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**Eccentric resistance exercise as a method of inducing post-activation potentiation to acutely influence force, speed, and power in resistance-trained males.**

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## **Abstract**

Novel methods of acutely improving an individual's athletic performance are regularly utilised in an effort to gain unique advantages in competitive contexts. One such method is post-activation potentiation (PAP). Eccentric resistance exercise has been demonstrated to have unique properties to that of traditional resistance methods. Few studies have investigated the effects eccentric resistance exercise may have on potentiating physiological characteristics such as force, speed, and power. This thesis aims to: (1) review and synthesise existing literature regarding physiological and neuromuscular underpinnings of PAP and eccentric exercise (Chapter One); (2) examine test-retest reliability of the test conditions used to measure physiological aspects pertinent to athletic populations (Chapter Two); and (3), investigate the acute effects isokinetic eccentric resistance exercise has on expressions of force, speed, and power (Chapter Three). Chapter Four discusses and summarises key findings of the studies undertaken, outlining strengths and limitations, and provides recommendations for future research.

As part of the literature review in Chapter One, research regarding the pertinent variables of PAP and eccentric exercise was examined. While there is a consensus that PAP can occur and that eccentric exercise can have superior adaptive qualities to traditional exercise methods, it is evident there is little quantification for what training volumes, recovery periods, and individual characteristics are most conducive to the application of eccentric exercise to elicit PAP.

Chapter Two examined the inter-day reliability of the drop-jump, loaded counter-movement jump, and six-second peak power test metrics using equipment from OptoJump™, Kinetic Performance Technology, and Wattbike Ltd. The experimental set-up and metrics were found to be reliable (<10% CV) for measuring flight time, relative power, and jump height in the drop jump; jump height and peak velocity for the lighter loaded counter-movement jump

(25 kg); jump height, peak power, peak force, peak velocity and peak relative power for the heavier loaded counter-movement jump (45 kg); and peak power, relative power, peak cadence and cadence at which peak power occurred in the six-second peak power test.

In Chapter Three, 19 resistance trained males completed three sessions of drop jumps, loaded counter-movement jumps, and six-second peak power cycling tests pre- and post-interventions using an isokinetic eccentric ergometer to induce PAP or a concentric cycling control. Measures of relative power in heavier loaded counter-movement jumps were found to be significantly improved (0.02) with moderate effect sizes found in time to peak power (0.80) and cadence at which peak power occurred (0.92) in the six-second peak power cycling test. Results from this research demonstrate a need for higher quality methodological studies to be undertaken examining variables involved in novel training methods such as PAP and eccentric resistance training including volume, intensity, recovery times, and individual characteristics required for beneficial adaptations in this population.

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## **List of abbreviations**

CMJ – Counter-movement jump

LPT – Linear-position transducer

SSC – Stretch-shortening cycle

ATP-PC – Adenosine Triphosphate-Phosphocreatine

ECC – Eccentric resistance exercise

ERT - Eccentric resistance training

PAP – Post-activation potentiation

RM – Repetition maximum

DOMS – Delayed onset muscle soreness

*n* - Number

N – Force in Newtons

m/s – Metres per second

W – Wattage

Kg – Kilogram

s – Seconds

W/kg – Wattage per kilogram

ES – Effect size

CL – Confidence limits

SD – Standard deviation

RPM – Revolutions per minute

ANOVA – Analysis of variation

MBI – Magnitude based inference

y – Years

cm - Centimetres

## **Thesis Outline**

### **Chapter One:**

Review of literature on neuromuscular effects of post-activation potentiation and physiological and neuromuscular effects of eccentric resistance exercise.

### **Chapter Two:**

Inter-day reliability of OptoJump, GymAware, and Wattbike on drop jump, loaded counter-movement jump, and six-second peak power tests.

### **Chapter Three:**

Acute effects of isokinetic eccentric resistance exercise on force, speed and power.

### **Chapter Four:**

Discussion and conclusion.

## **Background**

It has consistently been demonstrated that vital components of an athlete's training program include the development of strength, speed, and power (Bompa & Buzzichelli, 2015; Joyce & Lewindon, 2014; McGuigan, Wright, & Fleck, 2012; Suchomel, Nimphius, & Stone, 2016). As the understanding of the physiological aspects underpinning athletic performance develops, training efficiency and efficacy are increasingly becoming a premium commodity (Bompa & Buzzichelli, 2015; Durell, Pujol, & Barnes, 2003). Thus, research appears to increasingly be addressing novel methods which will facilitate the highest physiological adaptation in the briefest time (Suchomel, Nimphius, Bellon, & Stone, 2018; Suchomel et al., 2016).

There is increasing evidence reporting eccentric resistance training (ERT) can elicit superior improvements in strength, power and hypertrophy when compared to traditional resistance training methods (Douglas, Pearson, Ross, & McGuigan, 2017a; Friedmann-Bette et al., 2010; Roig et al., 2009). An eccentric muscle contraction is characterized as the active lengthening of a muscle due to an external force being greater in magnitude than the force produced by the muscle (Douglas, Pearson, Ross, & McGuigan, 2017b). Beneficial sport-specific adaptations such as improving the composition of fast twitch muscle fibres relative to slow twitch muscle fibres and an increase in muscle tendon unit stiffness have been described following ERT (Suchomel et al., 2019).

Literature suggests that high intensity concentric (Anthi, Dimitrios, & Christos, 2014) and isometric exercises can be used effectively as a means of potentiating subsequent muscle actions. This post-activation potentiation (PAP) refers to executing a voluntary muscular movement at (or near) maximal intensity, acutely enhancing muscular force, output, and performance for subsequent biomechanically similar tasks (Hodgson, Docherty, & Robbins, 2005). Acute neuromuscular and physiological responses may regulate these temporary

improvements. There is currently limited information on the use of eccentric exercise (ECC) as a potentiating stimulus to acutely improve muscular force and velocity. As such, further research is required to establish appropriate volumes, intensities and recovery periods to incorporate ECC for PAP purposes within a training program (Beato, Bigby, et al., 2019; Beato, McErlain-Naylor, Halperin, & Dello Iacono, 2020; Beato, Stiff, & Coratella, 2019; Suchomel et al., 2016; Suchomel et al., 2019).

Therefore, the aim of this thesis was to assess the acute effects of eccentric resistance training on potentiation of lower limb muscular power in healthy, resistance trained males. A secondary aim was to investigate the reliability of the measurements obtained from the drop jump, counter movement jump, and a cycle ergometer-based six-second peak power test.

## **Chapter One: Review of Literature**

## **Review aim**

The aim of this literature review is to synthesise and critique existing literature on post-activation potentiation methodologies, the prospective utilisation of eccentric exercise to elicit potentiation, and how these concepts may have functional applications for healthy, resistance trained males.

## **Post-Activation Potentiation**

### **1.1 Physiological and neuromuscular factors**

Post activation potentiation (PAP) is a method of inducing acute improvements in expressions of power, through exposing the body to high intensity dynamic movements biomechanically similar to the manner in which the expression of power will subsequently be manifested (i.e. an high intensity back squat prior to a maximal effort vertical jump) (Anthi et al., 2014; Chiu et al., 2003; Hamada, Sale, & Macdougall, 2000; Hodgson et al., 2005). The mechanics of PAP are not conclusively understood (Anthi et al., 2014). One proposed physiological process is the phosphorylation of myosin regulatory light chains, theoretically making myosin and actin more reactive to the release of calcium into the muscle via the sarcoplasmic reticulum. The increased sensitivity to calcium may lead to myosin binding at a faster rate than typical. However, this proposed phenomenon has not been demonstrated in human muscle as consistently as it has been in animals (Fry & Smith, 2007; Stuart, Lingley, Grange, & Houston, 1988). Stuart et al. (1988) proposed that there is an increased incorporation of higher order motor units than there would otherwise be, as dictated by Henneman's size principle (Tillin & Bishop, 2009). Induced tetanic contractions can innervate motor-neurons which otherwise would not be innervated. This innervation increases the transmission of these motor-neurons across the junctions at the spinal cord, improving post-synaptic potential from the tetanic contraction and transferring to the pre-synaptic activation of the subsequent exercise (Hodgson et al., 2005; Tillin & Bishop, 2009). Güllich and Schmidtbleicher (1996) furthered this theory with the notion that the amplification of the H-reflex stimulates a greater number of

action potentials directly resultant from the prior stimulus, proportionate to the intensity of prior stimulus.

## **1.2 Training experience**

Chiu et al. (2003) suggest training level and strength may be indicative of the effect of PAP on the subject as recreationally resistance trained individuals did not significantly enhance performance whereas the athletic trained group did. Furthermore, Hamada et al. (2000) posited that the level of enhancement from PAP is directly influenced by the individual's training history in the specific muscle exposed to PAP. Literature from Güllich and Schmidtbleicher (1996); and Young, Jenner, and Griffiths (1998) clearly demonstrates that, in order for PAP to be induced, the previous conditioning strategy must be at a high- to maximum intensity. These findings were reinforced by a meta-analysis by Seitz and Haff (2016) on PAP. These authors found a greater effect size for studies involving plyometric based PAP (ES= 0.47) and traditional high-intensity (ES= 0.41) exercises compared to moderate intensity (ES= 0.19) or maximal isometric (ES= -0.09) conditioning exercises. In their 2005 review article, Hodgson et al. (2005) concluded that PAP can be elicited via maximal or near maximal muscular contractions, but presently it is unclear the best manner of which to transfer the potentiation to a clear and functional improvement in motor performance.

In sum, it would appear the phenomenon of PAP occurs through an increase of stimulated motor-neurons via the amplitude of the H-reflex and an upregulation of motor units that would otherwise not be recruited through neural responses within the spinal cord. While the physiological and neuromuscular underpinnings of PAP appear coherent, it is still to be determined the magnitude of effects PAP can have in an acutely functional environment.

## **1.3 Intensity-fatigue relationship**

The high-intensity of the stimulus required to induce a state of potentiation will also produce fatigue (Robbins, 2005). Kilduff et al. (2008); Hodgson et al. (2005) and Robbins

(2005) all suggest the fatigue of the muscle will dissipate sooner than the beneficial contractile elements of PAP. Therefore, recovery time and volume modulation must be considered when prescribing appropriate PAP. The time-course recommendations in literature range from 4 minutes (Nibali, Chapman, Robergs, & Drinkwater, 2015) up to 20 minutes (Jo, Judelson, Brown, Coburn, & Dabbs, 2010). In an effort to explain this variation, Seitz and Haff (2016) and Wilson et al. (2013) suggested that training status and overall muscular strength may be indicative of optimal recovery times, with weaker individuals benefitting from longer recovery periods (>10 minutes) and stronger individuals benefitting from shorter recovery periods (<10 minutes). Kilduff et al. (2008) found a time-course for recovery of 8 minutes to be of most consistent success for 70% of their population ( $n=20$  professional rugby players). Nibali et al. (2015) reported eccentric actions following PAP benefit after a longer rest period than concentric actions following PAP, with 8 minutes and 4 minutes, respectively.

