inversely proportional to mass of the barbell lifted. The increased mass at 80% 1RM is consistent with Newton’s second law of motion and agrees with the notion of Sato et al. (2011) that a force-generating threshold may be present due to the inverse nature of the barbell mass and its effect on acceleration.

Another factor that may have affected the results are the use of elite-level weightlifters in the Sato et al. (2011) study. The current study used local weightlifters and although they are considered technically sound, they may have slight insufficiencies in technique from inadequate years of experience (Table 2) in comparison to elite weightlifters. When absolute accelerations are observed between studies, it was shown club-level weightlifters might have a lower absolute force generation threshold compared to elite-level lifters (Appendix C; Sato et al., 2011). The lower technical experience when compared to elite weightlifters may impact the force threshold, motor unit recruitment, and the athlete’s ability to maintain optimal force generations over varying masses (Cormie et al., 2011a; Gabriel et al., 2006).

The current study supports utilizing the power hang clean over the power clean when coaches are concerned with peak acceleration. The use of peak barbell acceleration can be used as a marker for force production, and any decrease in peak barbell acceleration found may be used as a marker for decreased force production. The decrease in peak barbell acceleration as relative loads increased from 60% to 80% 1RM may be from increased mass of the barbell or incorrect technique (Sato et al., 2011). As previously mentioned, this is likely due to Newton’s second law of motion:

\[ F = ma. \]
Where $F = \text{force}$, $m = \text{mass}$, and $a = \text{acceleration}$. The use of this equation may also provide coaches with a rough estimate an athlete’s force capability without the use of expensive force plates and other apparatuses.

The power hang clean is a technically easier movement to teach, but it needs to be compared to power hang clean variations for further discussion (Hori et al., 2005). Although force and velocity were not statistically compared during the study, there appears to be common agreement that the power hang clean is a superior exercise compared to the power clean when the performance coach is interested in optimal athletic performance (Comfort et al., 2011a, 2011b; Comfort, Udall et al., 2012; Hori et al., 2005; Hori et al., 2008; Suchomel et al., 2014). The improved kinematics coupled with the ease of teaching only a portion of the full clean exercise provides further reason to use the power hang clean over the power clean.
Future Research

The use of appropriate normalization techniques is a strong consideration due to potential kinetic and kinematic differences that may result from anthropometric or technical disparities among the subject pool. Previous studies have used subjects that range from rugby players to recreational athletes, which may lead to higher variability, lower peak power output, lower barbell acceleration, and altered force generation because of the technical and neuromuscular differences from training when compared to weightlifting populations. Weightlifting populations are considered technically sound compared to less experienced athletes, and thus, they should offer less deviation in kinetic and kinematic parameters and patterns of movement with different styles of the clean exercise. The current study utilized regional competitive weightlifters. However, when compared to nationally ranked lifters, acceleration outputs were lower (Sato et al., 2011). Utilizing weightlifters in future studies should provide researchers with more reliable data in comparison to using subjects with varying levels of weightlifting experience.

Previous investigations have not exhibited a homogenous subject quality and because of this, future investigations need to account for the experience and technical differences among the various weightlifting exercises tested (Comfort, Udall et al., 2012; Hori et al., 2008; Kawamori et al., 2005; Winchester et al., 2009). Future studies should also consider comparing the magnitude and rates of force production during weightlifting exercises such as the power hang clean and mid-thigh power clean at various intensities. The rate and magnitude of force during these exercises can give coaches insight with how much and how fast force is being produced during the current exercises tested. This may be specific to certain sport applications and give performance coaches necessary information about power.
exercises and the potential they have to increase these force development factors during training.

During the power hang clean, all subjects were in a dynamic loaded position compared to an unloaded position in the power clean. Due to this dynamic loading condition, it must be considered a limitation in that the power hang clean was set at a lower absolute resistance although the relative percentage of the 1RM was the same as the power clean. This may indeed ultimately alter the absolute and thus normalized power and acceleration data. Clearly this lower absolute loading condition had an impact on absolute power values, positively favoring the hang power clean for all participants except Subject 7. It is not clearly understood why this particular subject demonstrated this disposition in comparison to the other subjects; however, given the barbell mass in the hang power position was of lower absolute mass, it does give rise to the fact that given a similar impulse the results would indicate greater power output. Future studies may benefit from assessing both impulse and ground reaction force in combination with utilizing similar absolute masses in both the power clean and power hang clean during comparisons of the exercises.

