The Acute and Longitudinal Effects of a Weighted Exo-Skeleton on the Performance of the Power Clean

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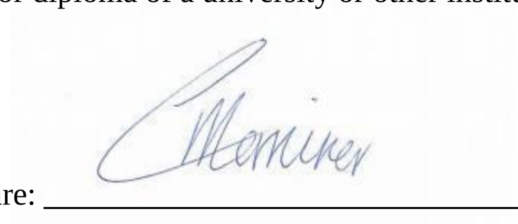
Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.



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Articles under review

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The following manuscripts have been submitted or are in preparation for submission in peer reviewed journals as a result of the work presented in this thesis.

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The student was the primary contributor (>80%) of the research in this thesis and the subsequent analysis and interpretation of the research results. The student was also the main contributor (>80%) to the writing of research ethics applications, progress reports and papers. All co-authors have approved the inclusion of the joint work in this thesis.

Signatures

Adam Storey

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Abbreviations

1RM	One repetition maximum
CV	Coefficient of variation
CMJ	Counter movement jump
CxH	Catch height
Dx2	backward bar movement from the first to second pull
DxL	the horizontal displacement of the bar from the most forward position during the 2nd pull to the catch
DxT	the total amount of horizontal displacement from the beginning of the lift to the catch position
DxV	the horizontal displacement from the second pull to the forward most position
GRF	Ground reaction force
ICC	Intraclass correlation coefficient
PGRF	Peak ground reaction force
PF	Peak force
PP	Peak power
SSC	Stretch-shorten cycle
TE	Typical error
WV	Weighted vest

Units of measurement

cm	Centimeter
ES	Effect size
kg	Kilogram
M	Mean
$m.s^{-1}$	Meters per second
N	Newtons
r	Correlation coefficient
SD	Standard deviation
sec	Seconds
W	Watts
%	Percentage

Abstract

The power clean exercise is commonly prescribed to athletes involved in strength and power sports due to the kinematic similarities that this exercise has to key phases during jumping and sprinting (e.g. explosive hip, knee and ankle extension). Another popular method to improve athletic performance and lower body power is training with a weighted vest (WV) (i.e. centralised loading) as it allows individuals to perform sports specific movements such as jumping and sprinting in an overloaded fashion. Weighted vest training may also be a possible alternative loading method that could allow individuals to continue to train with full body explosive exercises without being limited by the technique and mobility demands. However, it is currently unknown what effect this loading method has on full body explosive movements such as the power clean. Therefore this thesis sought to investigate the acute and longitudinal effects of centralised loading on the performance of the power clean exercise and athletic performance.

The purpose of the first study was to determine the optimal load to be worn during the performance of the power clean exercise. This was achieved by comparing the acute kinematic and kinetic effects of performing the power clean with loads of 50% and 70% 1RM across three conditions in nine recreationally trained males; 1) no Exo-skeleton, 2) 5% bodyweight Exo-skeleton and, 3) 12% body mass Exo-skeleton. Four of the kinematic variables measured were technique variables which were; 1) most forward position to catch (DxL), 2) start position to catch (DxT), 3) start position to beginning of 2nd pull (Dx2), and 4) 2nd pull position to catch (DxV). It was concluded that the optimal Exo-skeleton load to be worn during the power clean was a load ~12% of a lifter's bodyweight and such loading may positively influence kinematic and

kinetic variables during power clean performance.

Following the results from study one, a five week power clean training intervention was devised to determine and compare the longitudinal kinematic, kinetic and performance effects of wearing a weighted Exo-skeleton vs. no Exo-skeleton. Sixteen resistance trained males were randomly assigned to either a no Exo-skeleton or a 12% bodyweight Exo-skeleton group. Training with the 12% Exo-skeleton resulted in a number of desirable technique changes (as determined by the variables noted above) that included increases in the rearward displacement of the barbell, increases in barbell velocity, and improved peak power outputs. Furthermore, the cumulative effect of improved lifting kinematics, barbell velocity, and PP resulted in the 12% Exo-skeleton group improving the CMJ by 8.5% and 1RM power clean performance by 4.6%. Conversely, the no Exo-skeleton group demonstrated only a mild increase in 1RM power clean performance (1.9%) and a decrease in CMJ performance (-1.5%). In conclusion, training with a 12% Exo-skeleton is a viable alternative loading method for resistance trained males who wish to improve their power clean ability (both technique and performance) and CMJ performance.

CHAPTER 1. PREFACE

1.1 Thesis rationale and significance

Olympic weightlifting exercises such as the snatch and clean and jerk are full body movements that require the lifters to exert high forces in order to lift the barbell from the floor to an overhead position or to the shoulders in one continuous movement (Garhammer, 1998; Stone, Pierce, Sands, & Stone, 2006a; Storey & Smith, 2012). Due to the explosive nature of these exercises the reported peak power outputs are among the highest within the literature (Garhammer, 1998). Therefore, these exercises are popular among strength and power athletes due to their ability to improve power output (Arabatzi, Kellis, & Villarreal, 2010; Hoffman, Cooper, Wendell, & Kang, 2004; Hori, Newton, Nosaka, & Stone, 2005). The power clean exercise is often prescribed for strength and power athletes due to technical difficulties and mobility issues associated with the competition lifts of the snatch and, clean and jerk. Competitive weightlifters often train twice a day allowing the time to perfect their technique (Stone, Pierce, Sands, & Stone, 2006b). However, non-weightlifting athletes may only train with the power clean and other abbreviated weightlifting exercises 1-3 times per week (Stone et al., 2006a; Storey & Smith, 2012) which does not provide enough time for these athletes to master the power clean and other various weightlifting movements. Thus, non-weightlifting athletes often struggle to lift near maximal to maximal loads due to deficiencies in their lifting technique.

In the sport of Olympic weightlifting, the competition lifts require the lifters to squat to a full depth with the barbell in an overhead or front rack position. Therefore, these lifts require excellent mobility in a number of joints including the wrists, elbows, shoulders, hips, knees and ankles (Storey & Smith, 2012). The abbreviated versions require the lifter to catch the barbell above a parallel squat position and return to an upright standing position which requires less mobility from the aforementioned joints (Baker & Newton, 2009; Comfort, Allen, & Graham-Smith, 2011). The power clean exercise is also commonly prescribed to athletes involved in strength and power sports such as track and field and rugby, due to the kinematic similarities the power clean has to key phases during jumping and sprinting (Hori et al., 2008; Hori et al., 2005; Stone et al., 2006a). For example, key kinematic variables which are important during jumping and sprinting are explosive hip, knee, and ankle extension (Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005; Young, Benton, Duthie, & Pryor, 2001) and these variables are emphasised during the second pull phase of the power clean. Training with exercises that have similar kinematics to movements critical to sports performance are thought to enhance the transference of training adaptations to sports performance (Haff & Nimiphius, 2012). For example, following Olympic weightlifting training, improvements in squat jump and countermovement jump performance have ranged from 8.7% - 16.9% and 6.2% - 13.3%, respectively (Arabatzi et al., 2010; Hoffman et al., 2004; Tricoli et al., 2005).

Due to the full body explosive nature of weightlifting exercises, high forces are often required to lift the barbell in one continuous movement at high velocities which result in large power outputs (Hori et al., 2005). High peak force (PF) and peak power (PP) outputs are important in a range of sports including football codes (i.e. American football, rugby union, and rugby league) where the ability to forcibly move opponents is important and often requires the rapid application of high force (Baker & Nance, 1999; Hoffman et al., 2004; Pennington, Laubach, De Marco, & Linderman, 2010). As such, weightlifting exercises are often incorporated into resistance training programs of various strength and power athletes throughout the year to improve their force and power producing capabilities.

An alternative training method to assist in the development of force and power production is variable resistance which is the addition of chain links or resistance rubber bands to traditional exercises such as the bench press and squat (Berning, Coker, & Adams, 2004; Ebben & Jensen, 2002; Ghigiarelli et al., 2009; McMaster, Cronin, & McGuigan, 2009). This alternative loading method adds further external resistance during a specific phase of a given exercise which changes the kinetics of the lift (Baker & Newton, 2009; Coker, Berning, & Briggs, 2006). As such a number of changes in kinetic and performance measures have been reported. For example, following the acute performance of the back squat exercise at 85% of 1RM with 20% of the total training load coming from band resistance, PP and PF significantly increased by 24% and 4%, respectively, when compared to traditional loading methods (i.e. 100% of load coming from the bar and plates) (Wallace, Winchester, & McGuigan, 2006). Anderson et al. (2009) also reported significant increases in 1RM bench (8%) and squat (16%) performance following seven weeks of resistance training using 20% of the total load from bands. However, when such a training method is applied to the power clean and power snatch, no significant change in kinetic and kinematic variables have been shown to occur (Berning, Coker, & Briggs, 2008; Coker et al., 2006). A lack of change in kinematic and kinetic variables may have been due to unwanted changes in technique, as previous researchers have reported increases in PF and PP as a result of improved technique in the power clean and power snatch exercises. In light of these findings, further research needs to determine what effect alternative loading methods have on kinematic and kinetic variables during the performance of the power clean and/or power snatch.

One such alternative loading method that has been shown to improve athletic performance is “centralised loading” which is the addition of weight/resistance to the body (i.e. in the form of a weighted vest) (Khlifa et al., 2010). The rationale for centralised loading is to increase the overall resistance during dynamic movement tasks and/or exercises (Burkett, Phillips, & Ziuraitis, 2005; Clark, Stearne, Walts, & Miller, 2010; Faigenbaum et al., 2006; Khlifa et al., 2010; Thompsen, Kackley, Palumbo, & Faigenbaum, 2007). One area of contention surrounding centralised loading is the optimal WV load that should be used during training as previous researchers have reported contrasting results following acute WV interventions with loads of 2-20% of participant’s bodyweight. For example, significant improvements in vertical jump, broad jump, and CMJ performance were reported to occur following the use of WV loads of 2-10% following dynamic warm ups (Faigenbaum et al., 2006; Thompsen et al., 2007). Conversely, following a warm up using a WV load of 6% of participant’s bodyweight, Faigenbaum et al. (2010) reported no change in jump performance while, Reiman et al. (2010) reported a decrease in absolute and relative power during a sprint test. With regards to technique variables, the use of a 12% WV load has resulted in improved landing technique during vertical jumps (Janssen, Sheppard, Dingley, Chapman, & Spratfor, 2012). Conversely, WV loads of 15-20% have reduced sprint performance and technique (Clark et al., 2010; Cronin, Hansen, Kawamori, & McNair, 2008). With such conflicting results in the reviewed literature pertaining to the acute effects of WV loading, it is evident that further research is required to determine the optimal WV load to be used in training. Furthermore, as the combined use of WV resistance and whole-body strength and power resistance exercises (i.e. power clean) could prove to be a highly effective training strategy, further investigation is also warranted in this area. Therefore, due to the popularity and effectiveness of the power clean in resistance training programes and the lack of research on alternative loading methods to improve power clean force, power, and technique measures, this thesis will investigate the acute and longitudinal effects of centralised loading on the performance of the power clean exercise. The alternative loading method used for this thesis was a Lila™ Exogen™ Exo-skeleton suit (Sportboleh Sdh Bhd, Malaysia). This Exo-skeleton was chosen over a traditional WV due to the ability to perform functional high speed movements like the power clean. Furthermore, the Exo-skeleton was chosen due to the Velcro-like nature of the suit which allowed customised loading of the participants" posterior chain only as the researchers believed that anterior loading may have inhibited the performance of the power clean.

1.2 Research aims and hypothesis

The major aims of the work in this thesis were to:

1. Identify the optimal Exo-skeleton load to be worn during the power clean exercise.
2. Determine and compare the acute kinematic and kinetic effects of wearing a weighted Exo-skeleton vs. no Exo-skeleton during the power clean exercise.
3. Quantify and compare the longitudinal kinematic, kinetic and performance effects of wearing a weighted Exo-skeleton vs. no Exo-skeleton following five weeks of structured power clean training.

The following hypotheses were generated for the studies undertaken in this thesis;

1. The Exo-skeleton would improve power clean technique when compared to the

no Exo-skeleton condition.

2. The Exo-skeleton would result in increases in kinetic and kinematic variables when compared to the no Exo-skeleton condition.

3. Power clean training with the Exo-skeleton would result in improved counter movement jump performance when compared to the no Exo-skeleton condition.

1.3 Originality of the Thesis

1) There is conflicting evidence regarding the optimal centralised load to be worn during warm ups, jumping and sprinting. In addition, no recommendations currently exist for centralised loading during whole-body strength and power resistance exercises.

2) Little evidence exists on improving kinematic and kinetic variables for weightlifting exercises through alternative loading methods.

3) No evidence exists on improving acute and chronic weightlifting technique variables through alternative loading methods.

1.4 Thesis organisation

The thesis is organised to answer the over-arching question, what are the acute and longitudinal kinematic and kinetic effects of a weighted Exo-skeleton on the performance of the power clean exercise and athletic performance? This thesis consists of five chapters. Chapter 2 consists of a literature review pertaining to the intricacies of weightlifting and the power clean exercise. Chapter 2 will also discuss the inclusion and application of the power clean exercise amongst a range of athletes in different sports. Chapter 3 is a cross sectional study investigating the acute kinematic and kinetic effects that different Exo-skeleton loads has on the performance of the power clean.

The purpose of Chapter 3 is to identify the optimal Exo-skeleton load to be worn during structured power clean training. The results from this investigation inform loading for the training intervention study in Chapter 4, which investigated the longitudinal kinematic and kinetic effects of a weighted Exo-skeleton on the performance of the power clean exercise and other measures of athletic performance. The reader must be cognisant that there is repetition throughout chapters three and four. More specifically, the introductions are similar because the same rationale drives both chapters while similar sections during the methods have been replicated to ensure consistency. Finally Chapter 5 consists of a general summary of the research findings and the practical applications for athletes and strength and conditioning practitioners who are involved in strength and power sports. An overall reference list from the entire thesis has been collated at the end of the final chapter in APA (6th ed.) format. All the relevant material from the studies including abstract for the two scientific studies, step by step technique analysis, ethics approval, participant information sheet, informed consent forms, and questionnaires are presented in the appendices.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

In the sport of Olympic weightlifting two lifts are contested; the snatch and clean and jerk. While these exercises produce some of the highest power outputs within the literature, they also require exceptional strength, speed, flexibility, and mobility (Chiu & Schilling, 2005; Garhammer, 1993, 1998; Storey & Smith, 2012). Therefore, many athletes use abbreviated lifts such as the power clean, power snatch, and other variations of the competition lifts as training exercises (Garhammer, 1993; Stone et al., 2006a; Storey & Smith, 2012). The nature in which the barbell is lifted from the floor to the shoulders in one continuous movement during the power clean means that this exercise has similar kinematics to many athletic movements such as jumping, sprinting, and throwing (Canavan, Garrett, & Armstrong, 1996; Tricoli et al., 2005). As these movements are critical to the success in many sports, the power clean is widely used by a number of different athletes who wish to improve kinetic variables such as peak force (PF) peak power and (PP) (Hori et al., 2005). These variables are thought to positively transfer in to athletic performance as athletes with superior PF and PP production are often greater skilled athletes (Gabbett, 2002; Tricoli et al., 2005).

This review details the intricacies of the power clean with particular emphasis on critical technique variables that are associated with this exercise. Further attention is directed towards the acute and longitudinal effects that power clean training has on kinematic and kinetic variables. Thus, supporting evidence and practical applications are provided for strength and conditioning practitioners for the use of the power clean. Finally, potential areas of future research have been highlighted.

2.2 Power clean performance

Olympic lifting exercise variations are commonly used among strength and power athletes due to the ability to generate large power outputs during these explosive, full body movements (Cormie, McGuigan, & Newton, 2011b; Garhammer, 1998; Storey & Smith, 2012). Due to the technical complexities of the full competition lifts (Hori & Stone, 2005; Stone et al., 2006a), modified versions, such as the power clean, are commonly used by non-weightlifting athletes in strength and power sports due to their effectiveness in increasing kinetic variables such as PF and PP (Comfort, Graham-Smith, Matthews, & Bamber, 2011; Cormie et al., 2011b; Storey & Smith, 2012). For example, the power clean is commonly used by college football players during the off-season in combination with traditional heavy strength training to increase strength and power production (Hoffman et al., 2004) while rugby players commonly use the power clean in conjunction with jumping exercises throughout the competition season (Argus, Gill, Keogh, McGuigan, & Hopkins, 2012). Furthermore, to improve power production and release velocities in athletes involved in track and field throwing events, the power clean is commonly prescribed with loads of 75-100% 1RM used during the off season while loads of 50-100% are included during the competition phase (Judge, 2007; Zaras et al., 2014). These examples demonstrate how the power clean is incorporated into a range of athlete's programs from a number of different sports which highlights the importance the power clean has for improving athletic performance.

During the performance of the Olympic lifts (both competition lifts and modified versions), advanced weightlifters often exhibit greater force and power producing capabilities when compared to lesser skilled counterparts (Comfort et al., 2011). These disparities are likely attributable to differences in lifting technique. As improvements in technique result in positive changes in kinetic variables such as PF and PP (Winchester, Erickson, Blaak, & McBride, 2005; Winchester, Porter, & McBride, 2009) the technique of the power clean should therefore be trained and be of a suitable level in order to maximise the effectiveness of this exercise.