#### **1.4 Establishing intensity**

Training intensities required to elicit PAP generally range from maximal to high-intensity submaximal repetitions completed within the traditional strength-based repetition parameters (1-5 repetitions) (Chiu et al., 2003; Dello Iacono & Seitz, 2018; Hamada et al., 2000; Nibali et al., 2015; Seitz & Haff, 2016; Tillin & Bishop, 2009; Wilson et al., 2013). Young et al. (1998) found significant improvement in loaded counter-movement jumps following a single set of 5-repetition maximum (RM) back squat with counter-movement jumps being repeated at a time-course of 4 minutes. However, Hrysomallis and Kidgell (2001) found no significant improvement in an explosive press-up exercise when utilising a single set of 5-RM bench press as a means to potentiate the muscle with a time-course of 3-minutes. The discrepancy in the results of these two studies may be due to methodological differences and it is acknowledged that the upper-body may require distinct potentiation loading and volume strategies. Chiu et al. (2003) examined two groups, one athletically trained ( $n=7$ ) and one recreationally trained

( $n=17$ ) found significant improvement in concentric only vertical jumps following a dose of PAP but only in the athletically trained study group. Güllich and Schmidtbleicher (1996) found significant improvements in upper and lower body tested exercises acutely following maximal voluntary contractions of 90-100% 1-RM in the active muscle. The population tested were active athletes ( $n=34$ ), competing at a high level in their respective sports with a mean resistance training age of 5 years which supports the research of Chiu et al. (2003) suggesting training age may mediate the potentiation response. Khamoui et al. (2009) conducted a PAP study with exclusively recreationally trained individuals ( $n=16$ ) wherein subjects completed maximal vertical jumps, rested for five minutes, completed one set of back squats of 85% their 1-RM to a randomised series of repetitions between two and five, rested for five minutes and repeated the maximal vertical jumps. Their findings reported a detrimental effect on ground reaction force and non-significant changes in vertical jump height. However, their methods in determining 1-RM did not appear to be substantiated by the literature with increments appearing to be arbitrarily selected until failure occurred. Therefore, establishing the 1-RM which would determine the loads of the PAP dose may have been flawed.

### **1.5 Dose-volume relationship**

Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, and Garas (2003) investigated multiple sets of two repetitions as a potentiating method for the countermovement jump (CMJ), using loads of 20, 40, 60, 80, and 90% of the participants 1-RM half-squat. They reported significant improvement with a mean increase of 2.39% in the jump height achieved after the warm-up compared to the jump height achieved prior. However, the study design means it is unclear which of the half-squat intensities had the greatest effect on this improvement.

While there is still uncertainty around the specific mechanisms underpinning PAP, optimal recovery times, and loading strategies, PAP can be beneficial in improving expressions of force and power, particularly in stronger, well-trained individuals. Current literature consistently

states maximal or near-maximal high-intensity exertions are most conducive to eliciting PAP (Hodgson et al., 2005). Training experience appears to be indicative to the likelihood of acute benefit from PAP. Seitz and Haff (2016) report a positive correlation between absolute strength and the efficacy of PAP, however, this claim is challenged by Hodgson et al. (2005) as the studies showing this improved efficacy have been retrospective rather than longitudinal studies. Such longitudinal studies could investigate the relationship between overall strength and PAP as the individual develops. There is also inconsistency in the literature as to what constitutes training experience, thus confounding results (Chiu et al., 2003; Seitz & Haff, 2016) and further evidencing more research is required to quantify PAP variables such as intensity, volume, and recovery time.

## **Eccentric exercise**

### **2.1 Physiological characteristics**

When a muscle contraction occurs, a neural impulse releases calcium into the muscle's sarcoplasm, attaching to the troponin in the muscle fibre which allows myosin heads to bind to the actin and form a cross-bridge. The cyclic binding and release of the myosin head causes the actin and myosin myofilaments to slide over each other to exert force and thus produce a muscle contraction (Herzog, Powers, Johnston, & Duvall, 2015). This series of structural deformations initiated by calcium to elicit muscular contraction is known as the sliding-filament theory (Huxley & Niedergerke, 1954). Whilst sliding-filament theory explains a muscular concentric contraction and isometric contraction, it does not sufficiently outline the properties of an eccentric muscle contraction. Sliding-filament theory fails to explain properties unique to eccentric contractions such as the residual force development occurring during an active stretch, the reduced energy expenditure during eccentric contractions, and greater force expression when compared to concentric or isometric contractions (Herzog, 2014). It is postulated that during an eccentric contraction there is a change to the passive structures underpinning the sliding-filament theory, namely a change in stiffness in the protein titin upon

binding with calcium (Herzog, 2014; Horowitz & Podolsky, 1987). This theory is supported by *in vivo* studies examining muscle contractions wherein titin was eliminated from one group of rabbit psoas muscles. The titin deficient muscle had a near zero change in active lengthening and shortening; supporting the claim that titin has a primary function in the greater force production in active muscle lengthening (Granzier & Labeit, 2002; Horowitz, Kempner, Bisher, & Podolsky, 1986; Leonard & Herzog, 2010; Wisdom, Delp, & Kuhl, 2015).

Furthermore, chronic implementation of eccentric-specific resistance training can lead to an increase in sarcomere length within the trained muscle (Toigo & Boutellier, 2006). The improvement in sarcomere length occurs via an active stretching of extramyofibrillar elements, particularly collagen. Extending the sarcomere allows for an increased site availability for actin and myosin to bind as well as increasing the elasticity of myofibrils through longer titin proteins (Toigo & Boutellier, 2006). Increased sarcomere length can result in improved hypertrophy in the active muscle as it provides access to greater ranges of motion during resistance training (McMahon, Morse, Burden, Winwood, & Onambélé, 2014; Tesch & Larsson, 1982).

Eccentric actions also induce an upregulation of satellite cell activation (Dreyer, Blanco, Sattler, Schroeder, & Wiswell, 2006). Satellite cells provide a source of new fibres by acting as pluripotent precursor cells (Dreyer et al., 2006) which become the precursor to muscular repair and subsequent growth (Schoenfeld, 2010). This hypertrophic process is achieved through satellite cell division within the muscle, producing new myonuclei, and enhancing protein synthesis efficiency (Dreyer et al., 2006; Tatsumi, Sheehan, Iwasaki, Hattori, & Allen, 2001). The satellite cell proliferation post exercise has been demonstrated to occur in a single bout of eccentric-only resistance training whereas similar findings were not found after a work-matched single bout of concentric-only resistance training (Hyldahl, Olson, Welling, Groscost, & Parcell, 2014).

It has been reported that chronic ERT increases the composition of type I, IIA and IIX muscle fibres (Friedmann-Bette et al., 2010; Vikne et al., 2006). Type IIA and IIX fibres are distinct to type I with improved rates of force production and shorter time to fatigue (Vogt & Hoppeler, 2014). Therefore, increasing type IIA and IIX fibres enables the individual to increase force and power output which is likely advantageous to athletic populations (Harries, Lubans, & Callister, 2012). It is noteworthy that, during an eccentric contraction, type IIX fibres are preferentially recruited (Enoka, 1996). Type IIX fibres have a greater cross-sectional area when compared to type I and IIA fibre which has been proposed to explain the increased type IIX fibre activation and subsequent increased hypertrophy (Roig et al., 2009).

Contrarily, in research conducted by Shepstone, Tang, Dallaire, and Schuenke (2005), test participants experienced a shift from type IIX towards type IIA muscle fibre composition after an 8-week isokinetic eccentric training program with velocities for the training groups set to 0.35 rad/s and 3.66 rad/s. Shepstone et al. (2005) hypothesized that type IIX may be the default motor protein within muscle. Therefore, when untrained individuals begin a resistance training intervention they experience a shift towards type IIA muscle fibre as type IIA fibres are more resistant to fatigue (Shepstone et al., 2005). Despite this shift away from the most rapid contractile fibre type, Shepstone et al. (2005) concluded the “increase in fibre cross-sectional area (CSA) of both the IIA and IIX fibres more than compensates for any small shift away from IIX to IIA” thus suggesting the improved aggregation of both type IIA and IIX from isokinetic eccentric training means isokinetic ERT is still beneficial when the training purpose is to improve the rate and total expression of force production.

In sum, these morphological adaptations associated with ERT are thought to facilitate an improvement in contraction velocity (Douglas et al., 2017a). Specifically an increase in sarcomere length, muscle stiffness, potentially preferential type II muscle fibre recruitment

(Nardone, Romanò, & Schieppati, 1989), as well as enhanced stretch-shortening cycle utilisation may lead to improvements in athletic performance.

## **2.2 Neuromuscular characteristics of an eccentric contraction**

Eccentric muscular actions require unique neural pathways (Enoka, 1996). During a muscular movement, the greatest force output elicited by the active muscle is during the eccentric portion of a movement and can be up to 140% that of the concentric or isometric action of the muscle (Douglas et al., 2017b; Enoka, 1996). The superior force output may be explained by a neural gradation of the required muscle activity, that is, the signal impulse is modulated by recruiting the lowest amount of motor units (and thus force) required to complete the movement. Eccentric firing patterns appear to be distinct to those of concentric or isometric contractions. Research from Laidlaw, Bilodeau, and Enoka (1996) suggests older adults have greater difficulty than young adults in grading the force necessary to raise and lower submaximal loads through the hand muscles. This research of Laidlaw et al. (1996) indicates the efficacy of transitioning from eccentric to concentric movements can degrade. Importantly, Malisoux, Francaux, Nielens, and Theisen (2006) posit that the transition from eccentric to concentric can also be improved through a stretch-shortening specific program. Furthermore, Vogt and Hoppeler (2014) and Guilhem, Cornu, and Guével (2010) suggest the neural ability to recruit maximal quantities of motor units for an eccentric voluntary contraction may be influenced by training history, age and sex. Vogt and Hoppeler (2014) report the training experience of their subjects may have enabled a greater neuromuscular efficiency in maximal eccentric voluntary contractions as their studied population were elite alpine skiers, a sport with high levels of eccentric muscle actions due to the sport's repeated slalom action. Reports vary as to the difference in muscle unit recruitment during a maximal voluntary eccentric contraction, with inhibition rates ranging from 5% to 30% (Babault, Pousson, & Ballay, 2001; Douglas et al., 2017b; Guilhem et al., 2010; Westing, Cresswell, & Thorstensson, 1991).

The difficulty in activating full maximal voluntary eccentric action for those not regularly exposed to high intensity eccentric muscle actions suggests the muscles ability to move load is typically mediated by the individual's concentric capacity as opposed to eccentric capacity (Douglas et al., 2017b). Tous-Fajardo, Maldonado, Quintana, Pozzo, and Tesch (2006) speculate that individuals inexperienced in eccentric resistance methods may involuntarily avoid producing the high forces required to induce PAP possibly due to self-protective physiological mechanisms. Furthermore, Fang, Siemionow, Sahgal, Xiong, and Yue (2004) found maximal eccentric muscle actions require significantly longer early phase preparation time, and a greater cortical excitability for later movement execution. Thus, the ability to elicit a maximal eccentric contraction requires a greater and more nuanced neural activation pathway to that of a concentric muscle action. This may be due to the inhibition of type 1A afferents via the H-reflex when activated in dynamic eccentric contractions. The activation of the H-reflex modulates the number of activated motor neurons and has been demonstrated to act at a lower amplitude during sub maximal eccentric contractions compared to concentric contractions. The decreased amplitude thus inhibits type 1A afferent signalling potentially explains the lower metabolic cost but higher muscle damage of eccentric contractions as less motor units are recruited to execute the same rate of work as that of a concentric contraction (Duclay & Martin, 2005; Guilhem et al., 2010). While ERT may physiologically and morphologically have greater potential growth rates than traditional resistance training, the above findings suggest it may be more difficult for inexperienced trainees to execute eccentric actions as accurately and reliably as traditional methods.