Although impact is expected to be minimal, the present research was only analyzed in the vertical axis, and as a result, muscular power and barbell acceleration may be increased or decreased from any additional barbell displacement in the medial-lateral and anterior-posterior axes. Although changes in force, power, velocity, and acceleration may be minimal, future research must be able to account for movement in all axes to calculate optimal power production and barbell acceleration. The calculation of kinetics and kinematics in all three axes may provide additional information on technical comparisons between subjects, which may support the use of the power hang clean in comparison to the power clean.
Future research should further scrutinize the normalization technique proposed during weightlifting trials to account for anthropometric differences based upon previous research (Jaric, 2002). The use of allometric scaling may help account for large differences in standard deviations of force production that are present in non-homogenous groups. The use of multiple normalization techniques for comparison would also help better understand the impact of various normalization techniques on statistical assessment and interpretation of data sets. Additionally, for this study only at 80% of 1RM did statistical significance arise in peak power output; thus, future studies might be better suited comparing other relative percentages (e.g. 30, 40, 50, and 90% 1RM), which may also provide coaches with information on changes in force, power, bar velocity, and bar acceleration when comparing Olympic weightlifting exercises. Information in this regard will help performance coaches best decide which exercise variants and relative percentages are best suited for the aims of their strength and conditioning programs with regard to power output and implement acceleration.

Ultimately, the high force production and resultant increase in barbell velocity may increase power output, leading to improvements in performance during anaerobic sport (Hori et al., 2005). The technical differences during the power hang clean over the power clean may allow novice and experienced athletes alike to focus on the force produced, thus allowing increased performance in anaerobic sports that require the high force and power capability during competition. The power hang clean has been suggested to produce rates of force that are similar to jumping, sprinting, and agility type movements and furthers the support for the power hang clean (Cormie et al., 2011b; Kawamori et al., 2006; Kirby et al., 2011; Kraemer & Newton, 2000). Altogether, the current research suggests using the power
hang clean over the power clean when the performance coach has limited time to teach and is concerned with increasing the performance of novice or experienced athletes when training to develop high levels of muscular power output and rapid changes in acceleration. All of which are considered important components for anaerobic sport.
References


APPENDIX A: Informed consent

Informed Consent

Eastern Michigan University
Applied Physiology Laboratory
Informed Consent for Research Involving Human Subjects

Title of Project:
Biomechanical Comparisons of the Power Clean and Power Hang Clean exercises at Different Relative Intensities

Introduction:

The purpose of this study is to compare the power clean and power hang clean at three submaximal loads of 60, 70, and 80% of subjects one repetition maximum (1RM) for an analysis between the difference in peak power output, peak barbell acceleration, and peak vertical impulse. Also to use these results to help improve the sport performance coaches knowledge for which exercise is the most useful during training.

Methods:

You will be asked to come to the exercise physiology laboratory at Eastern Michigan University on a single occasion. During this visit you will be completing 6 submaximal power cleans and 6 submaximal hang power cleans. When you first arrive to the lab, all anthropometric data will be collected. Weight will be assessed on a standard weight balance while you are wearing shorts and a t-shirt. Height will be assessed with a standard anthropometer. You will be warming up with the Olympic bar (20kg) and slowly increasing your weight 5 – 15 kg until you reach 90% of your 1RM. The submaximal trials will be completed in a random order and you will be given 2-3 minutes after each lift and before the next intensity to reduce fatigue. The study will take 1-1.5 hours to complete.

During the 12 submaximal trials, you will be randomly assigned to 60, 70, or 80% of your 1RM. You will be lifting each weight twice until the total of 12 submaximal lifts are completed. We will be using a video camera, Vicon camera system, and two Kistler force plates to track your exercises. These instruments will not inhibit your lifting in anyway because they will not be directly attached to you. The barbell will have 2 reflective markers on each end to track barbell accelerations. These devices will measure your power output, barbell accelerations, and impulses you generate from each lift. This information will help the physiologist learn which exercise will be more beneficial from a training standpoint.