2.2.1 Technique factors

The technical aspects of the power clean are very demanding and require a great deal of mobility and co-ordination from a number of joints (Storey & Smith, 2012). However, compared to other weightlifting variations such as the snatch and the clean and jerk, the power clean is less technically demanding and requires less time in order to become proficient at the movement (Souza, Shimada, & Koontz, 2002; Stone et al., 2006a). The power clean is a full body explosive movement which requires the barbell to be lifted from the floor (using a shoulder width grip) to the front of the shoulders in one continuous movement (Stone et al., 2006a; Storey et al., 2012). The power clean is comprised of five phases (Figure 1). From the set position, the *first pull* is initiated from the floor and requires the lifter to extend the knees raising the barbell off the floor to the bottom of the knee. The second phase is a *transition period* (also referred to the "double knee bend") where the knees are re-bent and moved under the bar while the trunk is extended to a near vertical position. This movement allows lifters to utilise the stretch-shorten cycle (SSC) during the following phase which is known as the *second pull* (Stone et al., 2006a; Storey et al., 2012). The second pull requires lifters to maximally extend through the hips, knees, and ankles (i.e. often referred to as a „triple extension‟) while pulling upright with the back and shoulders to maximally accelerate the bar as vertically as possible whilst maintaining the barbell close to the body. Once the second pull is complete with maximum extension of the body, the barbell travels vertically up and the lifter pull themselves under the bar during the *turnover* phase. The participant then drives the elbows forward and catches the barbell on top of the front of the shoulder (*catch position*) whilst returning to an upright standing position. The depth of the power clean can vary but is often to a maximum depth of a parallel squat (i.e. hips no deeper then knee level) (Kawamori et al., 2005; Stone et al., 2006a).

Figure 1. The five phases of the power clean: a) first pull. b) transition. c) second pull. d) turnover. e) catch position adapted from Storey et al. (2010)

While technique will vary amongst athletes due to weightlifting experience (Stone et al., 2006a, 2006b; Winchester et al., 2005), Winchester et al. (2005) identified kinematic variables that are highly correlated to the success or failure of the power clean. These variables included: backward bar movement from the first to second pull (Dx2); the horizontal displacement from the second pull to the forward most position (DxV); the total amount of horizontal displacement from the beginning of the lift to the catch position (DxT); and, the horizontal displacement of the bar from the most forward position during the 2nd pull to the catch position (DxL) (Figure 2). Previous investigations (Winchester et al., 2005; Winchester et al., 2009) have reported improvements in kinematic variables as a result of weightlifting training, however, this will be discussed in the following sections.

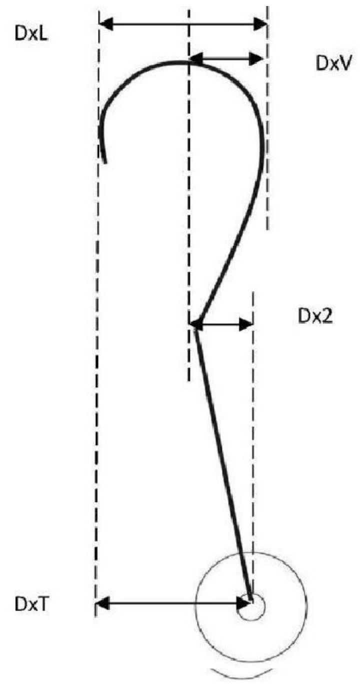

Figure 2. Kinematic variables Dx2, DxV, DxT, and DxL adapted from Winchester et al. (2005).

2.2.2 Kinetic factors

Specificity of training applies to the kinetics of exercise as the greater the similarity of kinetic variables such as PF and PP between training and competition, the greater the training effect will be (Haff & Nimiphius, 2012). Previous researchers have reported that a significant relationship (r=0.58-0.93) exists between the reported power outputs during weightlifting movements such as the power clean, jumping (Carlock et al., 2004; Hori et al., 2008) and sprinting (-0.57) (Hori et al., 2008). These findings demonstrate the specificity the power clean and other weightlifting exercises have towards power production for other athletic movements (Carlock et al., 2004; Garhammer, 1993; McBride, Triplett-McBride, Davie, & Newton, 1999).

Another kinetic variable associated with power clean performance is PF as lifters must apply large forces against the ground while accelerating the barbell throughout the pulling movements (Hori et al., 2008; Souza et al., 2002; Stone et al., 2006a). In non-weightlifting athletes, PF measures for the power clean exercise have been reported to range from 2,300 (N) at 60% 1RM to 3300 (N) at 90% 1RM (Comfort, Allen, et al., 2011; Kawamori et al., 2005). The production of large PFs in combination with large PP outputs during the power clean is important to athletes involved in contact sports such as rugby union, rugby league, and American football where large forces are needed in a number of game situations (e.g. tackling an opponent or breaking a tackle) (Baker & Nance, 1999; Pennington et al., 2010; Storey & Smith, 2012). While heavy resistance exercises such as the deadlift and squat also produce large PF's, the movement velocity is low thus low PP is produced (McBride, Haines, & Kirby, 2011; McBride et al., 1999). Therefore, coaches wishing to improve force production for contact sports should consider the power clean in conjunction with other heavy resistance exercises.

2.2.3 Relationship to athletic performance

Implicit in the principle of specificity is that the closer a training movement/exercise can mimic the desired movement pattern in competition, the greater the training effect towards that competition skill will be (Haff & Nimiphius, 2012). Since the basis of many athletic movements involve jumping and sprinting, training should therefore replicate such movements. A kinematic variable which is important in jumping and sprinting is hip extension (Tricoli et al., 2005; Young et al., 2001), which is also emphasised during the 2nd pull of the power clean (Canavan et al., 1996; Dawes, 2012; Storey & Smith, 2012). Furthermore, Canavan et al. (1997) reported a significant ($r = 0.87$; $p \leq 0.05$) relationship of the angular displacements of the hip, knee, and ankle for the vertical squat jump and the hang power snatch; the power snatch also has very similar kinematics to that of the power clean (Stone et al., 2006a; Storey & Smith, 2012). Practitioners wishing to improve jumping and sprinting ability, and in particular hip extension, could include the power clean and power snatch into their training, with particular emphasis on the second pull.

As previously stated, one movement critical during the power clean is the double knee bend whereby the SSC is utilised (Chiu & Schilling, 2005; Cormie, McGuigan, & Newton, 2011a; Cormie et al., 2011b). The SSC is important during jumping and sprinting as athletes who are able to apply greater eccentric and concentric forces over the least amount of time have superior jumping and sprinting performances (Arabatzi et al., 2010; Cormie et al., 2011a). Although no studies have investigated the relationship of the SSC during the power clean and jumping and sprinting, it is evident through the literature that the SSC is prevalent in all of these movements (Chiu & Schilling, 2005; Cormie et al., 2011a, 2011b; Komi & Gollhofer, 1997; Storey & Smith, 2012; Wilson & Flanagan, 2008). The kinematic similarities between these movements provides further justification for using the power clean exercise in resistance training programs designed to improve jumping and sprinting ability.

A kinematic variable that is important during throwing events is release velocity. For example during shot put, some authors have reported that release velocity is the most important factor to throwing distance when compared to release angle and height (Linthorne, 2001; Luthanen, Blomquist, & Vanttinen, 1997). As velocity has a direct relationship with distance (e.g. distance equals velocity multiplied by time) (Linthorne, 2001), improving release velocity is of importance to practitioners wishing to improve throwing performance. One exercise often prescribed to improve throwing performance and throwing velocity is the power clean as barbell velocities have been reported to be amongst the highest when compared to other exercises (Stone et al., 2006a; Storey & Smith, 2012; Zaras et al., 2013; Zaras et al., 2014). For example, during sub maximal power cleans, barbell velocities have been reported to exceed 2.5 $m.s^{-1}$ while barbell velocities during the 2nd pull of near maximal to maximal full cleans can range from 0.88 $m.s^{-1}$ to 1.73 $m.s^{-1}$ (Cormie, McCaulley, Triplett, & McBride, 2007). Such velocities are far superior to traditional heavy resistance exercises such as the squat (e.g. 2 $m.s^{-1}$ at 27% 1RM and 1.2 $m.s^{-1}$ at 85% 1RM) and the deadlift (e.g. 0.78 $m.s^{-1}$ at 30% 1RM and 0.52 $m.s^{-1}$ at 90% 1RM). Therefore, practitioners wishing to improve throwing velocity and subsequent throwing performance should incorporate the power clean into their resistance training programs. Such examples highlight the skill transference and the specificity that the power clean exercise has for various athletic movements and why this particular exercise is used among a range of different sporting codes.

2.3 Acute changes in power clean performance

To gain further insight into the power clean and other weightlifting styled exercises, a number of investigations have studied the acute kinematic and kinetic responses to these exercises. Such research allows enhanced prescription of training for these exercises for a variety of athletes wanting to improve both athletic and weightlifting performance. The following section will discuss key concepts that are applicable to the acute performance of the power clean and other weightlifting exercises such as technique factors and PF and PP.

2.3.1 Technique factors

Bar path parameters have been proposed to have an important link with the success of weightlifting movements (Souza et al., 2002) with superior lifters often exhibiting greater technical skills then lesser trained lifters (Stone, O'Bryant, Williams, & Johnson, 1998; Winchester et al., 2005). As such, three kinematic factors have been identified as being paramount for the success of the power clean exercise. These variables include: 1) rearward movement of the barbell during the first pull (Dx2), 2) the total horizontal displacement (≤20 cm) from the most forward position to the catch position and, 3) the catch position (DxT) in relation to the total horizontal displacement (DxL) (Winchester et al., 2005; Winchester et al., 2009). Due to the lack of research on the acute effect different loads have on bar path kinematics for the power clean, it is possible to refer to the pre-testing results from an intervention study (Winchester et al., 2005) to demonstrate this effect. When measuring the horizontal displacement during Dx2 at testing loads of 50%, 70% and 90% 1RM, Winchester et al. (2005) reported rearward displacements of -0.7 cm, -4.3 cm, and - 6.3 cm, respectively. It would seem that an increase in barbell load can result in an increase in rearward horizontal displacement. Currently, the optimal rearward displacement during the first pull is unknown. However, a number of authors have outlined the importance of an initial rearward movement, which keeps the barbell close to the body as this allows for greater vertical force production and velocities during the 2nd pull (Garhammer, 1985; Stone et al., 2006a).

As previously outlined, DxV is another technique variable that is important for the success of the power clean as lifters want to minimise the forward displacement of the barbell during the second pull and turnover phases which allows for a greater vertical displacement of the barbell. Winchester et al. (2005) described similar DxV values for the power clean at 50% (10.7 cm) and 70% (10.4 cm) while there was an increase during the 90% 1RM efforts (13.1 cm). It appears that during the second pull at near maximal loads, force is applied more horizontally in a forward direction thus increasing forward movement during the second pull and turnover phase. It is possible that this occurs due to lifters "hipping" the barbell whereby lifters make excessive contact with the upper thighs or hips resulting in unnecessary forward swing (Winchester et al., 2005; Winchester et al., 2009). Such a change in bar path mechanics diminishes vertical force production and vertical velocities which are unfavourable for improving power clean performance. Previous researchers have reported that PF and PP occurs during the 2nd pull phase of the power clean (Comfort, Allen, et al., 2011;

Cormie, McBride, & McCaulley, 2007; Enoka, 1979; Garhammer, 1993; Hori et al., 2007; Souza et al., 2002), which highlights the importance of being able to transfer force vertically as opposed to horizontally in order to maximise the benefits of these movements. Furthermore, Gourgoulis et al. (2009) also highlighted the importance of the direction of force application on to the barbell as a contributing factor towards the success in the performance of the snatch lift, which has very similar barbell trajectories and kinematics to the power clean (Stone et al., 2006a; Storey & Smith, 2012). This highlights the importance of technique for the power clean and emphasize the lack of research on bar path parameters at different loads for the power clean and the effect of different loading methods on technique. While analysis of bar path parameters is useful in understanding the effect that different 1RM loads have on technique, there is a lack of research on alternative loading methods to improve weightlifting performance. Therefore, further research needs to be directed towards understanding the influence different loads and different loading methods have on acute weightlifting performance.

2.3.2 Kinetic factors

A key kinetic variable that is important to the success of sports performance is PP (Blatnik et al., 2014; Pennington et al., 2010) as it relates to improvements in generic athletic movements such as jumping, sprinting, and throwing which are inherent in a large portion of sports (Hori et al., 2005). The optimal load for PP has been reported to vary amongst different exercises with PP outputs ranging from 588 (W) for the bench press throw at 70% of 1RM load, 1930 (W) for the deadlift at 70% 1RM, approximately 3200 W for the squat at 56% 1RM, and 5390 (W) for the counter movement jump at 40% of 1RM (Baker & Newton, 2006; Blatnik et al., 2014; Cormie, McCaulley, et al., 2007; Stone et al., 2003). However, Kawamori et al. (2005), Cormie et al. (2007), and Pennington et al. (2010) reported that PP for the power clean exercise occurred at loads of 70%, 80% and ≥80% of 1RM respectively. During these investigations, the authors reported PP ranges from approximately 1950 (W) to 4,800 (W). Although PP has been reported to occur at 70-80% 1RM for the power clean, Kawamori et al. (2005) observed significant increases in PP across loads of 50%, 60%, 70%, 80%, and 90% of 1RM when compared to 30% and 40% 1RM. Kawamori et al. (2005) also reported no significant difference in PP between loads from 50-90% 1RM. Additionally, Cormie et al. (2007) reported a significant increase in PP at a load of 80% when compared to 30% and 40% of 1RM. As power is the product of force and velocity, it would seem that loads of 30-40% 1RM do not require a great enough force production for the given velocity to maximise PP in the power clean (Cormie, McCaulley, et al., 2007; Kawamori et al., 2005). However, during loads of 50-90% 1RM, larger forces are produced at high velocities resulting in an increase in PP. This could have applications to various sports where the need for greater force or velocity is different and as such, training can be directed towards the sport's needs. For example, in rugby where the development of high force against large external loads (i.e. opposition players) is essential (Baker & Nance, 1999; Storey & Smith, 2012), rugby players may train at higher loads such as 70-90% of 1RM, with lower corresponding movement velocities in order to maintain high power outputs. Conversely in throwing events where high release velocities are a critical factor to success (Judge, 2007; Zaras et al., 2013; Zaras et al., 2014), throwers may opt to train at high velocities with lighter loads such as 50-70% of 1RM in order to maintain high power outputs.

To improve the force and velocity profiles during specific phases of a given movement, athletes and practitioners often use variable resistance. This alternative loading method involves the addition of chain links or rubber bands to the barbell which changes the kinetics of the lift by altering the external load through different phases of the lift (Bellar et al., 2011; Ghigiarelli et al., 2009). Previous researchers have noted improvements in performance measures of the squat and bench press exercises following peripheral loads ranging from 15%-35% of the total external load (Anderson, Sforzo, & Sigg, 2008; Baker & Newton, 2009; Bellar et al., 2011; Stevenson, Warpeha, Dietz, Giveans, & Erdman, 2010). To determine the acute effect peripheral loading had on the power clean and snatch performance, Berning et al. (2008) and Coker et al. (2006) applied the equivalent of 5% of the total external load in the form of chain links to barbell loads of 80% and 85% of the participants" 1RM. Both authors found non-significant differences for all measured variables which included; bar displacement (m), barbell velocity ($m.s^{-1}$), vertical GRF (N) (for the first pull, second pull, and un-weighting phase), and RFD ($N.s^{-1}$). A limitation of both studies is the lack of kinematic data, specifically horizontal barbell displacement, in order to assess changes in technique. As changes in technique have been shown to effect kinetic variables (Winchester et al., 2005; Winchester et al., 2009) it is possible that an unwanted change in technique may have limited the potential for improvements in kinetic variables. For example, an increase in the total horizontal displacement of the barbell during the lift would result in greater horizontal force production, thereby decreasing the vertical GRF which would not be advantageous for power clean and snatch performance (Stone et al., 1998). In light of these findings, further research needs to determine what effect alternative loading methods have on kinematic and kinetic variables during the performance of the power clean and/or power snatch.

Furthermore, by minimising or eliminating the external load as seen during centrally loaded exercises (i.e. through the use of a weighted vest), it is possible that injured athletes or those with limited joint mobility may continue to train in an effective manner. For example, rugby players with poor wrist mobility who need to continue to train with the power clean during the competition season to improve force and power production often struggle to complete near maximal to maximal loaded power cleans. However, a possible alternative loading method that could avoid this issue would be to redistribute some of the load off the barbell and onto the lifter themselves through the use of a weighted vest. In this training scenario the total system load (i.e. the total weight of the barbell plus the weight of the weighted vest) could be equated to meet the prescribed training intensity and volume, however, such contention needs further investigation.

2.4 Longitudinal changes in power clean performance

While acute studies give an in-depth analysis of different variables associated to the power clean and power snatch, they only provide a snap shot in time and fail to provide information on how these exercises effect performance over a training period. Therefore, the following sections will explore how longitudinal interventions using the power clean and power snatch exercises have affected technique, kinetic variables, and athletic ability.

2.4.1 Technique factors

Lifting technique is a critical variable that contributes to the success, or failure, in the sport of competitive weightlifting (Hori & Stone, 2005; Stone et al., 2006a). While elite Olympic level weightlifters hone their technique to the highest level, athletes involved in other sports using weightlifting exercises also seek to improve their technique as previous research has shown that technical improvements can increase kinetic outputs (Winchester et al., 2005; Winchester et al., 2009). Therefore, previous studies have attempted to measures changes in technique, the details of which have been outlined in the previous sections (Winchester et al., 2005; Winchester et al., 2009).

As previously discussed, a technique variable that is critical to the success of clean and snatch performance is the initial rearward displacement of the barbell from the start position to the beginning of the 2nd pull (Dx2) which has been shown to change following a training intervention (Winchester et al., 2005; Winchester et al., 2009). For example, following the course of three training sessions per week for four weeks in resistance trained sportsmen with a minimum of one year power clean experience, Winchester et al. (2005) reported significant increases in rearward displacement in Dx2 across a range of loads for the power clean (50% 1RM -7 cm; 70% 1RM-5.3 cm; 90% 1RM -2.2 cm). Using identical training methods for the power snatch, Winchester et al. (2009) also reported significant increases in Dx2 in the rearward direction across all testing loads (50% 1RM -7.3 cm; 70% 1RM-6.6 cm; 90% 1RM - 4.2 cm). Previous authors have noted the importance of an initial rearward movement as a key indicator to the success in the performance of the power clean (Chiu & Schilling, 2005; Stone et al., 2006a). Establishing a sound starting position whereby lifters have their knees in front of the bar and their hips above or over their ankles will help to ensure the barbell will travel rearwards when the lifter extends their knees during the first pull off the ground. This in turn enables the lifter to be in the best position to produce large vertical forces and barbell velocities during the 2nd pull, which has been identified as a critical phase of the power clean and other weightlifting exercises (Winchester et al., 2005; Winchester et al., 2009). While improving the 1st pull is important for the performance of the power clean and snatch, it will also allow for greater force and power production. This can then transfer to athletic movements where an improvement in force and power producing capabilities are needed.