Upon an initial dose of ECC, the body typically experiences significantly greater levels of delayed onset muscle soreness (DOMS) relative to traditional resistance training methods. DOMS is characterized as a disruption of the intracellular muscle structure; prolonged impairment of muscle function; acute inflammation; and hyperalgesia (Douglas et al., 2017b;

Kamandulis, Skurvydas, Brazaitis, Škikas, & Duchateau, 2010). DOMS usually does not require specified medical or clinical treatments as the sense of discomfort within the fatigued muscles will dissipate between 24-72 hours post-exercise (Byrne, Twist, & Eston, 2004; Mizumura & Taguchi, 2016). During the period wherein DOMS are present in the fatigued muscle, maximal expressions of strength and power are often suppressed (Byrne et al., 2004; Saxton et al., 1995). Doguet et al. (2019) suggest the increased fascicle lengths apparent during an eccentric contraction along with a greater motor unit recruitment rate may lead to the inflammation within the muscle indicative of fatigue and DOMS; however, recent findings have argued DOMS can occur in the absence of muscular damage or the subsequent inflammation (Hayashi, Abe, Yamanaka, Mizumura, & Taguchi, 2015). Therefore, Mizumura and Taguchi (2016) and Sonkodi, Berkes, and Koltai (2020) postulate the peptide bradykinin is upregulated post-exercise leading to a release of nerve growth factor which subsequently sensitizes afferent nervous pathways, inhibiting full muscle expressions of force. Further research is required to clearly understand the specific mechanisms underpinning DOMS; however, it appears conclusive that the sensation of DOMS is typically greater in magnitude after ECC (Chen, Chen, Lin, Yu, & Nosaka, 2016; Cleary, Kimura, Sitler, & Kendrick, 2002; Douglas et al., 2017b).

After multiple doses of ECC, many studies have shown a neural adaptation which mitigates the magnitude of DOMS, particularly pain indices (Kamandulis et al., 2010). The reasons behind this phenomenon, known as the repeated bout effect are currently not clear; however, there does appear to be protective processes which occur once the body is exposed to ECC regularly (Douglas et al., 2017b). These mechanisms include an apparent increased aptitude in dispersing load stress throughout a greater number of muscle fibres to limit the intracellular damage per muscle fibre (McHugh, 2003). Furthermore, there may be an increase

to the sarcomeres recruited in repeated ECC exertions, thus reducing individual sarcomere disruption (Newton, Morgan, Sacco, Chapman, & Nosaka, 2008).

Currently, findings are equivocal regarding the specific neuromuscular nuances of ECC, but it is apparent the patterns denoting eccentric muscle actions are distinct to those of concentric and isometric movement patterns, evidenced by unique motor unit gradation patterns; the inter-individual ability to recruit maximal motor units during eccentric contractions; and the greater magnitude of DOMS elicited from ECC. It would also appear that eccentric training methods may be technically and neuromuscularly more difficult than traditional training and that novice trainees may struggle to appropriately elicit maximal eccentric muscle contractions without appropriate familiarity with the movement (Vogt & Hoppeler, 2014).

### **2.3 Eccentric resistance training as a means of post-activation potentiation**

Presently, most studies have investigated the chronic effects of eccentric resistance training (Beato, Stiff, et al., 2019). The findings of acute effects of ECC through potentiating methods have been equivocal. Tous-Fajardo, Gonzalo-Skok, Arjol-Serrano, and Tesch (2016) found significant acute benefits for change of direction times in their eccentric overload training group ( $n= 12$ ) compared to a conventional training group ( $n= 12$ ). The study did not find an improvement in 30-m sprint times in either group, and suggest the eccentric overload training group did not attain sufficient stimulus, thus indicating intensity and specificity are vital components of any ECC as a potentiating tool.

Beato, Stiff, et al. (2019) investigated the effects of a bout of eccentrically overloaded exercise on the counter-movement jump (CMJ). They recruited 18 physically active men between the ages of 18-24 to execute a series of CMJs prior to and following a bout of either inertial eccentric half-squats, loaded via a flywheel, or a control group which completed a traditional warm-up. To gauge the time-course of potentiation, the CMJs following the

potentiation stimulus were performed across 15-seconds, and then 1, 3, 5, 7, and 9 minutes. Beato, Stiff, et al. (2019) found trivial to small benefits in the counter-movement jump from the 1 minute mark onwards with a peak mean difference at the 5 minute mark for jump force and at the 7 minute mark for impulse. There were also significant differences found in CMJ height, power, impulse, and force between intervention and control groups. Further research on the eccentric volume required to induce potentiation by de Keijzer, McErlain-Naylor, Dello Iacono, and Beato (2020), found no differences between training groups of 1, 2, or 3 sets of 6 repetitions. de Keijzer et al. (2020) did, however, suggest a greater magnitude in difference to occur at 6 minutes compared to 3 minutes, indicating fatigue appears to dissipate at approximately the 5 minute mark.

Bridgeman, McGuigan, Gill, and Dulson (2017) investigated the use of loaded and unloaded drop jumps and the subsequent acute effects on CMJs in resistance trained males (n=12). They reported a loaded drop jump of 20% subject's body mass resulted in the greatest potentiation effect for CMJ jump height, ground reaction forces, and peak power, relative to unloaded drop jumps, and jumps of 10, and 30% subject's body mass. The research addressed above suggests there is a potentiating effect achieved for ECC protocols; however, it is equivocal as to appropriate loads, rest times, and means by which to achieve eccentrically overloading stimulus. Furthermore, the ECC protocols incorporated in the above studies are isoinertial. To the best of this author's knowledge there is no literature investigating isokinetic eccentric exercise as a means of potentiation.

## **Conclusion**

Post-activation potentiation has been demonstrated to have beneficial outcomes when measuring indices of strength, power, and speed (Chiu et al., 2003; Hodgson et al., 2005; Robbins, 2005). Factors including overall strength, resistance training experience, volume and recovery times are important considerations; however, there is not a clear consensus on the

appropriate specific values. Tous-Fajardo et al. (2006) indicate there to be large variability in the effort exerted by the trainee in isoinertial eccentric training. This would suggest that quantifying external variables such as velocity and torque of which the trainee is exposed could further elucidate the equivocality of current ECC literature. There is a growing body of evidence that ECC is a viable method for inducing desirable physiological, neuromuscular and morphological adaptations in athletic populations, but equally, efficacious means of inducing these adaptations via volume, intensity, and recovery has not presently been quantified. Currently there is a paucity of research investigating the acute effects of ECC and there does not appear to be any research regarding isokinetic ECC as a means to facilitate PAP.

## **Research Questions**

The purpose of this research was primarily to investigate what, if any, effects isokinetic eccentric exercise had on lower body expressions of force and power. These expressions were examined via the drop jump, counter-movement jump, and the six-second peak power test. Two velocities were examined against a control group to provide insight to distinct properties of exposure to relatively slow (35 RPM) and fast (70 RPM) eccentric speeds. Secondly, a reliability study was conducted on pre-test measures to examine whether these measures were appropriate for our investigation and to inform the magnitude with which to base inferences upon.

## **Chapter Two: Inter-day reliability of force, speed, and power measures**

## **Abstract**

**Background:** Force, speed, and power are vital athletic characteristics in competitive sport. Accurately measuring these capabilities provides insight on how an individual has progressed over time. Our aim was to measure the reliability of the drop-jump, loaded-counter-movement jump, and the six-second peak power cycling test in resistance trained males.

**Methods:** 19 resistance trained males completed three sessions wherein they performed a series of 30 cm drop jumps, loaded counter-movement jumps, and a six-second peak power cycling test with a period of at least 72 hours between sessions. Measures of reactive strength index (RSI), ground contact time (s), flight time (s), jump height (cm), relative power (W/kg), absolute power (W), force (N), velocity (m/s), cadence (RPM), cadence at peak power (RPM), and time to peak power (s) were recorded with the use of OptoJump™ (Microgate, Bolzano, Italy), Gymaware™ LPT optical encoder (Kinetic Performance Technology, Canberra, Australia), and an air-braked cycle ergometer (Wattbike Ltd., Nottingham, UK). Reliability was assessed using intra-class correlation coefficients (ICC), typical error (TE), and coefficient of variation (CV) statistics.

**Results:** Flight time (TE= 0.02 s, ICC= 0.84, CV= 3%), relative power (TE= 2.95 W/kg, ICC= 0.89, CV= 3.39 %), and jump height (TE= 2.33 s, ICC= 0.85, CV= 6.92%) were found to be reliable in the drop jump, with peak force (TE= 256.49 N, ICC= 0.79, CV= 9.19%) reliable in the 45 kg loaded counter-movement jump. Reliability of RSI from the drop jump was found to be high (ICC= 0.89) but absolute measures were insufficient for statistical reliability (CV= 10.70%).

**Conclusion:** 14 of the 20 measures were deemed to have acceptable inter-day reliability. Drop jump measures and loaded CMJ metrics tended to be the most reliable, while time to peak power in the six-second peak power cycling test was highly unreliable. These data give

practitioners valuable information regarding the typical errors expected in these performance measures to enable confident inferences from monitoring and assessment.

## **Introduction**

High expressions of force, speed, and power are crucial determinants for sport performance (Banyard, Nosaka, Sato, & Haff, 2017; Harries et al., 2012; McGuigan et al., 2012). The improvement of these athletic characteristics- measured through indices such as force, reactive strength, velocity and jump height are not readily observable without specialised equipment. As technology in sport science evolves, cost-efficient, portable options are becoming commonplace and regularly used in field-testing settings across a range of sporting contexts and levels of competitiveness (Pereira & Gomes, 2003). Therefore, it is equally as important that the methods used to measure these characteristics are reliable in their measures (Glatthorn et al., 2011).

The ability to produce bilateral force both reactively and under load, as well as the ability to cyclical produce unilateral force are actions which occur frequently in most competitive sports (Blazevich, 2012; Cronin, McNair, & Marshall, 2002; Pazin et al., 2013; Pereira & Gomes, 2003). These biomechanical actions are typically measured in a sporting context via drop jumps (Struzik, Juras, Pietraszewski, & Rokita, 2016), counter-movement jumps (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; O'Donnell, Tavares, McMaster, Chambers, & Driller, 2018; Wadhi, Rauch, Tamulevicius, Andersen, & De Souza, 2018), and bouts of cyclical sprinting (Herbert, Sculthorpe, Baker, & Grace, 2015). The instruments used to measure these tests often include photoelectric cells, linear-position transducers (LPT) and cycling ergometers.

Given these tests measure neuromuscular capabilities, they are also appropriate diagnostic tools to identify neuromuscular fatigue (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015; Wadden, Button, Kibele, & Behm, 2012). Therefore, ensuring the reliability of these instruments allows for appropriately identifying when an individual may be at risk of injury through overtraining (Gathercole et al., 2015)

The drop jump is regularly used to measure athletic function and performance (Khuu, Musalem, & Beach, 2015). These high, fast expressions of force are characterized by rapid stretch-shortening cycles within the active muscle (Struzik et al., 2016). Previous studies have validated the use of motion sensors such as OptoJump™ (Microgate, Bolzano, Italy) for monitoring drop jumps (Glatthorn et al., 2011). Reactive strength index, relative power, contact time and jump height have all been investigated through drop jump protocols to inform an individual's athletic potential (Markovic, Mirkov, Knezevic, & Jaric, 2013; Pazin et al., 2013; Šarabon, Kozinc, & Marković, 2020).

The counter-movement jump (CMJ) is also routinely used for indications of athletic potential and lower body power (O'Donnell et al., 2018). Loaded CMJs allow the eccentric portion of the SSC to develop force, which has been suggested as a reason for greater force productions in a loaded CMJ relative to concentric only squat jumps (Bobbert et al., 1996). Loaded CMJs also allow insights to how an individual responds to external forces in plyometric movements (Jimenez-Reyes et al., 2016; Morin & Samozino, 2016) and can inform future directions of training programs. A common method of testing the CMJ is via the use of a linear position transducer (LPT) which can provide information pertinent to athletic populations such as velocity, force, and both absolute and relative power.