You will be asked to adhere to several restrictions prior to the testing sessions. You will be asked to refrain from exercise 2 days before testing. You will also be asked to abstain from alcohol or caffeine use for 24 hours prior to testing.
**Benefits:**

You are being asked to participate in this study because you are a competitive weightlifting athlete and have 3+ years of weightlifting experience. You will benefit from learning kinetic and kinematic variables associated with your power clean and the power hang clean. Which will include a look into impulses, barbell accelerations, and the power output you generate. It is important for you to understand that at any time, you may withdraw from the study without prejudice or effect on your relationship to Eastern Michigan University.

All of the results from this study will be kept confidential. All participants will be assigned an ambiguous study number to maintain confidentiality. Only the investigators directly working with the participants will know the identities of study participants, and only the primary investigator of this study will know the coding of subject information. If publication occurs, only numbers, not names, will be used. Throughout the study, some of the data obtained from your participation will be made available to you. At the conclusion of the study, any additional data obtained from your participation will be made available to you.

**This research protocol and informed consent document has been reviewed and approved by the Eastern Michigan University Human Subjects Review Committee (UHSRC) for use from 1/13/2014 to 4/1/2014. If you have questions about the approval process, please contact the UHSRC at human.subjects@emich.edu or call 734-487-0042.**

**Risks:**

The potential risks involved with this study are similar to those associated with exercise. The risk of cardiac event and even death is possible given the nature of the maximal physical effort required. These risks are minimal in a young, healthy population, and the individual being constantly monitored during testing will minimize any remaining risk.

Your signature(s) below indicates that you give permission to the investigators to utilize/show videotapes and still images of your participation for academic purposes including research presentations, seminars and other clinical or classroom settings. Should you decide to withdraw from the study, all videotaped sessions and/or still images of your participation will be deleted and/or destroyed.

_________________________________ Participant’s Signature

I hereby certify that I have given an explanation to the above individual of the contemplated study and its risks and potential complications.

_________________________________ Principal Investigator
APPENDIX B: IRB Approval Form

Dear Jacob,

Congratulations! After careful review, your proposal "Kinetastic and Kinetico Comparisons During Variations of the Clean" has been accepted by the College of Health and Human Services Human Subjects committee. We stress that you do not stray from your proposed plan:

http://comets.ehio.edu/cgi-bin/ext.cgi?article=11428&context=chh_hs

Good luck with your research effort.

Jayne Yatskevich, PhD, CHS
Chair, CHHS IRB
APPENDIX C: Raw Values

Table 7: Individual Peak Power Outputs at 60%, 70%, and 80% 1RM.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age</th>
<th>Mass (kg)</th>
<th>Power clean 60% 1RM (W)</th>
<th>Power clean 70% 1RM (W)</th>
<th>Power clean 80% 1RM (W)</th>
<th>Power hang clean 60% 1RM (W)</th>
<th>Power hang clean 70% 1RM (W)</th>
<th>Power hang clean 80% 1RM (W)</th>
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<td>Mean ± SD</td>
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<td>85.25 ± 11</td>
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<td>4147 ± 985</td>
<td>4340 ± 758</td>
<td>4714 ± 1072</td>
<td>5018 ± 1034</td>
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Table 8: Raw Mean Power Outputs Between Each Exercise.

<table>
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<tr>
<th>Exercise</th>
<th>Relative intensity (%)</th>
<th>Mean ± SD Watts</th>
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<td>Power hang clean</td>
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<td>5144 ± 1057</td>
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Table 9: Individual Peak Barbell Accelerations at 60%, 70%, and 80% 1RM.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age</th>
<th>Mass (kg)</th>
<th>Power clean (m/s²) 60% 1RM</th>
<th>Power clean (m/s²) 70% 1RM</th>
<th>Power clean (m/s²) 80% 1RM</th>
<th>Power hang clean (m/s²) 60% 1RM</th>
<th>Power hang clean (m/s²) 70% 1RM</th>
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<td>10.13</td>
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<td>6.51</td>
<td>19.6</td>
<td>15.62</td>
<td>13.72</td>
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<tr>
<td>Mean ± SD</td>
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<td></td>
<td>24.8 ± 3.04</td>
<td>85.25 ± 11</td>
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<td>12.34 ± 2.6</td>
<td>11.75 ± 3.2</td>
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</table>
Table 10: Raw Mean Peak Barbell Acceleration Outputs Between Each Exercise.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Relative Intensity (%)</th>
<th>Mean ± SD (m/s²)</th>
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<tr>
<td>Power clean</td>
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<td>Power hang clean</td>
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<td>13.8 ± 3.68</td>
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