Another technique variable reported to have changed over the course of these training interventions, was the rearward displacement of the catch position in relation to the start position (DxT). Winchester et al. (2005) reported significant increases in the rearward displacement for DxT across all loads for the power clean (50% 1RM 14.7 cm; 70% 1RM 12.5 cm; 90% 1RM 12.7 cm). Similarly, Winchester et al. (2009) reported significant increases in rearward displacement for the power snatch (50% 1RM 17.2 cm; 70% 1RM 11.2 cm; 90% 1RM 13 cm). In light of these significant technique improvements that have been shown to occur over relatively short training periods, it would appear that athletes who have a small amount of experience with the power clean are prone to initially catching the barbell in a forward position. This often occurs due to failing to maximally extend the hips, knees, and ankles during the 2nd pull (Dawes, 2012). In sportswomen (soccer and volley ball athletes) with 2-48 months of power clean training, Rucci et al. (2010) failed to note any significant changes in technique during the catch position following eight power clean sessions over the course of two weeks. However, Rucci et al. (2010) did report that the angle of the body in full extension and the bar relative to the toe in full extension did change during the 2nd pull phase. While Rucci et al. (2010) failed to publish the magnitude of the changes, these findings support the notion that novice lifters fail to maximally extend during the 2nd pull which results in a forward catch position. Thus, it would be advisable for novice athletes training with the power clean and snatch to focus on the triple extension during the second pull, which in turn should help to increase the rearward position of the catch.

As previously discussed the horizontal displacement from the forward most position during the second pull to the catch position (DxL) is also important to the success of weightlifting movements. During both Winchester and colleagues investigations (Winchester et al., 2005; Winchester et al., 2009) DxL only changed ($p < 0.05$) at testing loads of 50% of 1RM for the power clean (-15.7 ± 4.5 cm to -20.8 ± 6.5 m) and power snatch (-10.4 ± 5.2 cm to -21.2 ± 7.6 m). This suggests that different loading intensities may have a different minimum threshold of change for horizontal displacement. Both studies resulted in increases beyond the ideal horizontal displacement of ≤20 cm as reported by Winchester et al. (2005) and Winchester et al. (2009). Therefore, the lifters may have overemphasised horizontal force production during the second pull when training at lighter loads. During training, novice lifters should therefore be mindful of excessive “bar swing” during lighter loads as this may result in a training adaptation which is detrimental to the performance of the power clean and snatch at heavier loads.

2.4.2 Kinetic factors

As previously reported, the power clean exercise is highly effective at producing high force and power outputs and training with the power clean and other weightlifting exercises enhances the force and power producing capabilities of athletes

(Garhammer, 1993; Tricoli et al., 2005; Winchester et al., 2005; Winchester et al., 2009). For example, when comparing power outputs during the CMJ in resistance trained males following eight weeks of training, only the weightlifting group who trained with a combination of weightlifting exercises (power clean, snatch, high pull) improved both eccentric (-515 ± 141 W to -808 ± 270 W) and concentric power (1400 ± 571 W to 2090 ± 587 W) when compared to a plyometric only and a combined plyometric and weightlifting group (Arabatzi et al., 2010). Due to the training programmes which where un-equated for volume and intensity, caution must be taken when interpreting these results as increases in power may be due to differences in volume and intensities rather than exclusively on weightlifting exercises when compared to plyometric and combined approaches. These results highlight the transference of kinetic adaptations that arise from weightlifting style training to athletic abilities such as jumping. One possible reason for the increase in eccentric power during the CMJ could be the eccentric movement during the turnover phase of the snatch and clean where lifters are required to aggressively pull themselves under the bar in order to catch the barbell (Dawes, 2012; Stone et al., 2006a; Storey & Smith, 2012). This movement is often completed at high velocities in order to position the body under the barbell which is a critical component in the success of these weightlifting exercises (Dawes, 2012; Stone et al., 2006a; Storey & Smith, 2012). Therefore, for practitioners wishing to improve vertical jump performance, it is recommended to include the power clean exercise along with other weightlifting exercises (i.e. power snatch, hang pulls) that require participants to; 1) complete the double knee bend which requires an efficient SSC component and, 2) develop large eccentric braking forces during the turn over to catch phases of these lifts.

In support of incorporating power clean training to improve force and power producing capabilities, Winchester et al. (2005) reported significant increases in PF for the power clean across a range of loads (50% 1RM 28%; 70% 1RM 12.5%; 90% 1RM 12.2%) following three power clean sessions over four weeks. Using the same training methods, Winchester et al. (2009) supported these findings and noted significant increases in PF for the power snatch at 50% 1RM (26.2%), 70% 1RM (18.5%), and 90% 1RM (18.5%). While the power clean and snatch are not commonly used to improve PF outputs when compared to other traditional heavy resistance exercises such as the squat and deadlift, among young sportsmen (i.e. ~21-22 years old) who are relatively novice lifters as seen in these two investigation, the incorporation of such weightlifting exercises can further improve PF.

Both investigations also reported changes in PP across a range of loads. For example Winchester et al. (2005) reported a significant improvement in PP for the power clean at 50% 1RM (20.6%) and 90% 1RM (11.4%) loads. Additionally, during the power snatch, Winchester et al. (2009) also reported significant increases in PP across all testing loads at 50% 1RM (18.8%), 70% 1RM (15.8%) and 90% 1RM (16.5%). Although both investigations failed to measure changes in 1RM ability and other athletic movements such as jumping and sprinting, these results provide practitioners with the magnitude and time frame in which kinetic variables change in novice lifters following such training .Furthermore, both authors attributed improvements in PF and PP due to changes in technical ability which highlights the importance of improving technique among lesser skilled lifters.

An in-depth analysis of power clean and weightlifting training provides greater insight into identifying factors that affect technique variables and how such training improves force and power producing capabilities. As research has shown that changes in technique can improve kinetic variables, this justifies the need for strength and conditioning coaches to focus on the technical aspects of complex lifts such as the power clean and snatch.

2.5 Practical applications

During the power clean, lifters are able to produce high barbell velocities and large forces, and consequently high power outputs which results in improved athletic ability. Furthermore, the SSC component of the power clean exercise displays kinematic and kinetic similarities to jumping and sprinting movements which make it an ideal exercise for power athletes. A focus for strength and conditioning coaches prescribing the power clean and weightlifting exercises should be on improving technique as previous researchers have shown increases in PF and PP occur in response to improvements in lifting technique. Although the novel approach of adding chain links to the barbell during the power clean and power snatch failed to produce significant changes in strength and power measures, further research is needed to investigate the acute and longitudinal effect of alternative loading strategies using the power clean. Such loading could improve athletic performance as a result of improved force and power outputs as well as improve the technical aspects for lesser skilled lifters and/or lifters with mobility issues or injuries.

CHAPTER 3. THE ACUTE KINEMATIC AND KINETIC EFFECTS OF A WEIGHTED EXO-SKELETON ON THE PERFORMANCE OF THE POWER CLEAN

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3.1 Prelude

From the review of the literature it is evident that the power clean exercise is widely used by a number of athletes across a number of different sports as a means to assist in the improvement of athletic performance. While some areas associated with the power clean exercise have been extensively researched (e.g. the technical aspects and the relationship to athletic performance), further research needs to determine what effect alternative loading methods have on kinematic and kinetic variables during the performance of the power clean exercise. Weighted vests are often applied to jumping and sprinting movements to improve lower body power. However, it is currently unknown what effect centralised loading has on full body explosive movements such as the power clean. Therefore, the purpose of this investigation was to quantify the kinematic and kinetic effects a weighted Exo-skeleton had on the performance of the power clean exercise. An Exo-skeleton was chosen due to the ability of athletes to complete full body explosive movements at high speed without inhibiting movements.

3.2 Introduction

A type of resistance training that has become popular for increasing athletic performance is the addition of weight/resistance to the body in the form of a weighted vest (WV). This modality of training enables individuals to perform sports specific movements such as jumping and sprinting in an overloaded fashion. Researchers have reported both acute and chronic improvements in measures of athletic performance (e.g. a 5.3% increase in vertical jump, 12% increase in countermovement jump (CMJ), and 7.5% in a 5 jump test) (Burkett et al., 2005; Faigenbaum et al., 2006; Khlifa et al., 2010; Thompsen et al., 2007) and technique variables (Janssen et al., 2012) using a WV load from 2%-12% of participants bodyweight. However, additional research is required to determine what the optimal loading schemes are with regards to WV training. Furthermore, to date limited research has documented what effects the use of a WV has on kinematic measures (i.e. "technical changes") in a sporting context (Clark et al., 2010; Cronin et al., 2008; Janssen et al., 2012).

Athletes involved in strength and power sports such as jumping, sprinting, and throwing frequently use Olympic lifting exercises, such as the power clean, due to their effectiveness in increasing kinetic variables such as PGRF, PP, and rate of force development (RFD) (Berning et al., 2008; Coker et al., 2006; Comfort, Graham-Smith, et al., 2011; Cormie et al., 2011b; Storey & Smith, 2012). However, the technical aspects of the Olympic lifts are very demanding and require a great deal of mobility and co-ordination from a number of joints (Deweese, Serrano, Scruggs, & Smas, 2012; Storey & Smith, 2012). For example, during the power clean a loaded barbell is lifted in an explosive fashion from the floor to the level of the shoulders in one continuous movement (Chiu & Schilling, 2005; Stone et al., 2006a; Storey & Smith, 2012). In order to “catch” the barbell on the shoulders, the lifter requires excellent wrist mobility to allow their body to efficiently move around the barbell. However, lifters who need to continue to improve their peak force and power producing ability but exhibit poor wrist mobility, often as a result of injury, often struggle to complete near maximal to maximal loaded power cleans (Fitzgerald & McLatchie, 1980). However, a possible alternative loading method that could avoid this issue would be to redistribute some of the load off the barbell and onto the lifter themselves through the use of a WV. A reduction in barbell load would correspond to a reduction in the loading of the wrists during the catch phase of the power clean which could minimise the potential for injury in athletes who exhibit poor wrist mobility. Although the total external load (i.e. the weight on the barbell) would be less in this “centrally loaded” scenario, the total “system load” (i.e. the combined load of the barbell plus the WV load on the lifter) could be equated to ensure that the prescribed training volumes and intensities are achieved.

In addition, the use of centralized loading during complex movements such as the power clean may potentially result in a desirable change in technique as lifters learn to focus on the high speed elements of these lifts without being hampered by large external loads. However, such a contention is speculative and warrants investigation. Thus, the purpose of this study was to quantify the kinematic and kinetic changes associated with various WV loading schemes (i.e. 5% and 12% bodyweight) through the use of a weighted Exo-skeleton. The results of this investigation will aid in the identification of the optimal Exo-skeleton load to be used as an addition to Olympic lifting and will provide insight into the technique changes associated with this type of combination loading. It was hypothesised that the 12% Exo-skeleton load would result in; 1) a desirable change in technique measures when compared to the no Exo-skeleton baseline condition as the Exo-skeleton would require participants to pull the barbell closer to the body and, 2) an increase in barbell velocity when compared to the no-Exo-skeleton baseline condition as a result of a decrease in the external load.

3.3 Methods

Experimental approach to the problem

A cross-sectional study was implemented to determine what effects different Exo-skeleton loading had on the kinematics and kinetics of the power clean exercise. Exo-skeleton loads of 5% and 12% were chosen as previous researchers reported both acute and chronic improvements in measures of athletic performance (Burkett et al., 2005; Faigenbaum et al., 2006; Khlifa et al., 2010; Thompsen et al., 2007) and technique variables (Janssen et al., 2012) using similar loads. The effects of Exo-skeleton loads of 5% and 12% of bodyweight were investigated via videography, force plate and linear position transducer (LPT) technology.

Subjects

Nine participants (average age 22.5 ± 4 years, weight 91 ± 11.8 kg, power clean 101 ± 10.9 kg and resistance training experience 4.4 ± 1.7 years) were recruited for the study. Inclusion criteria for this study were; 1) recreationally trained male adults aged between 18-35 years, 2) free from acute and/or chronic injury at the time of the testing period, 3) not using any performance enhancing or banned substances (World anti-doping agency 2014) and, 4) able to power clean ≥ 1x body mass which is deemed to be a novice to intermediate standard of ability with regards to this type of exercise (Rippetoe & Kilgore 2009). Sample size was computed according to technique changes observed in power clean performance in resistance trained individuals following a short-term training period (Winchester et al., 2005). A total of nine participants would be required to yield a power of 80% at an $\alpha = 0.05$ with this repeated measures study design. Before the participants commenced any testing, it was ensured that all participants met the inclusion criteria, had signed an informed consent form, and were proficient at the power clean. In order to determine the proficiency of the power clean, the participants' technique was assessed by an international-level Olympic weightlifting coach to ensure they met the required inclusion criteria for the study. To ensure the safety of the participants, all testing conditions were examined and approved by the Auckland University of Technology Ethics Committee (AUTEC).

Procedures

Before commencing the data collection process, all participants were informed of what the testing procedure involved with the associated risks outlined. All participants proceeded to complete a standardised warm up that consisted of mobility and activation exercises commonly used amongst resistance trained athletes. In order to determine the subsequent testing loads for this investigation, all participants completed 1RM testing for the power clean exercise. A standardised testing protocol was designed in which participants were required to reach their 1RM within approximately six sets. The participant's previous self-reported 1RM served as a baseline measure in which their sub-maximal lifts were calculated for the 1RM testing protocol. The criteria for a successful 1RM power clean required the participants to catch the barbell in an above parallel thigh position before returning to an upright standing position. This differs from a full clean whereby lifters can catch the barbell below a parallel thigh position before descending into a deep squat position (Storey & Smith, 2012).

Participants then completed three submaximal repetitions of the power clean at 50% and 70% 1RM without the Exo-skeleton to attain a baseline measure of technique variables as determined by Winchester et al. (2005). For the purposes of this investigation a Lila™ Exogen™ Exo-skeleton suit (Sportboleh Sdh Bhd, Malaysia) was used instead of a traditional WV due to the ability to perform functional high speed movements like the power clean without inhibiting movement. Due to the velcro-like nature of the Exo-skeleton, the custom designed 400 gm, 200 gm, 100 gm, and 50 gm weight cells were able to be loaded principally on the posterior chain of the participants. The posterior loading configuration was chosen as the addition of weight cells to the anterior aspects of the thighs would have compromised the participants' ability to maximally accelerate the barbell during the second pull of the power clean during which time the barbell makes contact with the thighs (Deweese et al., 2012; Drechsler, 1998; Storey & Smith, 2012). The loading configuration was evenly distributed from the upper, mid and lower back, and glutes and hamstrings with each body section containing approximately 1/3 of the total load for both 5% and 12% conditions (Figure 3).

(a) (b)

Figure 3. Loading configuration of the Exogen weight cells. (a) 5% body weight. (b) 12% body weight.

In a randomised order, the participants were then required to complete the same three repetitions of sub-maximal power cleans with an Exo-skeleton load of 5% and 12% bodyweight to determine what influence the Exo-skeleton loads had on the kinematic and kinetic variables of interest (Table 1). During each Exo-skeleton condition, the load of the participant's Exo-skeleton was taken into account and the load of the barbell was adjusted accordingly to ensure that the total "system load" (i.e. the weight of the loaded barbell plus the total bodyweight of the participant) was matched.

Table 1. Standardized testing protocol for the measurement of sub-maximal power cleans.

Baseline measures of technique with no Exo-skeleton		
%1RM	**Repetitions**	**Rest**
50%	2	2-5 mins
70%	2	2-5 mins
Randomised order of 5% and 12% Exo-skeleton loads		
%1RM	**Repetitions**	**Rest**
50%	2	2-5 mins
70%	2	2-5 mins

Prior to the start of data collection, the lifting procedure was explained and demonstrated to the participants. To ensure each lift was executed from the exact position, the participants were instructed to move to the barbell as opposed to trying to roll the barbell towards them. To allow for accurate syncing of the camera, the participants were instructed to start in the set position and on a count of three were instructed to lift. Participants were instructed to pause for one second at the lock out position with knees fully extended to provide a definitive end point for the kinematic analysis. When testing loads were not whole numbers, the load was rounded to the nearest full number (e.g. 50% of a 105 kg 1RM power clean = 52.5 kg. Therefore, the testing load was rounded up to 53 kg).

Data collection and analysis

Kinematic analysis of the power clean

Kinematic data was collected using a Casio, EXLIM, EX-FH20 (Tokyo, Japan) and as filmed at 240 fps. The camera was positioned 5 meters away from the end of the barbell and at the participant‟s right hand side in the coronal plane (Figure 4) (Balsalobre-Frenandez, Terjero-Gonzalez, Campo-Vecion, & Bavaresco, 2014; Garhammer, 1993; Garhammer & Newton, 2013). The camera height was 75 cm above the force platform and manually zoomed to 65 cm so the total field of view included the bottom of the weight plates on the platform and the highest point of the lift (Garhammer & Newton, 2013). A 25 cm scaling rod was placed in the same depth of field at the end of the barbell to provide a known scaling measurement. A reflective marker was placed on the end of the barbell to allow a digitised bar path to be created from Kinovea 0.8.15 software. A previous investigation has demonstrated that the Kinovea digitizing software is a highly reliable (r= 0.9997) method to quantify athletic movements (Balsalobre-Fernández et al., 2014).