The six-second peak power test is a validated method for reporting an individual's capacity to produce power in a cyclical method and maximally taxes the ATP-CP energy system (Herbert et al., 2015). Cycling ergometers such as the Wattbike (Wattbike Ltd., Nottingham, UK) are used to report peak and relative power, peak torque velocity, and time taken to achieve peak power. Given many athletic populations require repeated high expressions of power at high velocities, the six-second peak power test is a sport-specific method of measuring these capacities.

Thus, we aimed to examine the reliability of these tools to provide insight into the appropriate inferential magnitude with which changes can thusly be observed in pre- and post-testing protocols for resistance trained males.

## Methods

### Participants

Nineteen resistance trained males participated in this study (Table. 1). All subjects had a resistance training age of at least two years and were recruited from a range of sporting backgrounds. Subjects were recruited via word-of-mouth and social media platforms and provided written informed consent prior to participating in the study with ethics approved by the University of Waikato Human Research Ethics Review Board [HREC(Health)2019#70] and in accordance with the declaration of Helsinki.

**Table 1.** Participant information ( $n=19$ ). Values presented as means  $\pm$  standard deviation.

Age (y)	22.16 $\pm$ 3.21
Height (cm)	1.82 $\pm$ 0.07
Mass (kg)	82.69 $\pm$ 11.98
Resistance training experience (y)	3.9 $\pm$ 2.41

**Table 2.** Warm-up

Exercise	Sets	Repetitions	Rest (s)
Squat	2	10	10
Reverse lunge and twist	2	10	10
Tuck knee jump	2	10	10
Butt kicks	2	10	10
High knees	2	10	10

Participants completed a familiarisation session one week prior to testing wherein appropriate technique for each test was demonstrated. Subjects were instructed to refrain from intense

lower-body physical exercise, caffeine, and alcohol 24-hours prior to testing. Upon completing a standardised warm-up (Table. 2) involving dynamic stretches biomechanically appropriate to the forthcoming tests, participants performed three separate sessions at least 72 hours apart wherein they executed three maximal effort drop jumps at 30 cm, three maximal effort loaded CMJs at 25 kg, three maximal effort loaded CMJs at 45 kg, and one six-second peak power test.

### **Drop jump**

Participants were instructed to stand atop a 30-cm box with hands placed on hips and step off with one foot. Upon contact with the ground, subjects were instructed to jump with maximal effort whilst attempting to minimize ground contact time. Appropriate cueing and verbal encouragement were provided throughout the testing (Healy, Kenny, & Harrison, 2016; Pedley, Lloyd, Read, Moore, & Oliver, 2017) and each jump was separated by 30 seconds recovery. Data were recorded using OptoJump™ (Microgate, Bolzano, Italy), with the drop-box within the OptoJump™ bars recording range and filtered out of the LED bars readings. Metrics collected were ground contact time (s), flight time (s), peak height (cm), peak power per kilogram (W/kg), and the Reactive Strength Index calculated as the ratio of flight time to ground contact time.

### **Counter-movement jump**

Individuals completed three familiarisation attempts with the CMJ wherein participants used the LPT attached to an unloaded trap-bar held with full elbow extension to closely replicate the testing movement and to reduce upper-body momentum. These familiarisation jumps were not recorded. Participants were instructed to drop to their normal loading depth as they would a maximal jump and pause, then jump as high as possible keeping elbows at full extension. Upon completing the CMJ familiarisation, three maximal effort repetitions of the CMJ with 25 kg and then 45 kg with a 30 second rest time between jumps were loaded via a

trap-bar. Data was recorded using Gymaware™ LPT optical encoder (Kinetic Performance Technology, Canberra, Australia) measured at 50-Hz sample period with no data smoothing or filtering. The datapoints collected were peak velocity (m/s), peak and relative power [(W) and (W/kg respectively)], and force (N).

### **Six-second peak power test**

The Wattbike was set accordingly for individuals with saddle and handlebar distance at a self-selected comfortable position. Participants position value was recorded from the pre-test to be replicated in subsequent sessions. The saddle height was set for the knee to be at near full extension (between 170 and 180°). The air brake was set to resistance 10 and the magnetic resistance was set to level 1. Subjects were instructed to prepare with their dominant leg initiating the first down-stroke. Subjects were verbally counted down from 5 and were instructed to perform a full exertion effort until verbally commanded to stop while remaining in seat for the entirety of the exertion (Herbert et al., 2015). Data collected from the Wattbike were peak and relative power [(W) and (W/kg respectively)], peak cadence (RPM), time to peak wattage (s) and cadence at which peak power occurred (RPM).

### **Statistical Analyses**

Peak values of all measurements were recorded as means with standard deviations to describe data analysed using a customisable statistical spreadsheet (Hopkins, 2017). Intraclass correlation coefficients (ICC), typical error (TE), and coefficient of variation (CV) with 90% confidence intervals [lower, upper] were calculated to quantify the relative (ICC) and absolute (TE and CV) reliability of measures. ICC reliability was quantified at: poor ( $ICC < 0.40$ ), fair ( $0.40 \geq ICC < 0.75$ ), good ( $0.75 \geq ICC < 0.90$ ), and excellent ( $ICC \geq 0.90$ ). Absolute reliability was deemed acceptable when the CV was  $< 10\%$  (Atkinson & Nevill, 1998), and suboptimal when  $\geq 10\%$ .

## **Results**

The results from this study indicate these measures to largely be reliable in their respective CV values. Reliable CV values were found in the drop jump indices of flight time (3.39%), relative power (7.54%), and jump height (6.92%). The loaded CMJ measures for jump height [25 kg (CV=9.61), and 45 kg (CV=8.63)] and velocity [25 kg (CV=8.29), [45 kg (CV=6.10)] were reliable for both loads, whereas power (CV=7.88%), relative power (CV=7.88%), and force (CV=9.19%) were all reliable in the 45 kg loaded jump only. The six second peak power test reliably reported peak power (CV= 6.55%), relative peak power (6.55%), peak cadence (CV=3.71%) and cadence at peak power (CV=3.62%) whilst time to peak power had an exceptionally large correlation of variation (162.96%).

**Table 3.** Typical error (TE), intraclass coefficient (ICC), and coefficient of variation (CV) with 95% confidence limits [lower, upper] in RSI, contact time, flight time, relative power, and jump height for 30 cm drop jump (n=19). Mean and standard deviations (mean ± SD) provided.

	Comparison					Statistics		
	Day 1	Day 2	Day 3	▲ day 2-day 1	▲ day 3-day 2	Typical error	ICC	CV (%)
<b>RSI</b>	1.55 ± 0.36	1.47 ± 0.42	1.60 ± 0.41	-0.08	0.13	0.14 [0.11, 0.19]	0.89 [0.76, 0.95]	10.70 [8.41, 14.76]
<b>CT (s)</b>	0.25 ± 0.04	0.26 ± 0.06	0.24 ± 0.05	0.01	-0.02	0.03 [0.02, 0.04]	0.74 [0.51, 0.88]	10.28 [8.08, 14.16]
<b>FT (s)</b>	0.56 ± 0.04	0.55 ± 0.04	0.56 ± 0.04	-0.01	0.01	0.02 [0.01, 0.02]	0.84 [0.67, 0.93]	3.39 [2.69, 4.62] *
<b>Relative power (W/kg)</b>	43.75 ± 7.75	41.98 ± 9.06	44.63 ± 8.86	-1.77	2.65	2.95 [2.34, 4]	0.89 [0.78, 0.96]	7.54 [5.95, 10.35] *
<b>Jump height (cm)</b>	38.24 ± 5.17	37.42 ± 6.00	38.36 ± 5.73	-0.82	0.94	2.33 [1.85, 3.16]	0.85 [0.69, 0.93]	6.92 [5.46, 9.49] *

Abbreviations: RSI- reactive strength index; CT- contact time; FT- flight time; (s)- seconds; (W/kg)- wattage per kilogram; (cm)- centimetres. \* indicates statistically reliable with CV value < 10%.

**Table 4.** Typical error (TE), intraclass coefficient (ICC), and coefficient of variation (CV) with 95% confidence limits [lower, upper] in jump height, power, relative power, force, and velocity for loaded CMJs (n=19). Mean and standard deviations (mean  $\pm$  SD) provided.

	Comparison					Statistics		
	Day 1	Day 2	Day 3	▲ day 2-day 1	▲ day 3-day 2	Typical error	ICC	CV (%)
<b>Jump height (cm)</b>								
-25 kg	0.85 $\pm$ 0.10	0.83 $\pm$ 0.10	0.85 $\pm$ 0.11	-0.02	0.02	0.07 [0.10, 0.06]	0.55 [0.25, 0.78]	9.61 [7.57, 13.24] *
-45 kg	0.77 $\pm$ 0.09	0.77 $\pm$ 0.08	0.76 $\pm$ 0.09	0	-0.01	0.06 [0.05, 0.08]	0.60 [0.31, 0.81]	8.63 [6.80, 11.87] *
<b>Power (W)</b>								
-25 kg	5747.57 $\pm$ 888.06	5480.2 $\pm$ 859.64	5923.56 $\pm$ 831.69	-267.37	443.37	622.8 [494.95, 843.51]	0.50 [0.18, 0.75]	11.22 [8.82, 15.49]
-45 kg	5325.40 $\pm$ 792.75	5198.82 $\pm$ 649.78	5429.69 $\pm$ 671.92	-126.58	230.88	404.04 [321.09, 547.22]	0.70 [0.44, 0.86]	7.88 [6.21, 10.82] *
<b>Relative power (W/kg)</b>								
-25 kg	69.95 $\pm$ 9.00	67.37 $\pm$ 13.38	72.19 $\pm$ 9.72	-2.58	4.83	7.32 [5.82, 9.91]	0.57 [0.27, 0.79]	11.22 [8.82, 15.49]
-45 kg	64.62 $\pm$ 6.20	63.54 $\pm$ 8.76	66.26 $\pm$ 8.26	-1.08	2.71	4.89 [3.89, 6.62]	0.63 [0.35, 0.83]	7.88 [6.21, 10.82] *
<b>Force (N)</b>								
-25 kg	3012.01 $\pm$ 533.28	2953.41 $\pm$ 574.53	3054.96 $\pm$ 672.77	-58.6	101.55	420.03 [333.81, 568.89]	0.53 [0.21, 0.77]	14.32 [11.22, 19.87]
-45 kg	2846.71 $\pm$ 528.80	2823.06 $\pm$ 503.87	2918.19 $\pm$ 557.80	-23.65	95.13	256.49 [203.84, 347.39]	0.79 [0.58, 0.91]	9.19 [7.23, 12.64] *
<b>Velocity (m/s)</b>								
-25 kg	2.98 $\pm$ 0.24	2.92 $\pm$ 0.37	2.99 $\pm$ 0.25	-0.06	0.07	0.23 [0.19, 0.32]	0.37 [0.04, 0.67]	8.29 [6.53, 11.39] *
-45 kg	2.62 $\pm$ 0.20	2.57 $\pm$ 0.20	2.61 $\pm$ 0.19	-0.05	0.04	0.15 [0.12, 0.20]	0.44 [0.12, 0.72]	6.10 [4.82, 8.35] *

Abbreviations: (cm)- centimetres; (W)- wattage; (W/kg)- Wattage per kilogram; (N)- newtons; (m/s)- metres per second. \* indicates statistically reliable with CV < 10%.

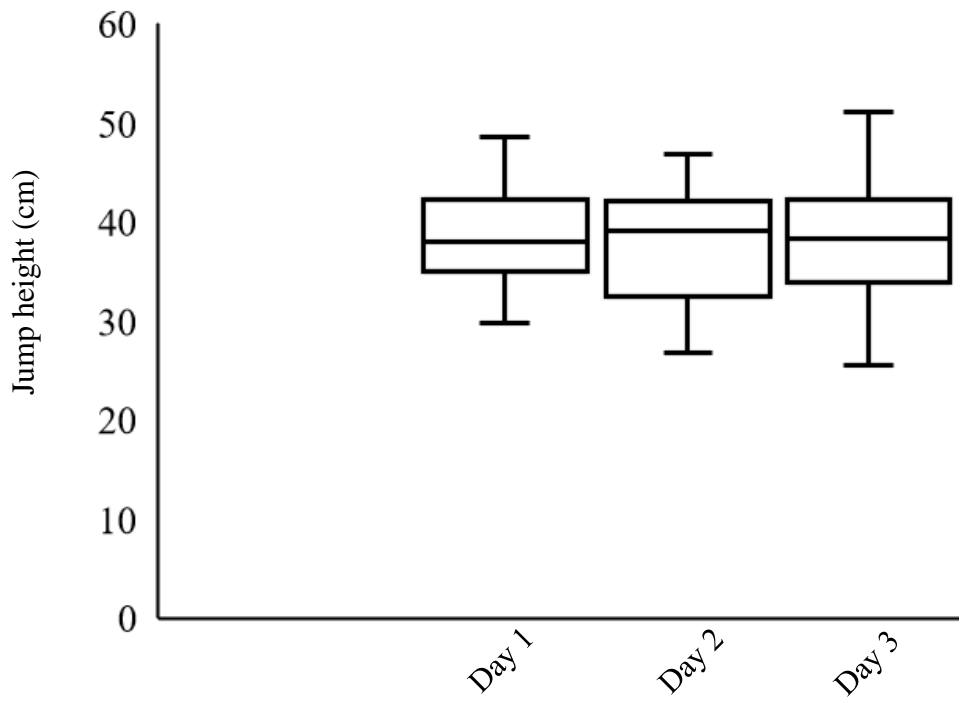
**Table 5.** Typical error (TE), intraclass coefficient (ICC), and coefficient of variation (CV) with 95% confidence limits [lower, upper] in power, relative power, cadence, cadence at peak power, and time to peak power in the six-second peak power test (n=19). Mean and standard deviations (mean ± SD) provided.

	Comparison					Statistics		
	Day 1	Day 2	Day 3	▲ day 2-day 1	▲ day 3-day 2	Typical error	ICC	CV (%)
<b>Power (W)</b>	1264.26 ± 136.64	1240.53 ± 141.15	1266.37 ± 180.22	-23.74	25.84	81.31 [64.61, 110.12]	0.74 [0.51, 0.88]	6.55 [5.17, 8.97]
<b>Relative power (W/kg)</b>	15.43 ± 1.69	15.18 ± 2.08	15.42 ± 1.92	-0.25	0.23	0.99 [0.78, 1.33]	0.75 [0.53, 0.89]	6.55 [5.17, 8.97]
<b>Cadence (RPM)</b>	132.37 ± 7.37	131.42 ± 7.07	131 ± 6.51	-0.95	-0.42	5.05 [4.02, 6.85]	0.50 [0.18, 0.75]	3.71 [2.94, 5.06] *
<b>CP (RPM)</b>	130.42 ± 5.89	129.74 ± 6.97	126.79 ± 6.65	-0.68	-2.95	4.60 [3.66, 6.23]	0.53 [0.21, 0.77]	3.62 [2.87, 4.94] *
<b>TTP (s)</b>	2.04 ± 1.20	2.00 ± 0.94	2.00 ± 1.66	-0.05	0	1.15 [0.91, 1.56]	0.23 [-0.09, 0.57]	162.96 [115.62, 270.42]

Abbreviations: CP- cadence at peak power; TTP- time to peak power; (W)- wattage; (W/kg)- wattage per kilogram; (RPM)- revolutions per minute; (s)- seconds. \* indicates statistically reliable with CV value < 10%.

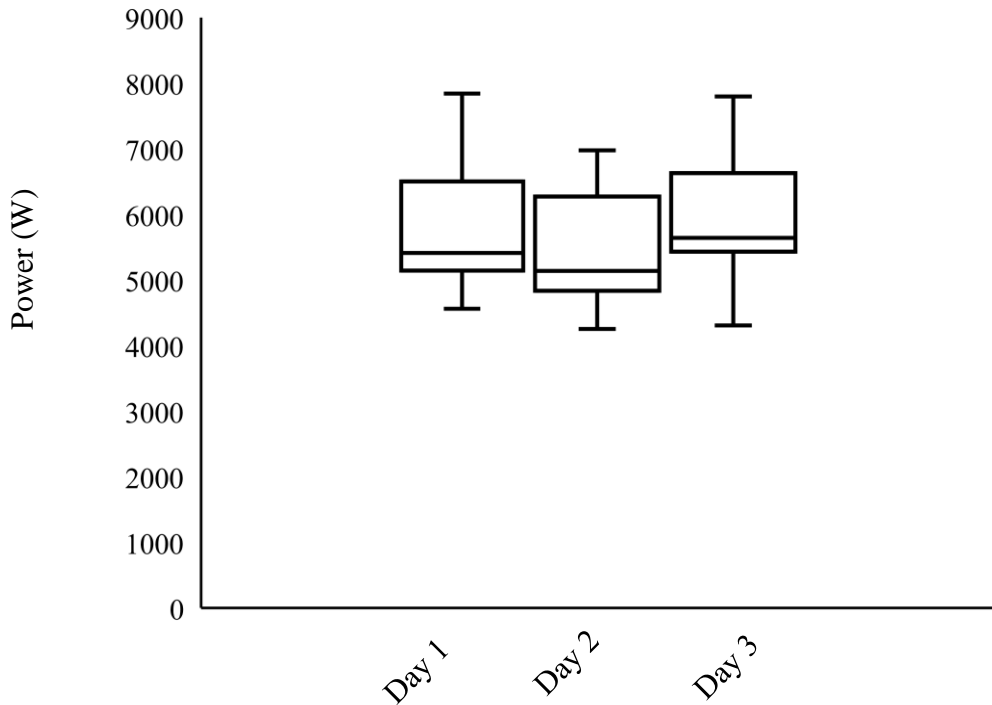
**Fig. 1.** Mean and range jump height (cm) values in the drop jump ( $n=19$ ) using photoelectronic cells (OptoJump) across days 1, 2, and 3.

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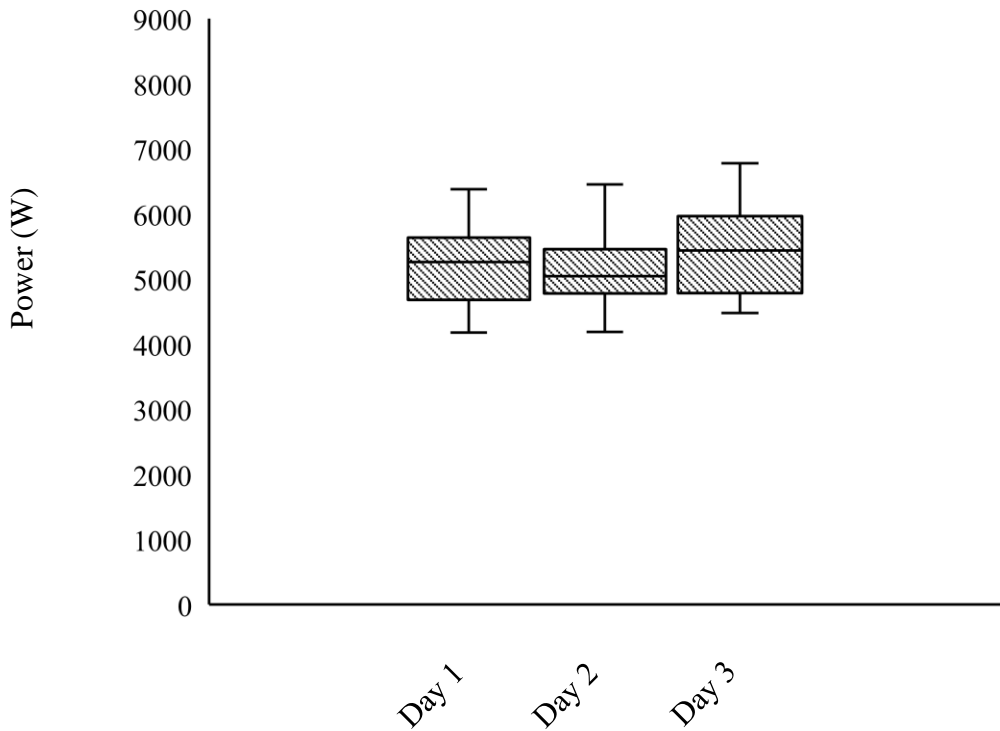
**Fig. 2.** Peak power in 25 kg loaded counter-movement jump ( $n=19$ ) using GymAware linear position transducer. Values presented as means and range.

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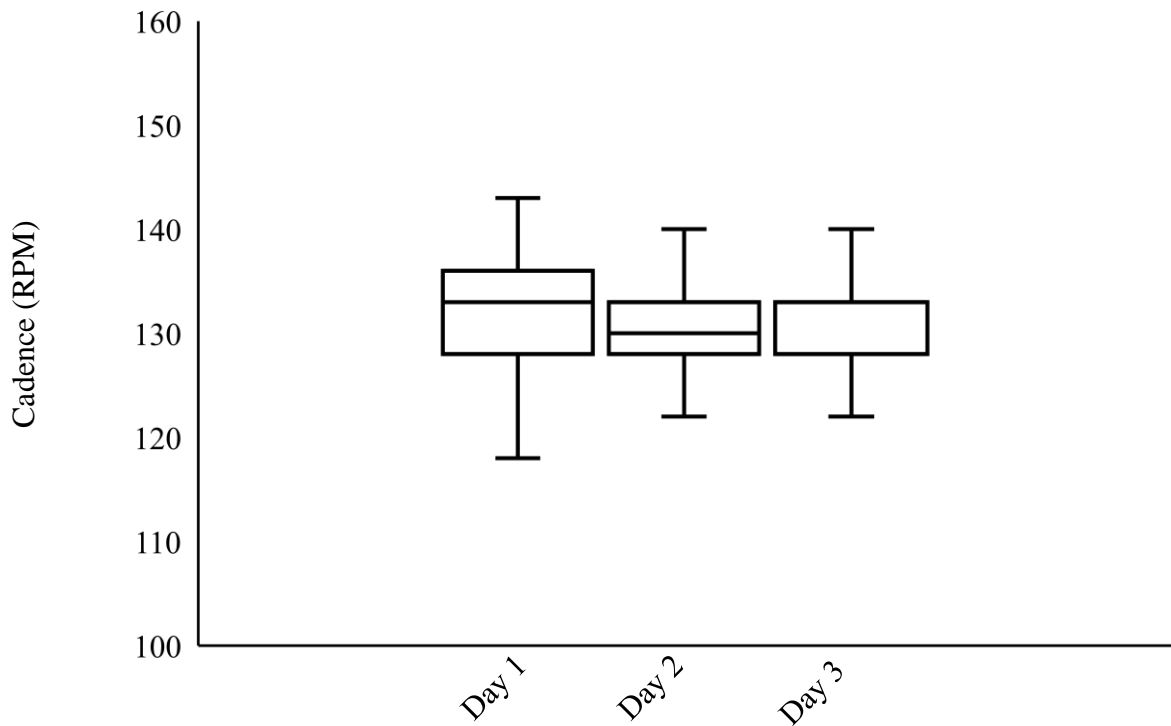


**Fig. 3.** Peak power in 45 kg loaded counter-movement jump ( $n=19$ ) using GymAware linear position transducer. Values presented as means and range.