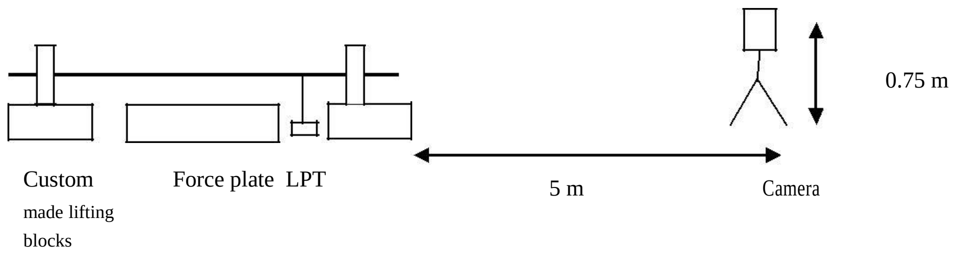

Figure 4. Testing equipment set up.

The video footage for each power clean repetition was loaded in to the Kinovea software where the following four technique variables were analysed as per Winchester et al. (2005); 1) most forward position to catch (DxL), 2) start position to catch (DxT), 3) start position to beginning of 2nd pull (Dx2), and, 4) 2nd pull position to catch (DxV) (Figure 5).

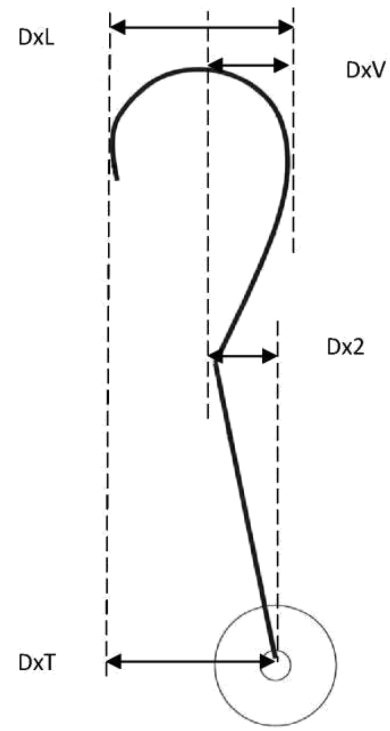

Figure 5. Technique variables Dx2, DxV, DxT, and DxL adapted from Winchester et al. (2005).

A Celesco PT5a linear positional transducer (LPT) (Chatsworth, USA) was used to measure barbell velocities at a sampling rate of 500 HZ. The LPT was placed directly under the loaded barbell with the Velcro strapping applied tightly to the barbell and this served as the "zero position". The LPT was calibrated according to the manufacture's recommendations using a known scaling distance of 1 meter.

Kinetic analysis of the power clean - force plate and LPT

A tri-axial force plate (Objective Design Ltd. Auckland, New Zealand) was used to measure the ground reaction force for the power clean at a sampling rate of 500 HZ. Previous research has recorded the tri-axial force plate to have an ICC ranging from 0.74-0.95 when measuring peak velocity, peak force, and power when compared to the AMTI force plate during the countermovement jump (McMaster & Chang 2011). On all testing occasions, the force plate was turned on ≥30min prior to the start of the session to allow the force plate to equilibrate to the ambient conditions within the laboratory. PO was chosen as a key variable of interest due to the importance in athletic performance and the reliability in performance testing (Cormie et al., 2011a; Hopkins et al., 2001; Moir et al., 2005). As previous researchers have reported that PGRF and PO occurs during the 2nd pull phase of the power clean (Comfort et al., 2011; Cormie et al., 2007; Enoka, 1979; Garhammer, 1993; Hori et al., 2007; Souza et al., 2002), PO was calculated from PGRF and the corresponding BV that occurred during this phase of the lift. Intraclass correlation coefficient (ICC) and coefficient of variation (CV) for the hang power clean using similar methods to this study have been previously established for PF (ICC= 0.89, CV= 4.7) and PP (ICC= 0.89, CV= 6.2) and peak velocity (ICC= 0.89, CV= 3.1) (Hori et al., (2007).

3.4 Statistical analyses

Descriptive statistics for all variables are expressed as mean ± SD. All data was log transformed to ensure data was normally distributed. A one way repeated measures ANOVA and Bonferroni post hoc contrasts were used to determine statistical difference between loading schemes for all kinematic and kinetic variables. Statistical significance was set at $P \leq 0.05$, with all analysis carried out using SPSS (version 22.0, SPSS, Inc, Chicago, IL). Standardised typical errors were also expressed using thresholds of 0.2, 0.6, 1.2, 2.0, and 4.0 as small, moderate, large, very large, and extremely large (Tables 2 and 3) (Hopkins, 2000).

3.5 Results

5% Exo-skeleton condition

At 50% 1RM, PO was greater (P= 0.03) by 11.5% when compared to the no Exo-skeleton condition (Table 2). During the 5% Exo-skeleton loading condition, there were no other statistically significant differences when compared to the no Exo-skeleton and 12% Exo-skeleton condition for all kinematic variables and PGRF when measured at both 50% and 70% testing loads.

12% Exo-skeleton condition

For the technique variable DxL there was an increase (P= 0.03) in rearward displacement by 17.9% at 50% 1RM when compared to the no Exo-skeleton loading condition (Table 3). Conversely, there were no significant changes in technique variables Dx2, DxV and DxT and barbell velocity when compared to the no Exo-skeleton and 5% Exo-skeleton conditions. At 50% 1RM, PO was greater (P= 0.03) for the 12% Exo-skeleton condition by 16.8% when compared to the no Exo-skeleton condition. No statistically significant differences were observed for PGRF or barbell velocity. Barbell loads were significantly lighter for the 12% Exo-skeleton condition when compared to the no Exo-skeleton condition (27.4%) and 5% Exo-skeleton condition (9.81%).

At 70% 1RM, no statistically significant differences were observed for all the technique variables measured. Peak barbell velocity was greater (P= 0.03) for the 12% Exo-skeleton condition by 3.33% when compared to the no Exo-skeleton condition. There were no statistically significant differences in the kinetic variables measured. Barbell loads were significantly lighter for the 12% Exo-skeleton condition when compared to the no Exo-skeleton condition (18.1%).

Table 2. Group averages for kinematic and kinetic variables at 50% and 70% 1RM testing for the no Exo-skeleton (ES), 5% Exo-skeleton, and 12% Exo-skeleton conditions.

Testing load	Condition	Barbell Velocity ($m.s^{-1}$)	TE	Peak Force (N)	TE	Power output (W)	TE
50%	No ES	2.28 ± 0.17	0.59	2250 ± 277	0.33	3160 ± 400	0.4
	5% ES	2.39 ± 0.02	0.37	2350 ± 295	0.39	3570 ± 463*	0.44
	12% ES	2.36 ± 0.25	0.82	2380 ± 272	0.8	3790 ± 285*	0.79
70%	No ES	2.15 ± 0.16	0.43	2620 ± 376	0.51	3960 ± 609	2.45
	5% ES	2.15 ± 0.18	0.45	2710 ± 272	0.34	3950 ± 340	0.38
	12% ES	2.22 ± 0.16*	0.16	2710 ± 232	0.32	3930 ± 552	0.26

TE- Typical error; * Significant difference to baseline at $p \leq 0.05$

Table 3. Group averages for technique variables at 50% and 70% 1RM testing for the no Exo-skeleton, 5% Exo-skeleton, and 12% Exo-skeleton conditions.

Testing load	Condition	Barbell loads (kg)	Dx2 (cm)	TE	DxV (cm)	TE	DxT (cm)	TE	DxL (cm)	TE
50%	No ES	51.4 ± 5.19	-3.06 ± 3.93	0.47	11.9 ±4.05	0.77	-4.38 ± 5.02	0.7	-12.10 ± 4.39	1.33
	5% ES	46.8 ± 4.76	-2.24 ± 34	0.28	14.0 ± 4.61	0.49	-3.44 ± 4.78	0.53	-13.50 ± 3.93	0.68
	12% ES	40.3 ± 4.19*+	-2.87 ± 2.46	0.69	13.7 ± 5.43	0.36	-3.67 ± 4.03	1.04	-14.70 ± .66*	0.27
70%	No ES	71.9 ± 7.27	-2.44 ± 3.33	0.35	11.0 ± 4.65	0.32	-3.93 ± 4.56	0.52	-11.2 ± 3.66	0.51
	5% ES	67.3 ± 6.8	-3.38 ± 2.83	0.37	11.8 ± 4.20	0.22	-3.83 ± 4.92	0.41	-11.6 ± 4.87	0.2
	12% ES	60.9 ± 6.25*	-3.45 ± 2.06	0.77	11.6 ± 4.90	0.28	-4.46 ± 6.01	0.64	-13.2 ± 3.50	0.73

TE- Typical error; * Significant difference to baseline at $p \leq 0.05$; + Significant difference to 5% condition at $p \leq 0.05$

3.6 Discussion

The primary findings of this investigation were; 1) during the 50% 1RM efforts the 12% Exo-skeleton condition significantly increased the rearward displacement (17.9%) of the barbell during the catch phase (DxL) when compared to the no Exo-skeleton group, 2) the mean barbell velocity at 70% 1RM loads during the 12% Exo-skeleton condition were 3.33% higher ($P < 0.05$) when compared to the no Exo-skeleton condition, 3) PO at 50% 1RM loads were significantly higher for 5% (11.5%) and 12% (16.8%) Exo-skeleton conditions when compared to the no Exo-skeleton condition and, 4) the 5% Exo-skeleton condition did not have a significant influence on technique factors at 50% and 70% of 1RM when compared to the no Exo-skeleton condition.

Previous researchers have identified key technique variables that contribute to the success of the power clean (Winchester et al., 2005). One such variable is the total horizontal distance from the most forward position during the 2nd pull to the catch (DxL) with an ideal distance being <20cm (Winchester et al., 2005). A significant increase in DxL at 50% of 1RM during the 12% Exo-skeleton condition (-14.73 ± 5.66 cm) when compared to baseline measures (-12.10 ± 4.39 cm) arose due to small but non-significant changes in horizontal displacement at DxV and DxT. Although the total horizontal distance increased during the 12% Exo-skeleton condition, it was still well within the recommended distance of <20cm (Winchester et al., 2005). With approximately 4% of bodyweight loaded on the upper back, this may partly explain the increase in DxL as the lifters were required to fully extend their bodies more aggressively to counteract the increased loading during the second pull phase. Reinforcing such a movement pattern may have a desirable training effect on lifters who are prone to catching the barbell in a forward position as a result of failing to maximally extend their bodies during the critical second pull phase.

Other key technique variables that are highly correlated to the success of the power clean include backward bar movement from the first to second pull (Dx2), the horizontal displacement from the second pull to the forward most position (DxV), and the total amount of horizontal displacement from the beginning of the lift to the catch position (DxT) (Winchester et al., 2005). During both the 5% and 12% Exo-skeleton conditions, no significant changes in these three aforementioned variables occurred, which indicates that the addition of Exo-skeleton loading did not negatively influence the performance of the power clean during these critical phases. The effect of the Exo-skeleton on the current group of participants during Dx2 was shown to be minimal with participants maintaining a backward bar movement from the first to second pull which is a sought after technical trait. The posterior loading of the Exo-skeleton weight cells may account for this ability to maintain an initial rearward movement of the barbell as it was felt that anterior loading would have had a negative influence on the participants' set position from the floor (i.e. anterior loading would have resulted in an excessive forward lean of the participants). At present, only two previous research groups have investigated the acute changes in technique that occur whilst wearing a WV during a sporting movement (i.e. sprinting) (Alcaraz, Palao, Elvira, & Linthorne, 2008; Cronin et al., 2008). Although it is difficult to compare results between different exercise modalities (i.e. sprinting vs. power clean kinematics), one conclusion that can be deduced from the collective research is that excessive loading of the anterior chain is detrimental to technique as observed by Cronin et al. (2008). This further supports the justification for the loading of the posterior chain in the current study as anterior loading could have compromised the participants‟ ability to maximally accelerate the barbell during the second pull of the power clean during which time the barbell is required to remain in close contact to the thighs and hips (Deweese et al., 2012; Storey & Smith, 2012).

As barbell velocity is a critical variable in the successful performance of the power clean (Garhammer & Hatfield, 1985; Haff et al., 2003), the 3.33% significant increase in barbell velocity through the use of 12% Exo-skeleton loads, when compared to both no Exo-skeleton and 5% Exo-skeleton conditions, is indicative of desirable changes in power clean performance. In two previous studies, Berning et al. (2008) and Coker et al. (2006) demonstrated that the addition of chains to the barbell did not have a significant influence on barbell velocity for the power clean and snatch at 1RM loads of 80% and 85%. It is important to note that in the two aforementioned studies, the external loads for the power clean and snatch were equated between conditions (i.e. 80% and 85% 1RM with and without chains). However, in the present investigation, the external loads differed between the baseline, 5% and 12% Exo-skeletons conditions whilst the total system load was equated (i.e. the weight of the loaded barbell plus the Exo-skeleton). Thus, the differences in barbell velocity during the 12% Exo-skeleton condition was attributable to the decrease in external bar load, equivalent to 12% of participants' body weight, as opposed to changes in power clean technique.

Barbell velocity has been closely related to the lifting success of weightlifting (Garhammer, 1998) and Garhammer et al (1985) suggested that the final velocity of the barbell is critical to allow the lifter time to get under the bar in the catch position. Additionally, greater vertical barbell velocities allow for increased vertical displacement, which may allow for increases in the total load lifted and/or an increase in peak power (Bartonietz, 1996). Furthermore, as high release velocities are critical during throwing sports such as shot put, increases in barbell velocities could positively influence throwing performance (Zaras et al., 2013; Zaras et al., 2014). Thus, it is possible that this increase in barbell velocity, which arises due to a rapid triple extension of the hip, knee and ankle joints, may also lead to improvements in other high velocity movements such as throwing, sprinting, and jumping ability (McBride et al., 2011). However, such a contention needs further investigation.

Although the total external loads were different for the baseline, 5%, and 12% conditions, the fact that the total system load was still equated did not have any effect on PGRF. These findings are in agreement with Berning et al. (2008) and Coker et al. (2006) who demonstrated non-significant changes in vertical GRF for the first pull, second pull, and un-weighting phase during the power clean and snatch exercises performed at 80% and 85% of 1RM with the inclusion of chains. It would seem that the addition of a weight via the Exo-skeleton as well as chains provide similar PGRFs to traditional loading methods. Producing similar PGRFs with less external load is advantageous to weaker or less technically proficient lifters thus allowing lifters to focus on barbell velocity and technique without being compromised by large external loads.

As a result of increases in barbell velocity and no change in PGRF at 50% 1RM loads, PO was 11.5% and 16.8% greater for both the 5% and 12% Exo-skeleton conditions when compared to the no Exo-skeleton condition. The findings from this investigation demonstrate that there is the potential to increase PO as a result of a decrease in external load whilst total system load is maintained. Such findings may provide an avenue for less technically proficient lifters to increase their PO outputs using lighter training loads which in turn will help to minimise the risk of potential injury. As no previous research has investigated the effects alternative loading methods (i.e. chain links or weighted vests) have on PO during the power clean, this is an area of future research as PO is a critical variable to the performance of many sporting actions (Hoffman et al., 2004; Hori et al., 2005)

Lastly the 5% Exo-skeleton condition did not have a significant influence on any technique variables at 50% and 70% loads when compared to the no Exo-skeleton condition. Therefore, the ability to influence power clean technique using Exo-skeleton loads of ≤5% bodyweight is unlikely to occur. Such findings suggest that a minimum threshold for each technique variable exists. However, averaged data has been reported and within the current data set there were individuals whose technique were affected by the 5% Exo-skeleton load. From this preliminary investigation it appears that centralised loading >12% body mass is required to elicit changes in Dx2, DxV, and DxT. However, whether or not this will result in a desired change in technique is yet unknown and future research can be directed towards determining the threshold load for each technique and kinetic variable.

Based on these findings, it was proposed that the optimal Exo-skeleton load to be worn during the power clean exercise is ~12% of body mass. A number of benefits arise from this form of loading such as an improvement in the rearward displacement of the bar, which is helpful to lifters who are prone to catching the barbell in a forward position as a result of failing to maximally extend through the 2nd pull phase. This will ensure they aggressively complete triple extension of the hips, knees, and ankles during the 2nd pull phase thus improving this technical aspect of the power clean. Future research is needed to compare the longitudinal effect that training with an Exo-skeleton has on the performance of the power clean and performance measures such as jumping and sprinting.

3.7 Practical applications

The addition of an Exo-skeleton load of 12% of a lifter's bodyweight may positively influence kinematic and kinetic variables during the power clean exercise. Due to the highly technical nature of the power clean exercise, decreasing the total external bar load while maintaining the total system load may allow lifters to focus on the technical aspects of the lift (e.g. minimising the total horizontal displacement of the barbell), thus acutely improving their technique. Furthermore, as barbell velocity is a critical variable in the success of the power clean, the inclusion of 12% Exo-skeleton loading during training at 70% 1RM could improve this aspect. Similar PGRFs were reported between all three loading conditions despite a significant difference in the weight of the loaded barbell. A reduction in the external load, whilst total system load is maintained, may enable injured athletes or those who exhibit poor wrist mobility to introduce power clean training earlier than previously allowed. Future research should determine which exercises are best suited for Exo-skeleton training, the optimal loading and the subsequent influence on sporting performance.

CHAPTER 4. THE LONGITUDINAL KINEMATIC AND KINETIC EFFECTS OF A WEIGHTED EXO-SKELETON ON THE PERFORMANCE OF THE POWER CLEAN EXERCISE AND ATHLETIC PERFORMANCE

To be submitted to the Journal of Strength and Conditioning

4.1 Prelude

While study one demonstrated improvements in acute power clean performance such as improved technique, increased peak power and barbell velocity when using a 12% Exo-skeleton, the effects of power clean training with an Exo-skeleton on longitudinal power clean and athletic performance were still unknown. Therefore, the purpose of this investigation was to determine what effects power clean training with an Exo-skeleton equivalent to 12% bodyweight had on the power clean exercise and countermovement jump performance.