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**Fig. 4.** Peak cadence in the six-second peak power test ( $n=19$ ) using an air-braked cycle ergometer (Wattbike). Values presented as means and range.



## Discussion

Results above indicate the drop jump (measured with OptoJump), loaded CMJ (measured with GymAware) and the six-second peak power test (measured with Wattbike) were reliable for 12 of the 20 measures within this cohort.

## Drop jump

The drop jump reliability in jump height is concordant with previous literature (Glatthorn et al., 2011). Whilst this study did not investigate OptoJump validity, previous literature has identified a systematic bias for OptoJump in underreporting jump heights, therefore to improve future research wherein OptoJump is to be implemented it may be of benefit to cross-reference results with other equipment used to measure vertical jumps such as force-plates (Glatthorn et al., 2011) or LPT devices (Dorrell, Moore, Smith, & Gee, 2019). Flight time and relative power had acceptable CV% values whereas both RSI and contact time

were minorly outside the threshold of acceptance at 10.70% and 10.28% respectively. It has previously been discussed that underestimations in flight time and overestimations in contact time may occur due to transmitter and receiver units positioned 0.003 m above floor level (Healy et al., 2016). It is also worth noting that the type of footwear was not standardised in this study. These recording variations along with a possible confounding factor such as various shoe-sole thickness or material may explain why contact time was insufficiently reliable.

Previous literature has examined the intra-day reliability of the RSI in the drop jump for male elite athletes (Beattie & Flanagan, 2015; Markwick, Bird, Tufano, Seitz, & Haff, 2015). In the research of Markwick et al. (2015), RSI values were found to be reliable in jump heights of 20-, 40-, and 50-cm however, the investigators did not examine a jump height of 30-cm therefore, it is unclear if the drop height affected the reduced reliability. Standardised instruction was consistently provided to each participant in this study as previous literature has shown drop jump scores to be influenced by the verbal cueing techniques provided to participants (Khuu et al., 2015; Struzik et al., 2016). Given previous literature has demonstrated RSI to be a reliable measure for the OptoJump (Beattie & Flanagan, 2015; Beyer et al., 2020; Healy et al., 2016; Markwick et al., 2015), our own research's insufficient reliability may be due to cohort size.

### **Loaded counter-movement jump**

Jump height was reported as reliable in the GymAware device across the three sessions, which supplements previous literature (Dorrell et al., 2019; Wadhi et al., 2018). Both studies demonstrated a systematic bias in the accuracy of the GymAware in reporting jump height. It would be beneficial to incorporate the GymAware in conjunction with other jump measuring instruments to ensure data validity. Interestingly, all jumps at 45 kg had acceptable CV values whereas only jump height and velocity were reliable in the 25 kg loaded CMJ. To the best of this author's knowledge, there is presently no literature investigating the reliability of loaded

CMJ's using LPT at different absolute loads. Further research investigating this apparent trend may be of benefit particularly for generating force-velocity profiles. Aside from peak force produced in the 45 kg loaded CMJ, the ICC values for all other measures were lower than 0.75. Variability may indicate there was a large heterogeneity in this cohort regarding the ability to produce powerful neuromuscular expressions under loaded conditions. The heterogeneity may be explained through inclusion criteria not requiring a relative strength value (such as 1 RM back squat relative to bodyweight) to be indicative of physiological development as opposed to training age being reported through a subjective report on time spent exercising.

### **Six-second peak power test**

Results from the WattBike indicate these findings were reliable in this cohort. This reliability is consistent with literature supporting the use of WattBike in a research setting (Herbert et al., 2015; Wainwright, Cooke, & O'Hara, 2017). Wainwright et al. (2017) investigated the reliability of multiple Wattbikes and found measures to still maintain reliability therefore, our own findings in time to peak power are unlikely due to any unintentional discrepancies between which Wattbike was used per day. When performing the six-second peak power test there is verbal instruction counting the participant in to the test. There is inherently a reactive component to the test as the participant may pre-emptively pedal prior to the software has started recording. This lag between subject initiation and data collection may explain the abnormally large CV value of 162% in the time to peak power being achieved. Seat heights, handle length distance to the seat, and crank position prior to testing were all standardised prior to each exertion. Furthermore, as the six-second peak power test is more anaerobically fatiguing relative to actions such as the drop jump or CMJs, only one exertion was completed, as opposed to 3 for other testing protocols. Therefore, it is reasonable to infer, if a subject performed sub-optimally without any evident errors occurring throughout their exertion (e.g. feet slipping out of the pedals), the data recorded may not have been a maximal

exertion without the knowledge of the data collector. Future research may benefit from instituting multiple repetitions of the six-second peak power test with appropriate rest intervals between each exertion to reduce the likelihood of such errors.

### **Conclusion**

The inter-day reliability of the above results is mixed, with 12 of the 20 indices measured reporting a CV% of < 10. Closer controls regarding footwear may improve reliability in the drop jump whilst a clearer quantification of training level such as strength values relative to bodyweight could reduce heterogeneity in the intraclass results for loaded CMJ exertions. Future practitioners may wish to collect the metric time to peak power using alternative instruments as this data was demonstrated to be unreliable in this cohort using Wattbike recording software. With greater access to resources, it would be of benefit to repeat multiple exertions per session in measures such as the six-second peak power test to reduce the magnitude of individual errors not readily apparent during data collection.

**Chapter Three: Effects of isokinetic eccentric exercise on post-activation potentiation in the lower-body for resistance trained men.**

## **Introduction**

It has consistently been demonstrated that vital components of an athlete's training program include the development of strength, speed, and power (Bompa & Buzzichelli, 2015; Joyce & Lewindon, 2014; McGuigan et al., 2012; Suchomel et al., 2016). As the understanding of the physiological aspects underpinning athletic performance develops, training efficiency and efficacy are increasingly becoming a premium commodity (Bompa & Buzzichelli, 2015; Durell et al., 2003). Thus, research appears to increasingly be addressing novel methods which will facilitate the highest physiological adaptation in the briefest time (Suchomel et al., 2018; Suchomel et al., 2016).

There is increasing evidence reporting eccentric resistance exercise (ECC) can elicit superior improvements in strength, power and hypertrophy when compared to traditional resistance training methods (Douglas et al., 2017a; Friedmann-Bette et al., 2010; Roig et al., 2009). An eccentric muscle contraction is characterized as the active lengthening of a muscle due to an external force being greater in magnitude than the force produced by the muscle (Douglas et al., 2017b). Beneficial sport-specific adaptations such as improving the composition of fast twitch muscle fibres relative to slow twitch muscle fibres and an increase in muscle tendon unit stiffness have been described following ERT (Suchomel et al., 2019).

Literature suggests that high intensity concentric (Anthi et al., 2014) and isometric exercises can be used effectively as a means of potentiating subsequent muscle actions. This post-activation potentiation (PAP) refers to executing a voluntary muscular movement at (or near) maximal intensity, acutely enhancing muscular force, output, and performance for subsequent biomechanically similar tasks (Hodgson et al., 2005). Acute neuromuscular and physiological responses may regulate these temporary improvements. There is currently limited information on the use of ECC as a potentiating stimulus to acutely improve muscular force and velocity. As such, further research is required to establish appropriate volumes,

intensities and recovery periods to incorporate ECC for PAP purposes within a training program (Beato, Bigby, et al., 2019; Beato et al., 2020; Beato, Stiff, et al., 2019; Suchomel et al., 2016; Suchomel et al., 2019).

Therefore, it was the aim of this study to investigate the effects ECC may have on PAP in indices measuring force, speed, and power in resistance trained males.

## **Methods**

The drop jump is regularly used to measure athletic function and performance (Khuu et al., 2015). In sport, rapid expressions of high amounts of force are vital determinants of performance (Suchomel, Sole, Bailey, Grazer, & Beckham, 2015). These high, fast expressions of force are characterized by rapid stretch-shortening cycles within the active muscle (Struzik et al., 2016). Reactive strength index, relative power, contact time and jump height have all been investigated through drop jump protocols to inform an individual's athletic potential (Markovic et al., 2013; Pazin et al., 2013; Šarabon et al., 2020).

The counter-movement jump (CMJ) is also routinely used for indications of athletic potential and lower body power (O'Donnell et al., 2018). Loaded CMJs allow the eccentric portion of the SSC to develop force, which has been suggested as a reason for greater force productions in a loaded CMJ relative to concentric only squat jumps (Bobbert et al., 1996). Loaded CMJs also allow insights to how an individual responds to external forces in plyometric movements (Jimenez-Reyes et al., 2016; Morin & Samozino, 2016) and can inform future directions of training programs. A common method of testing the CMJ is via the use of a linear position transducer (LPT) which can provide information pertinent to athletic populations such as velocity, force, absolute and relative power. The CMJ has a distinct SSC profile to that of the drop jump; however, it is still a lower limb explosive exercise, therefore it is appropriate to test to provide additional insight to the effects of isokinetic eccentric resistance training on the SSC (Cormie, McGuigan, & Newton, 2011; Struzik et al., 2016).

The six-second peak power test is a validated method for reporting an individual's capacity to produce power in a cyclical method and maximally taxes the ATP-CP energy system (Herbert et al., 2015). Cycling ergometers such as the Wattbike (Wattbike Ltd., Nottingham, UK) are used to report peak and relative power, peak torque velocity, and time taken to achieve peak power. Given many athletic populations require repeated high expressions of power at high velocities, the six-second peak power test is a sport-specific method of measuring these capacities.

### **Experimental approach to the problem**

The chronic effects of ECC on exercise have been widely examined, but there is a paucity of literature addressing ECC as a means of inducing PAP to acutely improve force-velocity profiles. Therefore, this observational case-control study was designed with subjects completing one session of each intervention: a dose of isokinetic eccentric ergometer cycling exercise with a volume of 2 sets of 15 seconds, an intensity of maximal individual resistance, a rest period of one minute between sets and a velocity of 35 RPM (SLOW); a dose of isokinetic eccentric cycling ergometer exercise with a volume of 2 sets of 15 seconds, an intensity of maximal individual resistance, a rest period of one minute between sets and a velocity of 70 RPM (FAST); and a dose of cycling on an air-braked cycle ergometer with a volume of 2 sets of 15 seconds, maximal resistance from the ergometer, and a cadence controlled by the individual at 70 RPM (CONTROL). 7 minutes of rest separated the intervention with the post testing protocol. Pre and post tests were measured in each session for expressions of force, speed, and power.

### **Participants**

Thus, 19 resistance trained males (Table. 6) participated in this study. All subjects had a resistance training age of at least two years and were recruited from a range of sporting backgrounds. Subjects were recruited via word-of-mouth and social media platforms. Subjects provided written informed consent prior to participating in the study with ethics being approved

by the University of Waikato Human Research Ethics Review Board [HREC(Health)2019#70] and in accordance with the declaration of Helsinki.

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**Table 6.** Participant information ( $n=19$ ). Values presented as means  $\pm$  standard deviation.