4.2 Introduction

Training with a weighted vest (WV) has become a popular form of resistance training for improving athletic performance as it allows individuals to perform sports specific movements such as jumping and sprinting in an overloaded fashion. Following the acute performance of warm up protocols and jumping exercises with the addition of a WV, researchers have reported acute improvements in athletic performance measures such as the vertical jump (5.3% - 13.5%), countermovement jump (CMJ) (12%), and broad jump (12.5%) (Faigenbaum et al., 2006; Thompsen, Kackley, Palumbo, & Faigenbaum, 2007). Additionally, following structured WV training sessions, other researchers have reported improvements in CMJ (12% increase) and squat jump (SJ) (9.9% and 10.4% increases) performance (Bosco, Rusko, & Hirvonen, 1986; Khlifa et al., 2010). However, there is limited research on the changes in kinetic variables and no research on changes in technique following training interventions utilising WV training.

Olympic weightlifting movements such as the power clean are often used by athletes in strength and power sports such as jumping, sprinting, and throwing due to the ability to increase kinetic variables such as peak force (PF), peak power (PP), and rate of force development (RFD) (Comfort, Graham-Smith, Matthews, & Bamber, 2011; Cormie, McGuigan, & Newton, 2011; Storey & Smith, 2012). While the power clean is less technically demanding compared to other Olympic lifts such as the snatch and clean and jerk, lifters are still required to have exceptional mobility and co-ordination from a number of joints such as the wrists, elbows, hips, knees and ankles (Fitzgerald & McLatchie, 1980). In some instances, poor mobility can be the major factor that limits an athlete's ability to progress further with such movements. For example, an athlete's ability to train at near maximal to maximal loaded power cleans as a means to improve their force and power producing capabilities may be hampered by poor wrist mobility as a result of injury. However, in such an instance, redistributing some of the load off the barbell and onto the lifter themselves through the use of a WV may be a potential alternative loading method that could allow lifters to continue to train at heavy loads. Reducing the barbell load would result in a decrease in loading of the wrist which could positively affect the lifter during the catch phase of the power clean. This may also reduce the risk of further injury. To ensure that equated training volumes and intensities are achieved in the "centrally loaded" scenario, the total "system load" (i.e. the combined load of the barbell plus the WV load on the lifter) would be equal to that of having the total load on the barbell alone. Furthermore, the use of centralised loading during complex movements such as the power clean may potentially result in desirable changes in technique as lifters learn to focus on the high speed elements of these lifts without being hampered by large external loads. Such a contention however, is speculative and warrants investigation. Therefore, the purpose of this investigation was to determine and compare the effects of power clean training with or without the addition of an Exo-skeleton equivalent to 12% bodyweight over a five week training cycle. It was hypothesised that wearing a 12% Exo-skeleton load would result in; 1) an improvement in technique measures when compared to the no Exo-skeleton baseline condition as the Exo-skeleton would require participants to pull the barbell closer to the body, 2) an increase in barbell velocity when compared to the no-Exo-skeleton baseline condition as a result of a decrease in the external load and, 3) an increase 1RM power clean and jumping ability.

4.3 Methods

Experimental approach to the problem

A five week training intervention was implemented to determine what effects training with an Exo-skeleton equivalent to 12% bodyweight had on performance of the power clean and CMJ. An Exo-skeleton equivalent to 12% of participants" bodyweight was chosen due to the acute improvements in technique and barbell velocity that were observed when compared to an Exo-skeleton equivalent to 5% bodyweight and a no Exo-skeleton condition (Chapter 3). The effects of the 12% Exo-skeleton were investigated at loads of 50%, 70%, and 90% of participants 1RM via videography, force plate, and linear position transducer (LPT) technology.

Subjects

Sixteen participants were recruited for the study (Table 4). Participants were randomly assigned to either an Exo-skeleton (N = 8) or no Exo-skeleton group (N = 8). Sample size was computed according to changes observed in athletic performance measures in resistance trained individuals following a short-term training period with the addition of a WV of 10-11% bodyweight (Khlifa et al., 2010). A total of 16 participants would be required to yield a power of 80% at an $\alpha = 0.05$ level. Inclusion criteria for this study were; 1) recreationally trained male adults aged between 18-35 years, 2) free from acute and/or chronic injury at the time of the testing period, 3) not using any performance enhancing or banned substances according to the World anti-doping agency 2014 and, 4) able to power clean $\geq$ 1x body mass. Before the participants commenced any testing, it was ensured that all participants met the inclusion criteria, were proficient at the power clean and had signed an informed consent form. To ensure the safety of the participants, all testing conditions were examined and approved by the Auckland University of Technology Ethics Committee (AUTEC).

Table 4. Participant descriptive data

	Age	Weight (kg)	Power clean 1RM (kg)	Training experience (yrs)
No Exo-skeleton group	23.1 ± 2.3	93.9 ± 11	103 ± 8	5.1 ± 1.1
12% Exo-skeleton group	23.3 ± 2.8	87.2 ± 9.8	102 ± 15	5.3 ± 1.3

Procedures

Before commencing data collection, all participants were informed of what the testing procedures involved with the associated risks outlined. In order to determine the subsequent testing (i.e. 50%, 70% and 90% 1RM) and training loads for this investigation, all participants completed 1RM testing for the power clean exercise. Participants then completed a familiarisation session followed by kinematic and kinetic baseline testing two days after the familiarisation. Following the five week training intervention, post-testing was conducted in the same fashion as the baseline measures.

Equipment

For the purposes of this investigation a Lila™ Exogen™ Exo-skeleton suit (Sportboleh Sdh Bhd, Malaysia) was used instead of a traditional WV due to the ability to perform functional high speed movements like the power clean without inhibiting movement. Due to the Velcro-like nature of the Exo-skeleton, the custom designed 400 gm, 200 gm, 100 gm, and 50 gm weight cells were able to be loaded principally on the posterior chain of the participants. The posterior loading configuration was chosen as the addition of weight cells to the anterior aspects of the thighs would have severely compromised the participants' ability to maximally accelerate the barbell during the second pull of the power clean during which time the barbell is required to remain in close contact to the thighs and hips (Deweese, Serrano, Scruggs, & Smas, 2012; Storey & Smith, 2012). The loading configuration was evenly distributed on the entire back, the glutes and hamstrings with each body section containing approximately 1/3 of the total load for the 12% condition (Figure 6).

Figure 6. Loading configuration of Exogen Exo-skeleton weight cells

Testing

All participants completed a standardised warm up which consisted of mobility and activation exercises commonly used amongst resistance trained athletes. A standardised testing protocol was designed in which participants were required to attain their 1RM within approximately six sets. The participant's previous self-reported 1RM served as a baseline measure in which their sub-maximal lifts were calculated for the 1RM testing protocol. The criteria for a successful 1RM power clean required the participants to catch the barbell in an above parallel thigh position before returning to an upright standing position. This differs from a full clean whereby lifters can catch the barbell below a parallel thigh position before descending into a deep squat position (Storey & Smith, 2012). Following the 1RM protocol, each participant also completed a familiarisation session with an Exo-skeleton load equivalent to 12% of participant's body mass which comprised of three repetitions at 50%, 60%, and 70% of participant's 1RM power clean.

Following a 48 hour recovery period, participants completed pre-testing which involved two CMJ which measured jump height. Participants were instructed to lower themselves to a self-chosen depth before maximally extending themselves vertically in the air whilst using arm swing. Participants then completed a series of sub-maximal power cleans in order to determine baseline measures of technique, barbell velocity, peak ground reaction force (PGRF), and power output (PO). Both groups performed all power clean testing with no Exo-skeleton loading. To ensure each lift was performed from the exact position, the participants were instructed to move to the barbell as opposed to trying to roll the barbell towards them. To allow for accurate syncing of the camera, the participants were instructed to start in the set position and on a count of three were instructed to lift. Participants were instructed to pause for 1 second at the lock out position with knees fully extended to provide a definitive end point for the kinematic analysis. When testing loads were not whole numbers, the load was rounded to the nearest full number (e.g. 50% of a 105 kg 1RM power clean = 52.5 kg. Therefore, the testing load was rounded up to 53 kg).

Participants completed three sub-maximal power cleans at 50% and 70% 1RM loads, and two reps at 90% 1RM loads with no Exo-skeleton load (i.e. all the load was on the barbell). One practice repetition at 60% and 80% 1RM loads were also included to ensure the increase in load between the three identified intensity values was not too drastic (Table 5).

Table 5. Standardised testing protocol for the kinematic and kinetic assessment of sub-maximal power cleans without an Exo-skeleton.

%1RM	Repetitions	Rest
50%	3	2-5 mins
60%	1	2-5 mins
70%	2	2-5 mins
80%	1	2-5 mins
90%	2	

Training

Participants performed three supervised power clean training sessions per week across a five week intervention period. The Exo-skeleton group performed the designated training sessions with an additional load equivalent 12% of their bodyweight placed on their posterior trunk. In order to equate the training intensities for both groups, the associated training loads for each Exo-skeleton participant was adjusted accordingly to take into account the additional load placed on the participant's body.

The five week intervention followed an undulating periodisation model which culminated in a de-loading period prior to the retesting. Training days were broken up by level of intensity from medium-high-low sessions throughout the week as depicted in Table 5. Following a standardised warm up, consisting of dynamic drills and sub-maximal lifts, each participant performed the required number of sets and repetitions at the target training intensity (Table 6 and Figure 7).

Between training sessions, participants maintained their habitual training which included general resistance training work using a combination of machine based and free weight exercises. However, all participants were required to refrain from all power clean variations during the course of the investigation and no forms of exercise were performed 12 hours before each intervention session.

Table 6. Overview of the 5 week training intervention for the weighted vest and non-weighted vest training groups.

Training Week	1			2			3			4			5		
Classification	Moderate			Heavy			Heavy			Moderate			Light		
Training Day	Mon	Wed	Fri	Mon	Wed	Fri	Mon	Wed	Fri	Mon	Wed	Fri	Mon	Wed	Fri
Intensity (%1RM)	80%	85%	75%	85%	90%	80%	90%	95%	85%	80%	90%	75%	70%	60%	
Sets x Reps	3x2	3x1	3x3	3x2	3x1	3x3	2x2	3x1	3x3	3x2	2x1	3x2	2x3	2x2	Performance testing

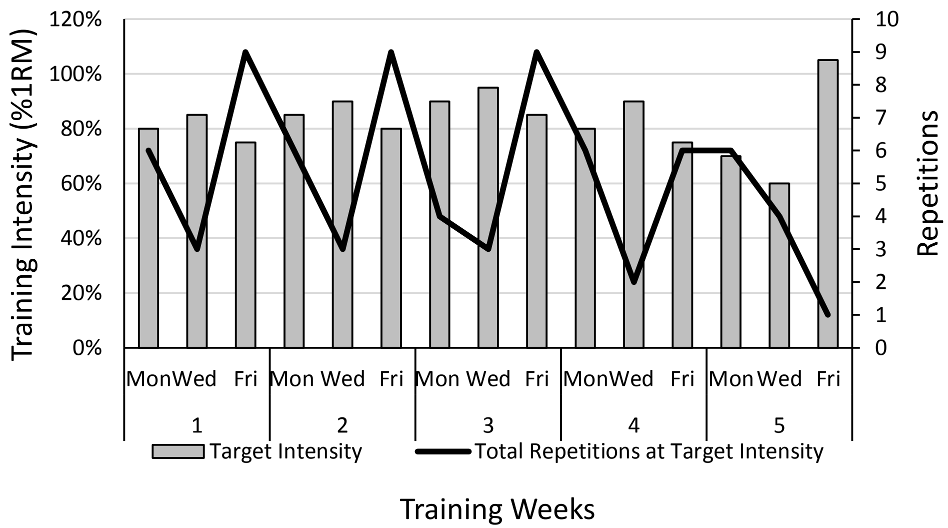

Figure 7. The prescribed target training intensities for each session and the total number of repetitions that were performed at each target intensity.

Data collection and analysis

Kinematic analysis of the power clean

Kinematic data was collected using a Casio, EXLIM, EX-FH20 (Tokyo, Japan) and was filmed at 240 fps. The camera was positioned 5 meters away from the end of the barbell and at the participant's right hand side in the coronal plane (Figure 8) (Balsalobre-Frenandez, Terjero-Gonzalez, Campo-Vecion, & Bavaresco, 2014; Garhammer, 1993; Garhammer & Newton, 2013). The camera height was 75 cm above the force platform and manually zoomed to 65 cm so the total field of view included the bottom of the weight plates on the platform and the highest point of the lift (Garhammer & Newton, 2013). A 25 cm scaling rod was placed in the same depth of field at the end of the barbell to provide a known scaling measurement. A reflective marker was placed on the end of the barbell to allow a digitised bar path to be created from Kinovea 0.8.15 software.

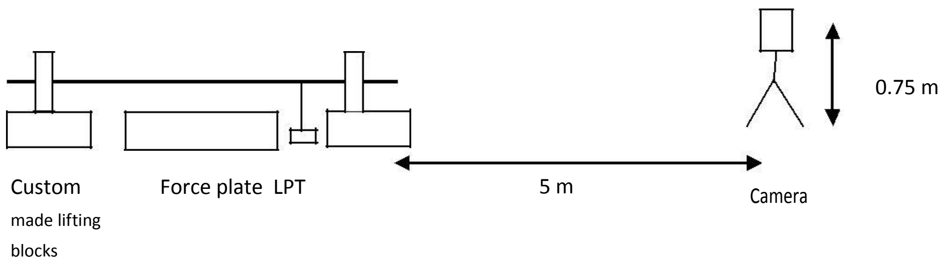

Figure 8. Testing equipment set up

The video footage for each power clean repetition was loaded in to the Kinovea software where the following four technique variables were analysed as per Winchester et al. (2005); 1) most forward position to catch (DxL), 2) start position to catch (DxT), 3) start position to beginning of 2nd pull (Dx2) and, 4) 2nd pull position to catch (DxV). In addition, the barbell catch height (CxH) was also determined during each trial (Figure 9).

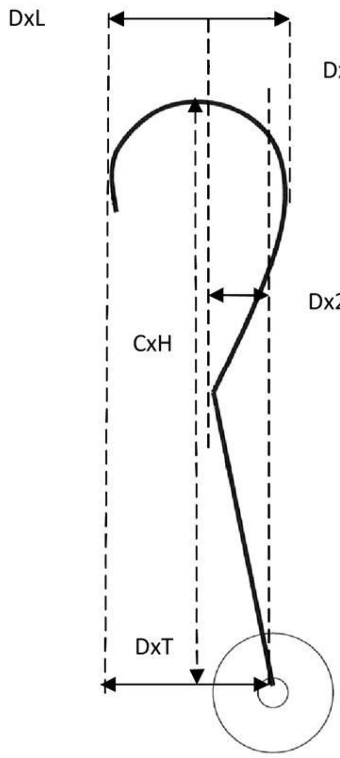

Figure 9. Technique variables Dx2, DxV, DxT, DxL, and CxH adapted from Winchester et al. (2005).

A Celesco PT5a linear positional transducer (LPT) (Chatsworth, USA) was used to measure barbell velocities at a sampling rate of 500 HZ. The LPT was placed directly under the loaded barbell with the Velcro strapping applied tightly to the barbell and this served as the "zero position". The LPT was calibrated according to the manufacturer's recommendations using a known scaling distance of 1 meter.

Kinetic analysis of the power clean - force plate and LPT

A tri-axial force plate (Objective Design Ltd. Auckland, New Zealand) was used to measure the ground reaction force for the power clean at a sampling rate of 500 HZ. On all testing occasions, the force plate was turned on ≥30min prior to the start of the session to allow the force plate to equilibrate to the ambient conditions within the laboratory. PO was chosen as a key variable of interest due to the importance in athletic performance and the reliability in performance testing (Cormie et al., 2011a; Hopkins et al., 2001; Moir et al., 2005). As previous researchers have reported that PGRF and PO occurs during the 2nd pull phase of the power clean (Comfort, Allen, & Graham-Smith, 2011; Cormie, McBride, & McCaulley, 2007; Enoka, 1979; Garhammer, 1993; Hori et al., 2007; Souza, Shimada, & Koontz, 2002), PO was calculated from PGRF and the corresponding BV that occurred during this phase of the lift. ICC and CV for the hang power clean using similar methods to this study have been previously established for PF (ICC= 0.89, CV= 4.7) and PP (ICC= 0.89, CV= 6.2) and peak velocity (ICC= 0.89, CV= 3.1) (Hori et al., (2007).

4.4 Statistical analyses

Means and standard deviations were presented for pre and post-test variables with typical errors presented for post-test only. A spreadsheet for analysis of pre-post parallel trials (Hopkins, 2011) was used to determine differences between the Exo-skeleton and no Exo-skeleton groups on the kinematic and kinetic variables of interest. The chances that the true value of each statistic was practically positive, trivial, or negative were calculated using the spreadsheets. Confidence limits (90%) were expressed for the uncertainty in the estimates of effects of performance. To determine the threshold for an effect, the smallest standardised change was assumed to be 0.2. Threshold values for assessing magnitudes of standardised effects were 0.20, 0.60, 1.2, 2.0 and 4.0 for small, moderate, large, very large and extremely large effects, respectively. These probabilities were not presented quantitatively but were used to make a qualitative probabilistic mechanistic inference about the effect in preference to a statistical inference based on a null-hypothesis test (Hopkins, Batterham, Marshall, & Hanin, 2009). The scale for interpreting the magnitude of the observed value was: 25–75%, possible; 75–95%, likely; 95-99.5%, very likely; >99.5%, most likely. The mechanistic inference was calculated off both the 12% Exo-skeleton and no Exo-skeleton groups but the effect was for the 12% Exo-skeleton group only. The effect was deemed unclear when the chance of benefit was sufficiently high to warrant use of the intervention but the risk of detriment to performance was unacceptable. This approach using probability statistics allows the reader to make decisions around the use of the intervention based on its predicted positive or negative effects (Hopkins et al., 2009)

4.5 Results

With regards to the power clean technique variables associated with the 50% load, training with the 12% Exo-skeleton produced both forward and rearward increases in bar path measures ranging from -3.9 ± 5 to 0.9 ± 5 cm (Table 7). The training effects were found to be trivial for the technique variables with the exception of DxL where a moderate but unclear effect was noted. In terms of PGRF, velocity and PO, trivial to moderate training effects were observed. However, the chances that the true value of the ES were beneficial was unclear.