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Age (y)	22.16 $\pm$ 3.21
Height (cm)	1.82 $\pm$ 0.07
Mass (kg)	82.69 $\pm$ 11.98
Resistance training experience (y)	3.90 $\pm$ 2.41

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## **Procedure**

### **Familiarisation**

All subjects completed a familiarisation session one full week prior to the study taking place. Familiarisation involved exposing the subjects to one half dose of the prescribed volume on the isokinetic eccentric cycling ergometer. Intensity remained the same to ensure all athletes were comfortable and aware of the sensation the velocity elicits.

### **Testing protocol**

Subjects were instructed to refrain from intense lower-body physical exercise, caffeine, and alcohol 24-hours prior to testing. Subjects completed a standardised warm-up (Table. 7) involving dynamic stretches biomechanically appropriate to the forthcoming tests and intervention protocol. Subjects completed a series of loaded counter-movement jumps (CMJ) at 25 kilograms and 45 kilograms, a drop jump, and a 6-second peak power test using an air-braked cycle ergometer (Wattbike Ltd., Nottingham, UK). Upon completing each test, subjects were randomly assigned to either the FAST, SLOW or CONTROL eccentric ergometer intervention. Once completing the prescribed training volume in their appropriate intervention, participants had eight minutes of rest, concordant with the mean values of best recovery for eccentric actions in the research of Nibali et al. (2015) before repeating the above tests in the same order. Subjects had a recovery window of at least 72 hours between sessions and repeated the above protocol in the alternate eccentric and control training interventions.

**Table 7. Warm-up**

Exercise	Sets	Repetitions	Rest (s)
Squat	2	10	10
Reverse lunge and twist	2	10	10
Tuck knee jump	2	10	10
Butt kicks	2	10	10
High knees	2	10	10

Abbreviations: (s)= seconds.

### **Drop jump**

Participants were instructed to stand atop a 30-cm box with hands placed on hips and step off with one foot. Upon contact with the ground, subjects were instructed to jump with maximal effort whilst attempting to minimize ground contact time. Appropriate cueing and verbal encouragement were provided throughout the testing (Healy et al., 2016; Pedley et al., 2017). Data were recorded using OptoJump™ (Microgate, Bolzano, Italy), with the drop-box within the OptoJump™ bars recording range and filtered out of the LED bars readings. Metrics collected were ground contact time (s), flight time (s), peak height (cm), peak power per kilogram (W/kg), and the Reactive Strength Index calculated as the ratio of flight time to ground contact time.

### **Counter-movement jump**

Individuals completed three familiarization attempts with the CMJ wherein participants used the LPT attached to an unloaded trap-bar held with full elbow extension to closely replicate the testing movement and to reduce upper-body momentum. These familiarization jumps were not recorded. Participants were instructed to drop to their normal loading depth as they would a maximal jump and pause, then jump as high as possible keeping elbows at full extension. Upon completing the CMJ familiarization, three maximal effort repetitions of the CMJ with 25 kg and then 45 kg with a 30 second rest time between jumps were loaded via a trap-bar. Data was recorded using Gymaware™ LPT optical encoder (Kinetic Performance Technology, Canberra, Australia) measured at 50-Hz sample period with no data smoothing or

filtering. The datapoints collected were peak velocity (m/s), peak and relative power [(W) and (W/kg respectively)], and force (N).

### **6-second peak power test**

The Wattbike was set accordingly for individuals with saddle and handlebar distance at a self-selected comfortable position. Participants position value was recorded from the pre-test to be replicated in the post-test. The saddle height was set for the knee to be at near full extension (between 170 and-180°). The air brake was set to resistance 10 and the magnetic resistance was set to level 1. Subjects were instructed to prepare with their dominant leg initiating the first down-stroke. Subjects were verbally counted down from 5 and were instructed to perform a full exertion effort until verbally commanded to stop while remaining in seat for the entirety of the exertion (Herbert et al., 2015). Data collected from the Wattbike were peak and relative power [(W) and (W/kg respectively)], peak cadence (RPM), time to peak wattage (s) and cadence at which peak power occurred (RPM).

### **Isokinetic eccentric cycling ergometer**

Upon completing the pre-testing phase of the session, subjects completed two sets of 15 seconds providing maximal resistance against either 35 RPM (SLOW) or 70 RPM (FAST). Eccentric cycling was performed in a recumbent seat position with handles either side for the participant to brace with. Participants were seated at a leg length that allowed 170° extension of the knee. Participants were provided standardized encouragement throughout and completed 1 minute of rest between exertions.

### **Control**

Those not prescribed to either ECC intervention during that testing day completed 2 sets of 15 seconds at 70 RPM on an air-braked cycle ergometer (Wattbike Ltd., Nottingham, UK). The CONTROL group completed their exertions with the air-brake resistance set at 10 and magnetic resistance at level 1. Participants had 1 minute of rest between exertions.

**Fig. 4.** Overview of testing protocol. Each session subjects would complete 2 sets of 15 seconds at either 35 RPM (SLOW) or 70 RPM (FAST) on an isokinetic eccentric cycling ergometer. CONTROL group completed 2 sets of 15 seconds at 70 RPM on an air-braked cycling ergometer. All groups had one minute rest between sets.

	<b>Pre-test</b>	<b>Intervention (completed 1 per testing session)</b>		<b>Post-test</b>
<b>Warm up</b>	Drop jump Counter-movement jump Six-second peak power test	SLOW CONTROL FAST	<i>Rest 8 minutes</i>	Drop jump Counter-movement jump Six-second peak power test

## Statistical analysis

Data was analysed using ANOVA with SPSS (IBM, Version 26.0.0.0) and magnitude-based inferences (MBI) were calculated using customized spreadsheets. We made magnitude-based inferences about true (population) values of effects by expressing the uncertainty in the effects as 95% confidence limits (Sterne & Smith, 2001). For brevity, confidence limits are shown as  $\pm x$ , where  $x$  represents half the confidence interval. An effect was deemed unclear if its confidence interval overlapped the thresholds for substantiveness (that is, if the chances of the effect's being substantially positive and negative were both  $>5\%$ ); otherwise the magnitude of the effect was reported as the magnitude of its observed value (Batterham & Hopkins, 2006). Magnitudes of the standardized effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate and large, respectively, a modification of Cohen's thresholds of 0.2, 0.5, and 0.8 (Cohen, 1988); the modifications are based primarily on congruence with Cohen's thresholds for correlation coefficients. Alpha values were set at 0.05 for identification of statistical significance.

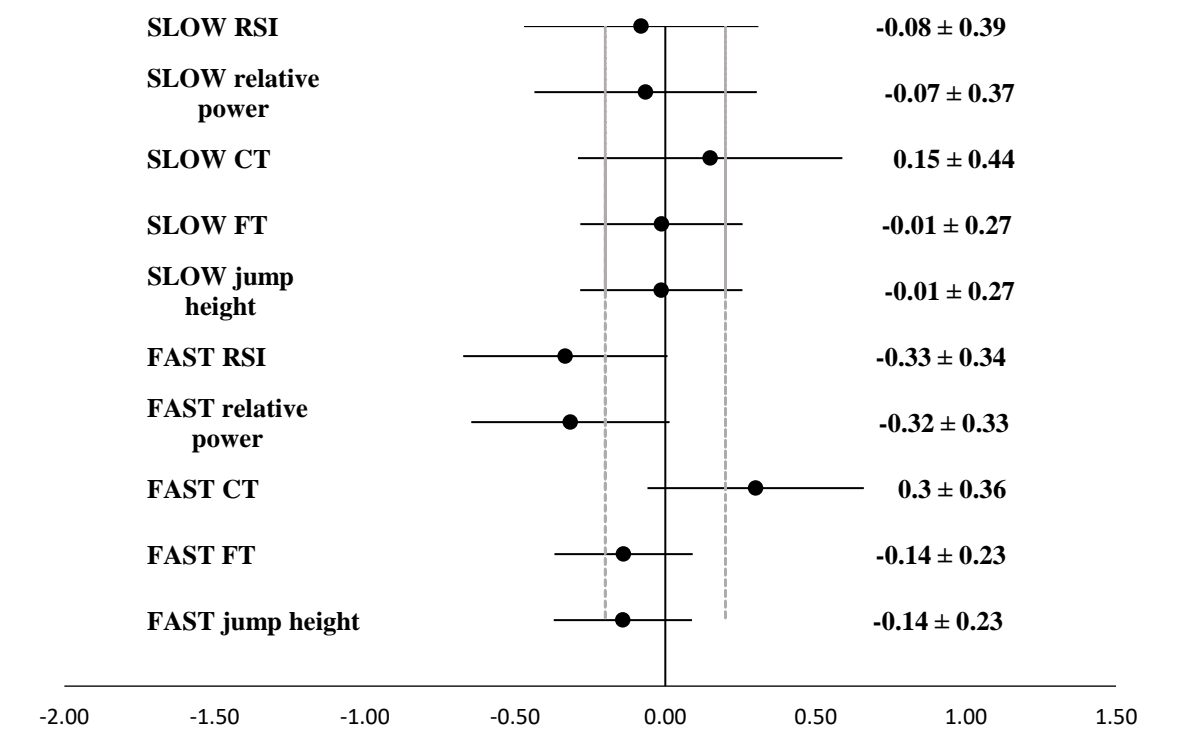
## Results

Figures below show effect sizes measured against CONTROL per intervention. A 2x3 ANOVA (time [pre and post] x condition [SLOW, FAST, CONTROL]) found significant condition differences ( $p < 0.05$ ) in peak power per kilogram in the 45 kg CMJ while the differences in all other metrics were not statistically significant (all  $p > 0.05$ ) (See Fig. 3). Individual differences in pre- and post-interventions for SLOW, FAST, and CONTROL have been plotted in figures 4, 5, and 6, with mean pre- and post-values graphed. Tables of mean values and standard deviations ( $\pm$  SD) for data analyzed in drop jump, CMJ, and the 6-second peak power test can be found in the appendix. Tables below demonstrate ES ( $\pm$  CL) findings for each measure with qualitative interpretations.

## Drop jump

No significant changes were found in either the FAST or SLOW intervention for any of the observed measures in the drop jump test. One positive effect size was found in the drop jump, a small ( $0.30 \pm 0.36$ ) effect in the contact time between the FAST intervention and CONTROL. There was a small negative effect on relative power ( $0.32 \pm 0.32$ ) for the FAST intervention relative to CONTROL.

**Fig. 5.** Drop jump reactive strength index, relative power, ground contact time, flight time, and jump height pre- and post- isokinetic eccentric intervention (n=19). Values presented as effect sizes  $\pm$  confidence limits [95%].



Abbreviations: RSI- Reactive strength index; CT- Contact time; FT- Flight time.