Table 7. Pre to post changes for kinematic and kinetic variables at 50% 1RM

	Control group				Intervention group					
Kinematic and kinetic variables	Pre	TE	Post	Change in mean scores	Pre	TE	Post	Change in mean scores	Net effect ± confidence limits	ES: Mechanistic inference
50% 1RM loading										
Dx2 (cm)	-0.29 ± 2.6	2.36	-1.94 ± 4.1	-1.66 ± 2.6	0.42 ± 4.9	2	-0.5 ± 4.5	-0.9 ± 2.4	0.7 ± 2.3	0.17: Unclear
DxV (cm)	11.3 ± 4.7	2.51	12.5 ± 5.6	1.23 ± 2.6	8.18 ± 4.9	1.1	8.72 ± 6.2	0.55 ± 3.4	-0.7 ± 2.7	-0.12: Unclear
DxT (cm)	-3.17 ± 4.7	2.81	-3.98 ± 4.6	-0.82 ± 4.7	-5.36 ± 5.2	3.77	-5.27 ± 4	0.09 ± 6.5	0.9 ± 5	0.16: Unclear
DxL (cm)	-14 ± 4.7	1.7	-12 ± 4.3	2.01 ± 6.1	-11.5 ± 4.4	7.8	-13.4 ± 3.1	-1.9 ± 5.2	-3.9 ± 5	-0.76: Unclear
CxH (cm)	118 ± 9.6	3.49	115 ± 9	-2.98 ± 7.6	113 ± 9.8	3.1	111 ± 11	-2.14 ± 6.5	0.8 ± 6.2	0.08: Unclear
BBV (ms^{-1})	2.52 ± 0.2	0.12	2.38 ± 0.17	-0.14 ± 0.2	2.43 ± 0.41	0.1	2.37 ± 0.39	-0.06 ± 0.27	0.1 ± 0.2	0.23: Unclear
PGRF (N)	2430 ± 470	86.7	2380 ± 450	-48 ± 223	2140 ± 480	116	2090 ± 480	-46.3 ± 280	2.2 ± 220	0.00: Unclear
PO (W)	4150 ± 880	296	3690 ± 1100	-457 ± 1000	3980 ± 760	288	4090 ± 640	102 ± 560	560 ± 750	0.62: Unclear

TE = typical error

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During 70% 1RM loading, training with the 12% Exo-skeleton resulted in an increase in the rearward displacement for DxL by 17.5% (moderate beneficial: likely) when compared to the increase in the forward displacement for the no Exo-skeleton group (3.4%) (Table 8). The training effects were found to be trivial to small for the other technique variables, barbell velocity, PGRF and PO, which were all unclear.

Table 8. Pre to post changes for kinematic and kinetic variables at 70% 1RM

	Control group				Intervention group					
Kinematic and kinetic variables	Pre	TE	Post	Change in mean scores	Pre	TE	Post	Change in mean scores	Net effect ± confidence limits	ES: Mechanistic inference
70% 1RM loading										
Dx2 (cm)	-2.23 ± 2.4	1.71	-3.19 ± 3.5	-0.96 ± 3.6	-0.55 ± 3.4	1.04	-0.35 ± 4.6	0.2 ± 3.1	1.2 ± 3	0.35: Unclear
DxV (cm)	11 ± 4.8	1.51	11.5 ± 3.6	0.49 ± 2.4	7.12 ± 4.1	0.7	7.29 ± 4.7	0.17 ± 1.3	-0.3 ± 1.7	-0.06: Unclear
DxT (cm)	-3.64 ± 3.2	2.93	-4.67 ± 4.4	-1.03 ± 6.8	-4.75 ± 4.5	1.94	-4.81 ± 4	-0.05 ± 5	1 ± 5.3	0.23: Unclear
DxL (cm)	-12.7 ± 3.1	1.91	-12.3 ± 3.4	0.42 ± 2.2	-9.53 ± 3.5	6.72	-11.6 ± 3.2	-2.02 ± 3.6	-2.4 ± 2.7	-0.60: Likely ↑
CxH (cm)	118 ± 9.6	4.9	115 ± 9	-2.98 ± 7.6	113 ± 9.8	2.2	111 ± 11	-2.14 ± 6.5	0.8 ± 6.2	0.01: Unclear
BBV (ms^{-1})	2.26 ± 0.13	0.07	2.23 ± 0.16	-0.03 ± 0.11	2.16 ± 0.30	0.1	2.17 ± 0.20	0.01 ± 0.18	0.0 ± 0.1	0.16: Unclear
PGRF (N)	2670 ± 390	152	2750 ± 340	87.8 ± 250	2490 ± 520	129	2450 ± 240	-32.9 ± 330	-120 ± 260	-0.24: Unclear
PO (W)	4140 ± 940	295	4070 ± 1000	-66.7 ± 600	4330 ± 870	298	4580 ± 550	246 ± 751	313 ± 630	0.33: Unclear

↑ - Beneficial effect or increase
TE= Typical error

In regards to power clean technique during 90% 1RM loading, training with the 12% Exo-skeleton resulted in a decrease in the rearward displacement for DxV by 24% (moderate beneficial: very likely) when compared to the increase in the forward direction for the no Exo-skeleton group by 14.7% (Table 9). The 12% Exo-skeleton group also increased DxT by 76.9% (moderate beneficial: likely) in the rearwards direction compared to the increase in forward direction for the no Exo-skeleton group by 59.4%. The training effects were found to be small to moderate for the other technique variables, however, were unclear. Training with the 12% Exo-skeleton resulted in an increase in barbell velocity for the 12% Exo-skeleton group by 3.5% (moderate beneficial: likely) in comparison to the decrease for the no Exo-skeleton group by 4.3%. PGRF and PP resulted in trivial and moderate training effects respectively while an unclear effect was noted.

Table 9. Pre to post changes for kinematic and kinetic variables at 90% 1RM

	Control group				Intervention group					
Kinematic and kinetic variables	Pre		Post	Change in mean scores	Pre		Post	Change in mean scores	Net effect ± confidence limits	ES: Mechanistic inference
					90% 1RM loading					
Dx2 (cm)	-2.46 ± 3.5	1.28	-2.49 ± 3.2	-0.02 ± 3.2	0.55 ± 4.2	1.2	-1.40 ± 4.5	-1.95 ± 3.9	-1.9 ± 3.1	-0.42: Unclear
DxV (cm)	10.0 ± 5.4	0.81	11.78 ± 4.5	1.73 ± 1.4	7.96 ± 4.1	1.5	6.4 ± 3.9	-1.56 ± 1.98	-3.3 ± 1.5	-0.62: Very likely ↑
DxT (cm)	-4.24 ± 4.1	2.07	-1.72 ± 4	2.52 ± 5.8	-1.04 ± 6.6	2.68	-4.52 ± 4.2	-3.48 ± 6.9	-6.0 ± 5.7	-0.96: Likely ↑
DxL (cm)	-11.9 ± 1.4	1.3	-10.31 ± 3.6	1.59 ± 3.6	-8.38 ± 4.2	0.8	-8.10 ± 4.2	0.28 ± 2.8	-1.3 ± 2.8	-0.33: Unclear
CxH (cm)	109.45 ± 11	4.23	106.7 ± 9.6	-2.76 ± 5.5	98.7 ± 4.3	1.4	99.6 ± 10.9	0.93 ± 9.7	3.7 ± 7.1	0.31: Unclear
BBV (ms^{-1})	2.04 ± 0.12	0.04	1.95 ± 0.12	-0.08 ± 0.13	1.92 ± 0.22	0.1	1.99 ± 0.15	-0.07 ± 0.16	0.2 ± 0.1	0.74: Likely ↑
PGRF (N)	2950 ± 340	50	2950 ± 430	-5.13 ± 270	2710 ± 480	84	2710 ± 450	-1.5 ± 300	3.6 ± 250	0.01: Unclear
PO (W)	4290 ± 1100	103	4040 ± 870	256 ± 740	4261 ± 780	129	4440 ± 520	175 ± 730	560 ± 750	0.41: Unclear

↑ - Beneficial effect or increase

TE= Typical error

As can be observed from Table 10, larger training effects were observed for CMJ and 1RM performance following 5 weeks of training with the 12% Exo-skeleton. The 12% Exo-skeleton group improved CMJ performance by 8.7% (small benefit: likely) when compared to the no Exo-skeleton group which decreased by 1.4%. The 12% Exo-skeleton group also resulted in greater improvements in 1RM power clean performance 4.2% (small benefit possible) when compared to the no Exo-skeleton group 1.8%.

Table 10. Pre to post changes for performance measures

	Control group				Intervention group					
Performance measures	Pre	TE	Post	Change in mean scores	Pre	TE	Post	Change in mean scores	Net effect ± confidence limits	ES: Mechanistic inference
Performance measures										
CMJ (cm)	41.7 ± 4.9	4.8	41.1± 2.4	-0.58 ± 3.9	37.1 ± 8.2	0.9	40.6 ± 8.8	3.52 ± 1.5	4.1 ± 2.8	0.53:Likely ↑
1RM (kg)	103 ± 7.97		105± 10	1.94 ± 3.9	102 ± 15.2		106 ± 14.5	4.5 ± 3.6	2.6 ± 3.3	0.20: Possible↑

↑ - Beneficial effect or increase
TE= Typical error

During the course of the training intervention, one participant had to withdraw from the study due to a non-related injury that occurred. This participant's results were not included. The remaining participants completed 100% of the prescribed training sessions which were observed by a qualified practitioner.

4.6 Discussion

The primary findings of this investigation were; 1) during 70% 1RM efforts, training with the 12% Exo-skeleton group increased the rearward displacement (17.5%) of the barbell during the catch phase (DxL) when compared to the increase in forward displacement (3.4%) for the no Exo-skeleton group, 2) during 90% 1RM efforts, training with the 12% Exo-skeleton group decreased (24%) the forward displacement for the forward most position during the second pull (DxV) when compared to the increase (14.7%) in forward displacement for the no Exo-skeleton group, 3) training with the 12% Exo-skeleton increased (76.9%) the rearward displacement during the catch position (DxT) when compared to the increase (56.9%) in forward displacement for the no Exo-skeleton group, 4) training with the 12% Exo-skeleton increased (3.5%) barbell velocity at 90% 1RM when compared to the decrease (4.3%) for the no Exo-skeleton group and, 5) the 12% Exo-skeleton improved CMJ (8.7%) and 1RM power clean performance (4.2%) when compared to the no Exo-skeleton group, where a decrease in CMJ performance (-1.4%) and an increase in 1RM power clean performance (1.8%) were observed.

Previous researchers have identified a number of technique variables that contribute to the success of the power clean (Winchester, Erickson, Blaak, & McBride, 2005; Winchester, Porter, & McBride, 2009), one of which is the total horizontal distance from the forward most position during the 2nd pull to the catch (DxL) with an ideal distance being < 20cm (Winchester et al., 2005). During 70% 1RM loading, the 12% Exo-skeleton group increased the rearward displacement of the barbell (DxL) by 17.5% (-9.5 ± 3.5 to -11.6 ± 3.2 cm) compared to the 3.4% increase in the forward direction for the no Exo-skeleton group (-12.7 ± 3.1 to -12.3 ± 3.4) which resulted in a total net effect of -2.4 ± 2.7 cm (90% CI). As such, this resulted in a moderate training effect which was likely to be beneficial for the 12% Exo-skeleton group as the total horizontal distance still remained within the recommended distance of <20cm (Winchester et al., 2005). These results are in agreement with Winchester et al. (2005) who reported a significant increase in DxL during 70% 1RM loading for the power clean exercise following four weeks of power clean training. Due to participants in the 12% Exo-skeleton group having approximately 4% of bodyweight loaded on the upper back, participants were required to fully extend their bodies more aggressively to counteract the increased loading during the second pull phase which may partly explain the increase in DxL. This was also reported in our previous investigation (Chapter 3) for the 50% 1RM loading condition where an increase in DxL of 17.8% occurred compared to no Exo-skeleton loading. As such, we postulate that wearing a posteriorly loaded 12% Exo-skeleton load during power clean training is beneficial for lifters who are prone to catching the barbell in a forward position as a result of failing to maximally extend their bodies during the critical second pull phase.

Another technique variable that is highly correlated to the success of the power clean is the horizontal displacement from the second pull to the forward most position (DxV). During 90% 1RM efforts, the 12% Exo-skeleton group improved DxV as determined by a decrease in rearward barbell displacement by -1.56 ± 1.98 cm compared to the increase in the forward direction for the no Exo-skeleton group (1.73 ± 1.40 cm). It was deemed that training with the 12% Exo-skeleton would result in a moderate training effect very likely to be beneficial. These findings are also in agreement with previous researchers who have reported a decrease in the forward swing during DxV following power clean and power snatch training (Winchester et al., 2005; Winchester et al., 2009). The 12% load on the participant's body may enforce a movement pattern which requires lifters to maximally extend the hips, knees, and ankles during the second pull while pulling the barbell closer to the body as opposed to letting the barbell travel forwards.

An additional technique variable which is critical to the success of the power clean is the rearward displacement of the catch position (DxT) and this variable improved in the 12% Exo-skeleton group during the 90% 1RM loading condition. With a net effect between the two groups of -3.48 ± 6.90 (cm; 90% CI), this resulted in a moderate training effect likely to be beneficial for the 12% Exo-skeleton group. This finding is in agreement with Winchester et al. (2005) and Winchester et al. (2009) who reported a significant increase in rearward displacement of the barbell during DxT following four weeks of power clean and power snatch training. An increase in the rearward displacement of the barbell during the catch position may be explained by the posterior loading of the upper and lower body as opposed to anterior loading. The posterior loading configuration was chosen as the addition of weight cells to the anterior aspects of the thighs would have likely compromised the participants' ability to maximally accelerate the barbell during the second pull of the power clean during which time the barbell is required to remain in close contact to the thighs and hips. In addition, it is likely that this configuration shifted the lifters' centre of mass slightly rearward which resulted in a more rearward catch position when compared to no Exo-skeleton loading condition. The decrease in external barbell load may have also allowed the lifters to forcefully drive the elbows forward during the catching of the bar which placed their wrists, elbows, and upper back in a better catching position. However, such contention needs further research.

Barbell velocity is another critical variable that has been linked to the success of the power clean (Garhammer, 1985; Storey & Smith, 2012; Winchester et al., 2005; Winchester et al., 2009). During 90% 1RM efforts, the 12% Exo-skeleton group increased barbell velocity load by 3.5% when compared to the 4.3% decrease for the no Exo-skeleton group. As both groups performed pre and post testing with no Exo-skeleton loading (i.e. all the load was on the barbell), this increase in barbell velocity for the 12% Exo-skeleton group is reflective of a genuine training adaptation that occurred in response to the 5 week training intervention. These results are likely due to the improvement in power clean technique that was exhibited for the Exo-skeleton group. During the DxV phase, the Exo-skeleton group reduced the amount of barbell swing which would have contributed to the increase in barbell velocity. Greater vertical barbell velocities are critical in allowing lifters time to get under the bar during the catch position (Garhammer, 1985). Furthermore, as high release velocities are critical during throwing sports such as shot put, discuss, handball and baseball, increases in barbell velocities could positively influence throwing performance across such events (Gorostiaga, Granados, Ibanez, & Izquierdo, 2005; Vaan Den Tillaar & Ettema, 2004; Zaras et al., 2013; Zaras et al., 2014). As such, our findings suggest that a moderate training effect that is likely to be beneficial may occur for resistance trained athletes looking to improve barbell velocity.

As strength and conditioning practitioners are interested about the effectiveness of power clean training on athletic performance, an 8.7% increase in CMJ height for the 12% Exo-skeleton group is indicative of desirable changes in athletic performance and these results indicate that the Exo-skeleton is an effective alternative loading method for power clean training. Such a finding is further strengthened by the 1.4% decrease in CMJ ability exhibited by the no Exo-skeleton group. Therefore, training with the 12% Exo-skeleton is likely to result in a small training benefit in improving CMJ height, which is advantageous to athletes whose sport relies on jumping ability such as basketball and volleyball (Baker, 1996; Janssen, Sheppard, Dingley, Chapman, & Spratfor, 2012). As previous researchers (Canavan, Garrett, & Armstrong, 1996) have reported a significant ($r = 0.87$; $p \leq 0.05$) relationship of the angular displacements of the hip, knee, and ankle for the vertical squat jump and the hang power snatch (the power snatch also has very similar kinematics to that of the power clean), it is evident from the improved technique associated with Exo-skeleton training, such loading has positively transferred to athletic performance. Specifically, as DxV improved, which is indicative of maximal extension of the hips, knees, and ankles during the second pull, this may further contribute to improvements jumping performance. However, such contention needs further research.

Another measure in which strength practitioners determine the effectiveness of training is through changes in 1RM performance. The 4.2% increase in 1RM power clean for the 12% Exo-skeleton group compared to the 1.8% increase for the no Exo-skeleton group may be indicative of a superior training program allowing for improved technique and barbell velocity. The improved technique and barbell velocity, specifically at 90% 1RM would suggest this has transferred to maximal effort power cleans allowing for greater loads to be lifted. These findings support the importance of technique to improve power clean performance (Winchester et al., 2005; Winchester et al., 2009). Thus, for resistance trained athletes looking to improve 1RM power clean performance, a small benefit is possible when using a 12% Exo-skeleton vest after five weeks of power clean training.

Finally, as PP is critical to the success in many sports (Hoffman, Cooper, Wendell, & Kang, 2004; Hori, Newton, Nosaka, & Stone, 2005), it is worthy of note that across all testing loads for the 12% Exo-skeleton group, the increase in PO was small to moderate (ES = 0.33 to 0.62). This increase in PO production was also thought to positively transfer to the improvement in CMJ height. As generic athletic movement such as jumping, sprinting, and throwing require large PP outputs, training with the 12% Exo-skeleton can be an alternative training method to improve these movements. Furthermore, the findings from this investigation demonstrate that training at reduced barbell loads while maintaining total systems loads can improve PO. Such findings provide an option for a range of athletes who wish to improve PO but are less technically proficient at lifting, injured, or have mobility issues.

While the above sections have discussed the clear mechanistic inferences, a number of technique variables resulted in small changes across 70% and 90% loads that are worthy of note. The small effect sizes for the technique variables of Dx2, DxT, DxL, and CxH, at their respective loads, suggests that each technique variable has a different threshold of change and with greater sample sizes and/or longer training periods may invoke greater training effects.

Based on these findings, it is evident that training with a 12% Exo-skeleton load improves power clean technique. Although changes in joint angles were not measured, the increase in rearward displacement of the barbell suggest the posterior loading of the body enhanced the lifter's ability to complete maximal extension of the hips, knees, and ankles during the second pull. In the absence of a full extension of the body, barbell trajectories during the second pull of the Olympic lifts have been shown to move forward in the sagittal plane (Gourgoulis et al., 2009; Häkkinen et al., 1984). This improvement in maximal extension may also transfer to CMJ performance due to improved kinematics. These improvements in technique also allow for greater barbell velocities which in turn lead to improvements in PO and 1RM power clean performance. A limitation of this study was the small sample size which resulted in a number of variables having unclear inferences. A longer training period may also allow for greater training effects to occur. As each technique variable appears to have a different threshold which could be affected by different Exo-skeleton loads, training length, and/or training status, further research is needed to assess; 1) the effects of Exo-skeleton loading at loads ≥12% bodyweight, 2) training interventions longer than five weeks and, 3) the application of Exo-skeleton loading on lifters with differing power clean ability.

4.7 Practical applications

Power clean training with an Exo-skeleton load of 12% of a lifters bodyweight positively influences kinematic and kinetic variables while improving CMJ and 1RM power clean performance. Reducing the total external bar load while maintaining the total system load allows lifters to focus on the technical aspects (e.g. increasing the rearward displacement of the barbell) thus improving lifting technique. This may be beneficial to less technically proficient lifters by allowing them to focus on the technical requirements without being inhibited by large external loads. Improving the technical aspects of the power clean also allows for improved barbell velocities and PO which are critical to success in many sports. The reduction in the total external load while maintaining equated total system loads may also provide an avenue for lifters with poor mobility to perform maximally loaded power cleans while improving jumping performance.

CHAPTER 5. GENERAL SUMMARY

5.1 Summary

This thesis sought to answer the over-arching question of what are the acute and longitudinal kinematic and kinetic effects of a weighted Exo-skeleton on the performance of the power clean exercise and athletic performance measures. A range of kinematic and kinetic variables were identified as critical to the success of the power clean exercise. These were used to compare the acute effects of Exo-skeleton loads equivalent to 5% and 12% of participants' bodyweight during the performance of the power clean at 50% and 70% of participants 1RM. Although the barbell load was un-equated, the total system load (i.e. barbell plus lifter with Exo-skeleton) was equated resulting in an improvement in the total rearward displacement of the bar from the most forward position to the catch position. This occurred at 50% of 1RM whilst wearing the 12% Exo-skeleton when compared to the no Exo-skeleton condition. With approximately 4% of bodyweight loaded on the upper back this may partly explain the improvement as the lifters were required to fully extend their bodies more aggressively to counteract the increased loading during the second pull phase. Only two previous research groups have examined the acute changes in technique that occur whilst wearing a WV during sporting movements (i.e. sprinting) (Alcaraz, Palao, Elvira, & Linthorne, 2008; Cronin et al., 2008). While it is difficult to compare results between different exercise modalities (i.e. sprinting vs. power clean kinematics), one conclusion from the collective research is that excessive loading of the anterior chain is detrimental to technique.

Another major finding was an increase in peak barbell velocity which occurred during 70% of 1RM for the 12% Exo-skeleton condition when compared to no Exo-skeleton loading. An increase in barbell velocity combined with similar PF measures as compared to the no Exo-skeleton loading resulted in increases in PO. These changes were attributed to a decrease in external bar load equivalent to 12% of participants' bodyweight even though the total system loads remained equal. Due to these aforementioned changes, it was determined the optimal Exo-skeleton load to be worn during the power clean exercises was ~12% of the participants bodyweight. The acute improvement in barbell velocity also

After five weeks of training with or without an Exo-skeleton equivalent to 12% of participant's bodyweight, resistance trained athletes training with the 12% Exo-skeleton improved aspects of power clean technique at 70% and 90% 1RM. For example, the 12% Exo-skeleton group increased the rearward displacement of the barbell during the catch phase compared to the increase in forward displacement for the no Exo-skeleton group at 70% 1RM loading. As these findings are in agreement with Winchester et al. (2005), the use of Exo-skeleton loading demonstrates an alternative loading method capable of improving a key technique variables that contribute to the success of the power clean (Winchester et al., 2005).

In regards to power clean technique during 90% 1RM loading, the 12% Exo-skeleton resulted in a decrease in the rearward displacement of the forward most position during the second pull when compared to the increase in forward displacement by the no Exo-skeleton group. Additionally, the 12% Exo-skeleton group also increased the rearward displacement during the catch position compared to the increase in forward displacement for the no Exo-skeleton group. The posterior loading of the body ensured lifters forcefully completed maximal extension of the hips, knees, and ankles during the second pull which forced lifters to pull the barbell rearwards as opposed to letting the barbell drift forwards. The improvement in technique was thought to contribute to the increase in barbell velocity and PP. As previous researchers (Hoffman, Cooper, Wendell, & Kang, 2004; Hori, Newton, Nosaka, & Stone, 2005) have highlighted the importance of PP to success in many sports and as generic athletic movement such as jumping, sprinting, and throwing require large PO outputs, the findings in the current study further demonstrate the effectiveness of the Exo-skeleton as an alternative loading method for improving PO. Additionally, the decrease in external barbell load while maintaining the total system load may provide an avenue for less technically proficient lifters and lifters with poor mobility to focus on the critical technique aspects when training at near maximal to maximal loads thus allowing for large PO.

The collective improvement in technique, barbell velocity, and PO was thought to positively affect the improved CMJ height and 1RM power clean performance. Due to the kinematic similarities between the power clean and CMJ, it was thought that the improved kinematics of the power clean positively transferred to CMJ performance. In particular, hip extension which has been highlighted as essential during jumping and sprinting (Tricoli et al., 2005; Young et al., 2001) and is also emphasised during the 2nd pull of the power clean (Canavan et al., 1996; Dawes, 2012; Storey & Smith, 2012). As such, training with the 12% Exo-skeleton produced a range of benefits which are possible to very likely to improve lifting performance in resistance trained athletes.

5.2 Practical applications

The review of the literature provided an in-depth analysis of the power clean exercise with critical variables related to power clean success identified. Additionally, different training modalities to improve lifting performance were reviewed. Based on the findings from the two investigations, a number of practical applications are provided to help strength and practitioners with the Exo-skeleton:

1. Due to the highly technical nature of the power clean exercise, decreasing the total external bar load while maintaining the total system load may allow lifters to focus on the technical aspects of the lift (e.g. minimising the total horizontal displacement of the barbell), thus improving power clean ability.
2. The reduction in the total external load while maintaining equated total system loads may also provide an avenue for lifters with low power clean training experience, injuries, or poor mobility to perform maximally loaded power clean without being inhibited with large external loads.
3. Resistance trained lifters who are prone to catching the barbell in a forward position as a result of failing to maximally extend through the 2nd pull phase can incorporate an Exo-skeleton load equivalent to 12% of their body mass to ensure triple extension of the hips, knees, and ankles is aggressively completed during the 2nd pull.
4. The 12% Exo-skeleton improves both acute and longitudinal barbell velocities. This is beneficial to lifters as this can lead to greater time for lifters to get under the bar in the catch position and increase the vertical displacement which may allow for increases in the total load lifted.
5. Improvements in PO across a range of loads during the performance of the power clean provides an avenue for less technically proficient lifters to increase their PP outputs using lighter training loads which in turn will help to minimise the risk of potential injury.

6. As high release velocities are critical during sports which involved throwing such as shot put, discus, handball and baseball, increases in barbell velocity could positively influence throwing performance across a number of sports.

7. The overall improvement in kinematic and kinetic variables following power clean training with Exo-skeleton loading can lead to improvements in CMJ height.

5.3 Limitations

The author notes and acknowledges the following limitations from the research performed:

Pilot Study

1. With conflicting evidence of WV loads between 2-20% of participants bodyweight, Exo-skeleton loads different to that of 5% and 12% loads may have resulted in different outcomes.

2. The use of resistance trained athletes reduces the application of the findings to other lifters with lesser or greater lifting ability.

Training Study

1. A limitation of this study was the small sample size which resulted in a number of variables having unclear inferences.

2. As each technique variable appears to have a different technique threshold, further research is needed to assess: 1) the effects of Exo-skeleton loading at loads ≥12% bodyweight; 2) training interventions longer than five weeks; and, 3) using lifters of differing power clean ability.

3. A lack of control of participants training outside of power clean sessions

5.4 Future research

This thesis has made a valuable contribution to the current body of knowledge on the power clean exercise and its use within various training methodologies. The alternative loading method of Exo-skeleton loading has also contributed to the knowledge of centralised loading (i.e. the addition of external loading to the body). However, due to the results and scope of these investigations, a number of areas still require further research. For example:

1. While a number of technique variables improved for the 12% Exo-skeleton group over the five week training period, the acute effect of power clean training demonstrated technique variables may have a minimum threshold which requires loads >12% bodyweight to elicit changes. An acute investigation to determine if loads >12% bodyweight result in changes in technique variables could provide such answers.
2. As technique improved during the second pull which is indicative of maximal extension of the hips, knees, and ankles, this may have positively affected CMJ performance. Further research could compare kinematic changes in power clean performance as a result of combined power clean training with Exo-skeleton loading and what kinematic, kinetic, and performance changes occur during athletic movements such as jumping and sprinting.
3. Due to the number of technique variables failing to result in clear inferences following the training intervention, an investigation with a longer training intervention, and/or a larger sample size may provide clearer results.
4. Longer exposure to Exo-skeleton loading during the power clean is also warranted as the potential for greater and clearer training effects may occur which will

give practitioners a greater insight into the long term training effect.

5. Since the participants' in both investigations had reasonable power clean technique, the effect of Exo-skeleton may be different in lesser or greater skilled lifters. Furthermore, different skilled lifters may require more or less percentage of bodyweight through Exo-skeleton loading to cause a change in technique.

5. As the power snatch is another common exercise used by strength and power athletes which is often difficult to complete due to the technique and mobility requirements, the investigation of Exo-skeleton loading during the power snatch is warranted.

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Appendices

Appendix 1: Abstracts

(Chapter 3)

Weighted vests are often applied to jumping and sprinting movements to improve lower body power. However, it is currently unknown what effect this loading method has on full body explosive movements such as the power clean. Therefore, the purpose of this investigation was to quantify the kinematic and kinetic effects a weighted Exo-skeleton had on the performance of the power clean exercise. Nine resistance trained males performed two power cleans at loads of 50% and 70% of 1RM with and without an Exo-skeleton equivalent to 5% and 12% of their bodyweight. Four technique variables, barbell velocity, peak ground reaction force (PGRF), and power output (PO) were compared. The main findings of this investigation were;1) the 12% Exo-skeleton condition significantly ($p \leq 0.05$) increased the rearward displacement (17.9%) of the barbell during the catch phase (DxL) when compared to the no Exo-skeleton group during 50% 1RM efforts, 2) at 70% 1RM efforts, peak barbell velocity during the 12% Exo-skeleton condition was 3.33% higher ($P < 0.05$)as compared to the no Exo-skeleton condition, 3) during 50% 1RM efforts, PO was significantly higher for 5% (11.5%) and 12% (16.8%) Exo-skeleton conditions when compared to the no Exo-skeleton condition and, 4) the 5% Exo-skeleton condition did not have a significant influence on technique factors at 50% and 70% of 1RM when compared to the no Exo-skeleton condition. In conclusion, the addition of an Exo-skeleton load of ~12% of a lifter’s bodyweight may positively influence kinematic and kinetic variables during power clean performance.

(Chapter 4)

A popular method to improve athletic performance and lower body power is to train with a weighted vest. However, it is currently unknown what training effect this loading method has on full body explosive movements such as the power clean. Therefore, the purpose of this investigation was to determine what effects an Exo-skeleton equivalent to 12% bodyweight had on the power clean exercise and countermovement jump (CMJ). Sixteen resistance trained males completed five weeks of power clean training with or without an Exo-skeleton. Five technique variables, barbell velocity, peak ground reaction force, peak power, 1RM power clean, and CMJ were compared. The primary findings of this investigation were; 1) during the 70% and 90% 1RM efforts, the Exo-skeleton group increased the rearward displacement (17.5% and 76.9%)of the barbell during DxL and DxT when compared to the increases in forward displacement (3.4% and 56.9%) for the no Exo-skeleton group, 2) the Exo-skeleton group increased (24%) the rearward barbell displacement during DxV compared to the increase in forward displacement (14.7%) for the no Exo-skeleton group at 90% 1RM, 3) the Exo-skeleton group increased barbell velocity at 90% 1RM (3.5%) when compared to the decrease for the no Exo-skeleton group (-4.3%) and, 4) the Exo-skeleton group increased CMJ (8.7%) and 1RM power clean performance (4.2%) compared to the decrease in CMJ (-1.4%) and increased 1RM power clean performance (1.8%) for the no Exo-skeleton group. In conclusion, training with a 12% Exo-skeleton can positively influence power clean ability and CMJ performance.

Appendix 2: Ethics approval

AUTEC

SECRETARIAT

7 April 2014

AdamStorey
Faculty of Health and Environmental Sciences
Dear Adam

Re Ethics Application: **14/60The biomechanical and neuromuscular influence of weighted vest resistance on the performance of the power clean in competitive athletes.**

Thank you for submitting your application for ethical review. I am pleased to confirm that the Auckland University of Technology Ethics Committee (AUTEC) has approved your ethics application for three years until 31 March 2017.

The Information Sheet requires a minor amendment to include the advice that the data will be kept indefinitely and the reason why it is being kept.

AUTEC would like to commend you and the researcher on the overall quality of the application.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 31 March 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 31 March 2017 or on completion of the project;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within their.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Caleb Marrinercaleb_marriner@hotmail.co.nz

Appendix 3: Study Flyer

REQUEST FOR STUDY PARTICIPANTS

Project title:

"The Influence of Weighted Vest Resistance on the Performance of the Power Clean in Competitive Athletes."

Are you:

1. A current competitive strength and power athlete (i.e. weightlifters, sprinters, jumpers, throwers, and/or rugby player) with the ability to power clean ≥ 1x body mass
2. Male aged between 18-35 years
3. Free form acute or chronic injury
4. Not using any performance enhancing or banned substances (WADA 2014)

Purpose of the study:

Acute increases in jumping, sprinting and agility have been shown to occur following dynamic warm up drills and exercises that have been performed with a weighted vest (i.e. "centralised loading"). The combined used of weighted vest resistance and whole-body strength and power resistance exercises, such as the power clean, could prove to be a highly effective training strategy and further investigation is warranted in this area. Therefore, the purpose of this investigation is to assess and compare the effects of centralised loading on the performance of the power clean across a 5 week training period.

What is involved:

Testing

Prior to the start of the study, you will be required to complete an exercise familiarisation and maximal (1RM) power clean testing session. In addition, your vertical jump and 30m sprint will be tested. Total approximate time= 4 hours

Training

You will randomly be assigned to a weighted vest (WV) group or no weighted vest/control group. All participants will be required to perform 3 supervised power clean training sessions a week across the 5 week study period. The WV group will be required to perform the designated training sessions with an additional load equivalent to 5-10% of their body mass placed on their posterior trunk (i.e. mid-lower back and glutes). Between training sessions, you may recommence your normal training but you will be asked to refrain from all exercise 12 hours before each intervention session.

Benefits of the study:

You will benefit from having expert Olympic lifting coaching while receiving information regarding your force and power producing ability which will be applicable to your sporting endeavours.Additionally, you will be contributing to the current body of knowledge in strength and power field.

Whom do I contact for further information about this research?

Researcher **Caleb Marriner** PH: 027 8291112 E: caleb_marriner@hotmail.co.nz

Project supervisor **Dr. Adam Storey PH:** 021 2124200 E : adam.storey@aut.ac.nz

Appendix 4: Participant information sheet

Participant Information Sheet

Date Information Sheet Produced: 4.3.14

Project Title:

The Biomechanical and Neuromuscular Influence of Weighted Vest Resistance on the Performance of the Power Clean in Competitive Athletes.

You are invited to participate in the above named study which is a research based investigation conducted by Mr. Caleb Marriner and supervised by Dr. Adam Storey and Professor John Cronin. Participation in this study in completely voluntary and any decision to participate or not participate does not affect in any way the relationship you have with the investigators.

What is the purpose of this research:

Acute increases in jumping, sprinting and agility have been shown to occur following dynamic warm up drills and exercises that have been performed with a weighted vest (i.e. “centralised loading”). The acute enhancements in performance are likely due to an increase in muscle fibre recruitment, which leads to an increased force producing ability.

Such findings have relevance to acute athletic performance in the context of sport-specific training (e.g. sprinting and jumping). However, the combined used of weighted vest resistance and whole-body strength and power resistance exercises, such as the power clean, could prove to be a highly effective training strategy for improving athletic performance and further investigation is warranted in this area. Therefore, the purpose of this investigation is to assess and compare the effects of centralised loading on the performance of the power clean exercise during a 5 week training intervention in well-trained athletes. These findings will contribute towards a Masters degree and will be presented in thesis and journal-article format which may also include conference presentations.

Am I eligible to participate?

You are eligible to participate in this study if you are; 1) male aged between 18-35 years, 2) free form acute or chronic injury at the time of the training intervention, 3) not using any performance enhancing or banned substances (World Anti-Doping Agency 2014), and 4) posse the ability to power clean ≥ 1x body mass.
Participation in this study is completely voluntary with you having the right to withdraw form the study at anytime without reason.

What will happen in this research?
Familiarisation and testing session:
If you are eligible to participate in this study, you will be required to attend a familiarisation session at least three days prior to the testing session. Participants will be required to perform a number of repeated sub-maximal power cleans with and without a weighted vest (WV). Additionally, maximal (1RM) power clean testing will be conducted for subsequent testing and training loads. Adequate familiarization will be provided prior to maximal efforts being performed. The total familiarisation session will last approximately one hour.

The pre- and post testing sessions will include quantitative measures of strength and power including the power clean, vertical jump test, 10m and 30m sprints. You will be videoed for the purpose of measuring „technique‟. The total testing time will last approximately one hour and thirty minutes.

Training

Once you have completed the familiarisation and testing session, you will randomly be assigned to a (WV) group or no weighted vest/control group. All participants will be required to perform 3 supervised power clean training sessions a week across the 5 week study period. The WV group will be required to perform the designated training sessions with an additional load equivalent to 5-15% of their body mass placed on their posterior trunk (i.e mid-lower back and glutes). The weighted vest, in the form of a cutting edge high performance exoskeleton garment (Exogen©), is designed to support multi-directional movements through the use of high tech compression materials following the natural architecture of the body. The "tear drop" weights (Fusiform Loads ©) can be specifically placed over targeted muscle groups and their flexible design allows for smooth and uncompromised movements. The associated training loads for the WV group will be adjusted accordingly to take into account the additional load placed on the actual body of the participant. Training days will be broken up by level of intensity from low-high-medium sessions throughout the week. Between training sessions, you may recommence your normal training but you will be asked to refrain from all exercise 12 hours before each intervention session.

What are the discomforts and risks.

As with any form of physical activity, the testing protocols and training sessions have the potential to cause fatigue. In addition, there is also the possibility that you may experience transient muscle soreness 12-48 hours after the testing and training sessions. However, this will be no different to any other training session.

What are the benefits?

You will receive a full written report, regarding your maximal speed force and power producing ability which will be applicable to your sporting endeavours. In addition, you will also benefit from having expert coaching in Olympic lifting.

What compensation is available for injury or negligence

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation‟s regulations.

How will my privacy be protected

All information collected for the purpose of this investigation will be stored in a secure database which will be accessible by Caleb Marriner (Primary Researcher), Dr. Adam Storey (Primary Project Supervisor), and Professor John Cronin (Secondary Project Supervisor). Any data that will be used for publications, presentations, and further investigations in the future will be encoded in such a way that it will not be possible to identify you and your data in any publication from this work.

What are the costs of participating in this research?

There will be no financial cost for you being involved with this study. You will be required to commit approximately 4 hours towards testing and familiarisation sessions and 3 hours per week for 5 weeks for the training intervention.

How do I agree to participate in this research?

If you choose to participate in this investigation you will be required to complete a Participant Consent Form which can be obtained from Caleb Marriner. After completing the consent form you will be required to complete a basic participantnquestionnaire which will provide the researchers with general information regarding your training and injury history and current dietary intakes.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Primary Project Supervisor: Dr. Adam Storey, adam.storey@aut.ac.nz, 021 2124200.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher	**Caleb Marriner** BSe, PGd, (Masters Student) AUT-Millennium, 17 Antares Place, Mairangi Bay 0278291112 caleb_marriner@hotmail.co.nz
Project supervisor	**Dr. Adam Storey** AUT-Millennium, 17 Antares Place, Mairangi Bay 0212124200 adam.storey@aut.ac.nz
Second research supervisor	**Professor John Cronin** AUT-Millennium, 17 Antares Place,

Mairangi bay
john.cronin@aut.ac.nz

Appendix 5: Consent form

Consent Form

Project title: "The Biomechanical and Neuromuscular Influence of Weighted Vest Resistance on the Performance of the Power Clean in Competitive Athletes."

Project Supervisor: Dr. Adam Storey

Researcher: Mr. Caleb Marriner

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ I am not suffering from any acute or chronic injuries

○ I am not using any performance enhancing or banned substances (WADA 2014)

○ I agree to take part in this research.

○ I wish to receive a copy of the report from the research (please tick one): Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on typethe date on which the final approval was grantedAUTEC Reference number type the AUTEC reference number*Note: The Participant should retain a copy of this form.*

Appendix 6: Participant questionnaire

PARTICIPANT QUESTIONNAIRE

Project title:

"The Influence of Weighted Vest Resistance on the Performance of the Power Clean in Competitive Athletes."

1. Full Name…………………………..…………………………………………
2. Date of birth. …………………………………………………………………
3. Contact numbers……………………………………………………………
4. Contact Address…………………………………………………………….
5. Are you currently taking any medication? If so, list the name and dosage…………………………………………………………………
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6. Are you currently taking supplements to your diet? (including creatine, protein, caffeine, and/or steroids)
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7. Do you have any injury history? If so, what is it and when did it happen?
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8. Do you have any current injuries that could interfere with you training in this study? If so, what is it and when did it happen?
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9. How often do you complete heavy resistance exercise training a week?
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10. What sport are you involved in competitively?
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Researcher **Caleb Marriner** PH: 027 8291112 E: caleb_marriner@hotmail.co.nz

Project supervisor **Dr. Adam Storey PH:** 021 2124200 E: adam.storey@aut.ac.nz

Appendix 7:Kinovea analysis steps

1. Import video in to Kinovea 0.8.15 soft wear.
2. Play video until one frame before the beginning of the lift which is when the bar begins to flex (Souza et al., 2002).
3. Zoom the video in and right click on the reflective marker at the centre of the bar
4. Select “track path”.

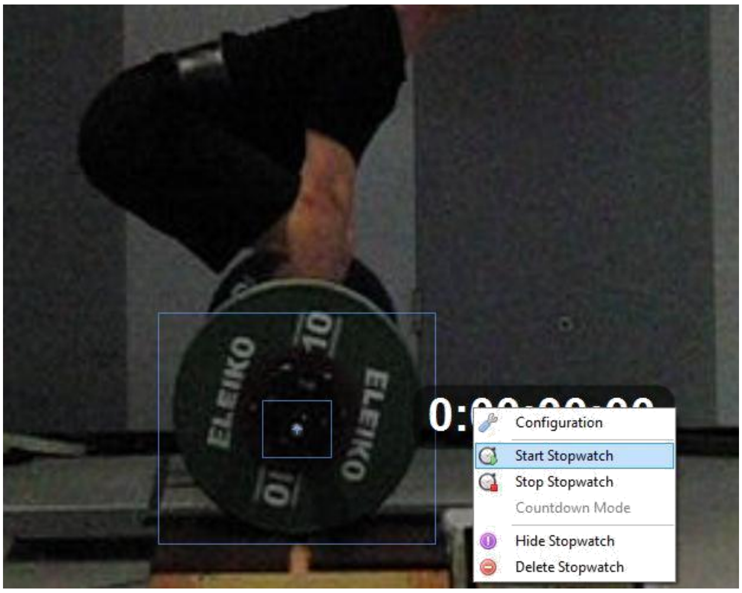

Figure 10. Bar path tracking

5. Insert a “stop watch” into the video and right click to start the stop watch to sync with the lift off and the bar path data.

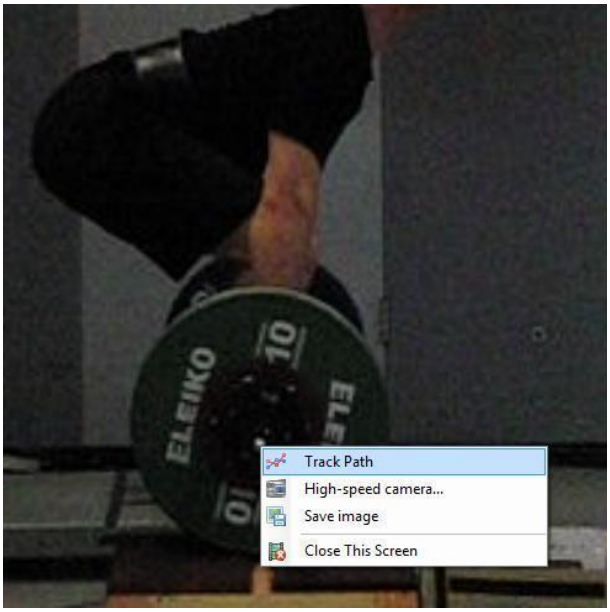

Figure 11. Syncing stop watch and bar path

Allow the video to run through in slow motion to develop a bar path. Adjust the barbell tracker manually if needed.

6. At the end point of the lift, right click on the path, select “End Path”, then “configure” and change the line style to a thin line.
7. Click File, Export to Spreadsheet, and select “trajectories to simple text”.
8. Use the “Line” function to trace over a standardised calibration stick that is included in the original video. Right click on the line to calibrate it to the known length. Note: the calibration line must be in the same depth of field as the barbell reflective marker.

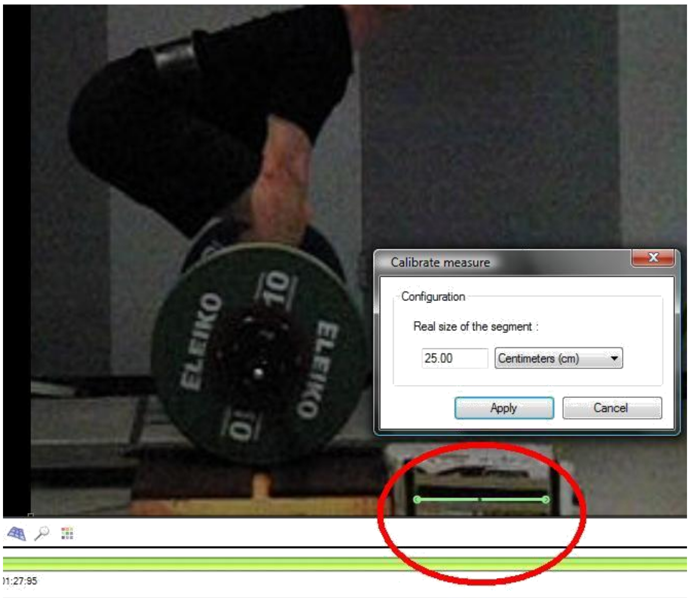

Figure 12. Calibration of measuring stick

DX2 (start position to second pull) is measured using the following steps:

1. Move the video to the start of the second pull. To increase accuracy, use the “Trajectories to simple text” file and marry the time and distance co-ordinates with the video. If more than one time reference exists for the same distance, use the median time point.

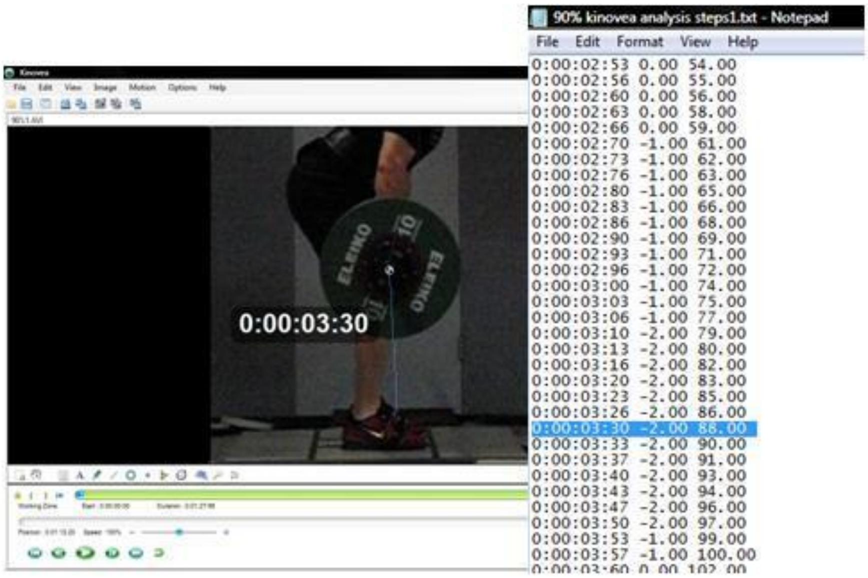

Figure 13. Syncing of trajectories to simple text and video

2. Using the "Angle" function, draw a vertical 180deg line from the start of the lift upwards.
3. Using the "Line tool, measure the horizontal distance between the vertical line and the reflective marker at the start of the second pull.

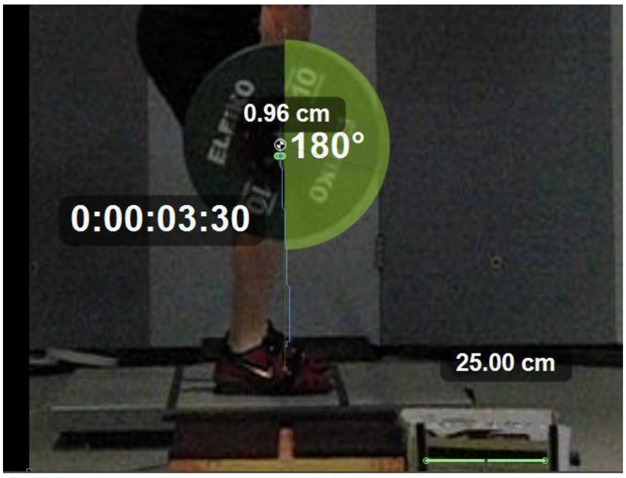

Figure 14. Measuring of DX2 using angle and line tools

DXV (second pull position to the most forward position) is measured using the following steps:

1. Play the video to the most forward position after the second pull. To increase accuracy, use the "Trajectories to simple text" file and marry the time and distance co-ordinates with the video. If more than one time reference exists for the same distance, use the median time point.
2. Using the "Line" tool, draw a vertical line up from the second pull to in line with the most forward position. Use the "Angle" tool to ensure line is vertically straight.
3. Using the "Line" tool, measure the horizontal distance between the vertical line and the reflective marker on the barbell. To ensure the line is accurate,

use the “Angle” function at 270°.

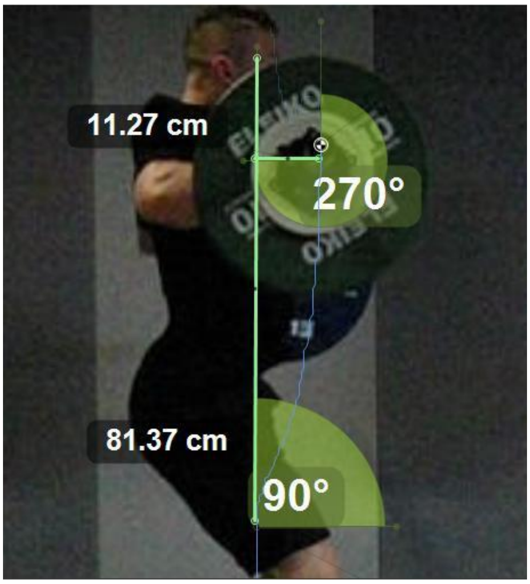

Figure 15. Measuring of DXV using angle and line tools

DXT- (Start position to catch position), is measured using the following steps:

1. Play the video to the point where the participant catches the barbell. To increase accuracy, use the “Trajectories to simple text” file and marry the time and distance co-ordinates with the video. If more than one time reference exists for the same distance, use the median time point.
2. Using the “Line” tool, draw a line vertically from the reflective marker. Use the “Angle” function to ensure accuracy. Note – this vertical line is a measure of the catch height (CxH).
3. Measure the horizontal distance between the vertical line and the stat point. To ensure the line is accurate, use the “Angle” function at 270°.

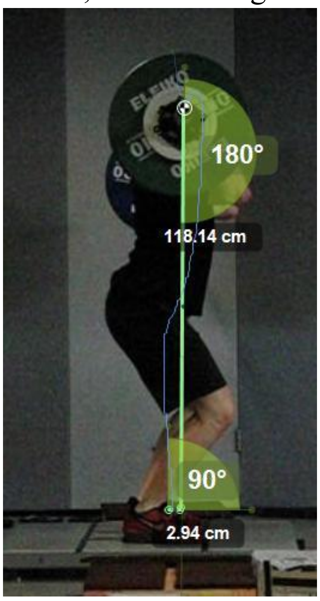

Figure 16. Measuring of DxT and CxH using angle and line tools

DXL- catch position to forward most position using the following steps:

1. Using the same vertical line drawn for the DxT variable, measure the horizontal distance between the vertical line and the "forward most position" points. To ensure the line is accurate, use the "Angle" function at 270°.
2. From the vertical line drawn for DxT, draw a horizontal line to the forward most position. To ensure the line is accurate, use the "Angle" function at 270°.

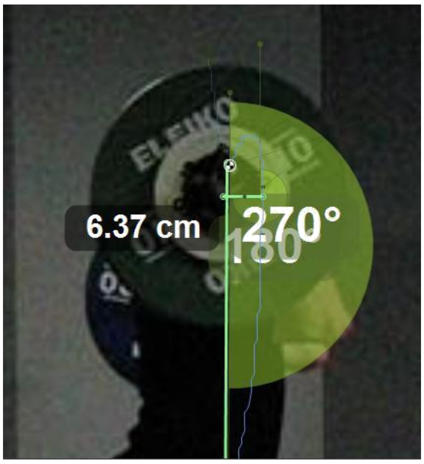

Figure 17. Measuring of DxL using angle and line tools