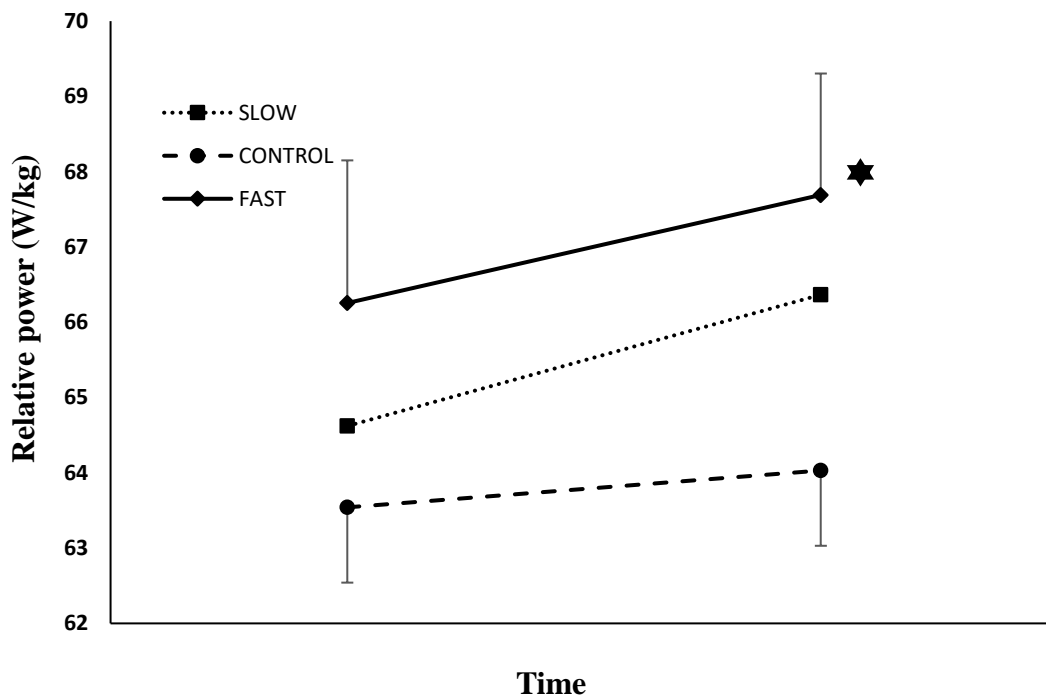
**Table 8.** Drop jump reactive strength index, relative power, contact time, flight time, and jump height effect sizes for comparison between SLOW and FAST relative to CONTROL interventions. Values presented as effect sizes  $\pm$  confidence limits [95%].

	SLOW, <i>interpretation</i>	FAST, <i>interpretation</i>
<b>RSI</b>	-0.08 $\pm$ 0.1, <i>unclear</i>	-0.33 $\pm$ 0.34, <i>unclear</i>
<b>Relative power (W/kg)</b>	-0.07 $\pm$ 0.33, <i>unclear</i>	-0.32 $\pm$ 0.33, <i>trivial</i>
<b>CT (s)</b>	0.15 $\pm$ 0.44, <i>unclear</i>	-0.30 $\pm$ 0.36, <i>small</i>
<b>FT (s)</b>	-0.01 $\pm$ 0.27, <i>unclear</i>	-0.14 $\pm$ 0.23, <i>trivial</i>
<b>Jump height (cm)</b>	-0.01 $\pm$ 0.27, <i>unclear</i>	-0.14 $\pm$ 0.23, <i>trivial</i>

Abbreviations: RSI- Reactive strength index; (W/kg)- Wattage per kilogram; CT- Contact time; FT- Flight time; (s)- Seconds; (cm)- Centimetres. MBI values are < 0.2- *trivial*; 0.2 - 0.59- *small*; 0.6 - 1.19- *moderate*; >1.2- *large*.

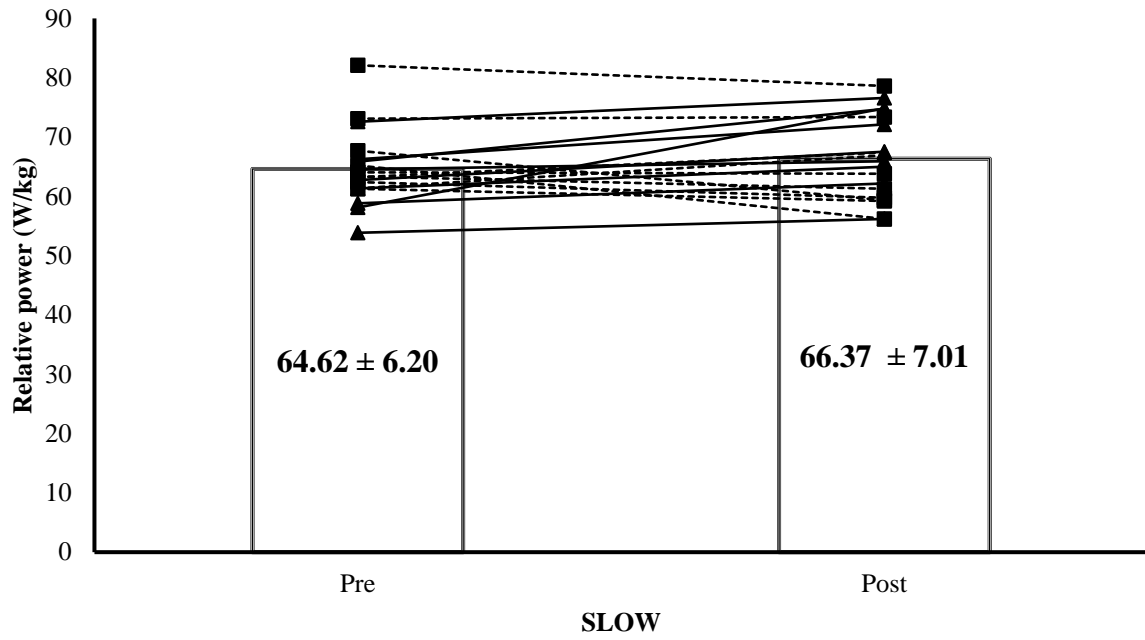
### Counter-movement jump

The ANOVA identified a statistically significant condition effect for peak power per kilogram on the CMJ at 45 kg ( $p=0.028$ ) with an unclear effect size. Peak relative power in the 25 kg CMJ ( $p=0.07$ ), and peak power in the 45 kg CMJ ( $p=0.063$ ) trended towards improvement. Both measures had unclear effect sizes. Peak power in the 25 kg CMJ had a value of  $p=0.067$  and a small negative effect ( $0.39 \pm 0.51$ ). No other statistically significant differences were observed in the CMJ.

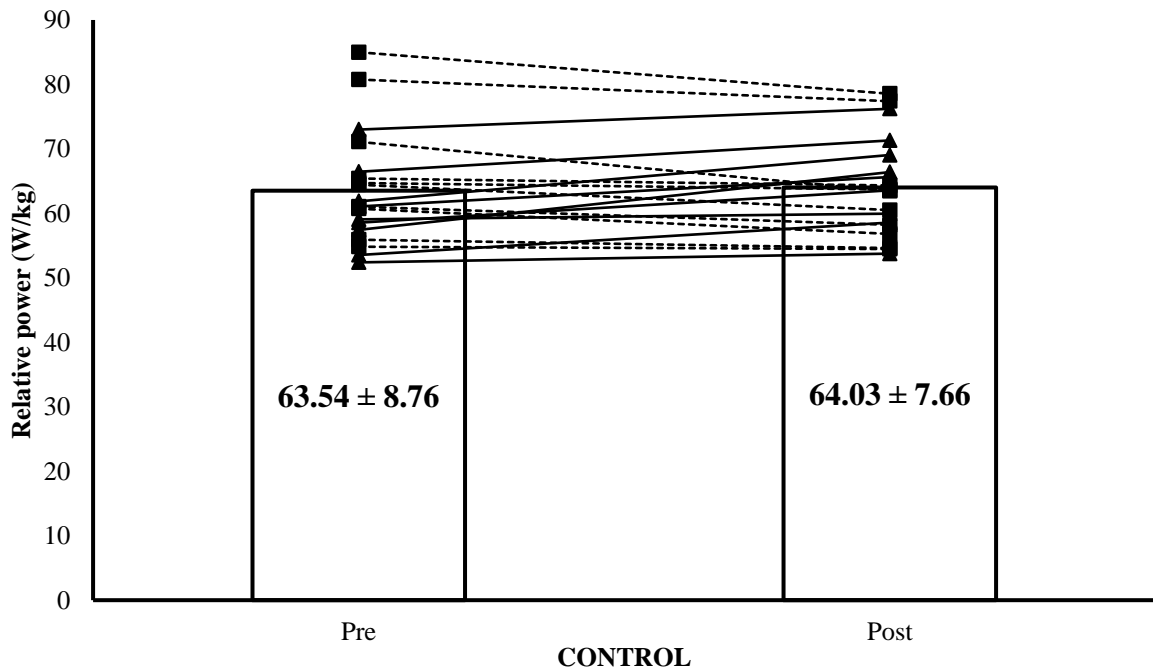


**Fig. 6.** Relative power (W/kg) expressed in loaded counter-movement jump (45 kg) pre- and post-isokinetic eccentric intervention (FAST= 70 rpm, SLOW= 35 rpm) for resistance-trained males ( $n=19$ ).

Abbreviations: (W/kg)- wattage per kilogram, ★ = significant difference between FAST and CONTROL conditions (0.02).

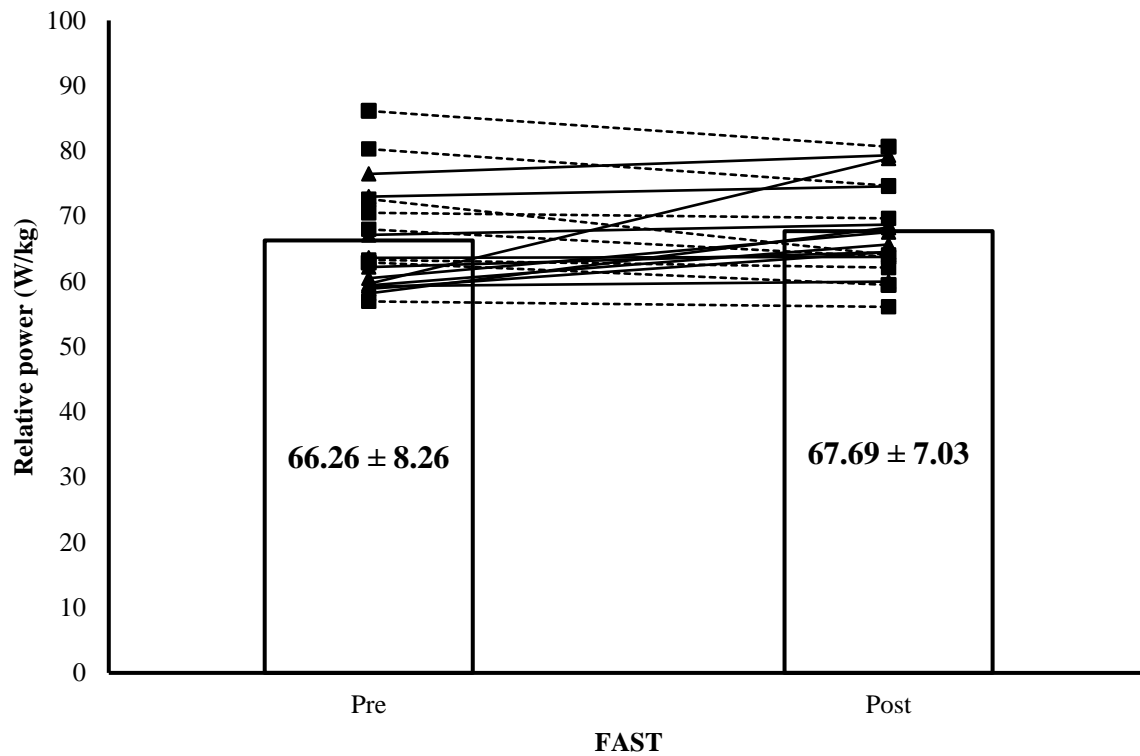


**Fig. 7.** Pre- and post-SLOW (35 RPM) intervention results for peak relative power. Individual points are plotted as a line graph ( $n=19$ ), mean values plotted as bars. Values within bars presented as means ( $\pm$  SD).



**Fig. 8.** Pre- and post-CONTROL (70 RPM) intervention results for peak relative wattage. Individual points are plotted as a line graph ( $n=19$ ), mean values plotted as bars. Values within bars presented as means ( $\pm$  SD).

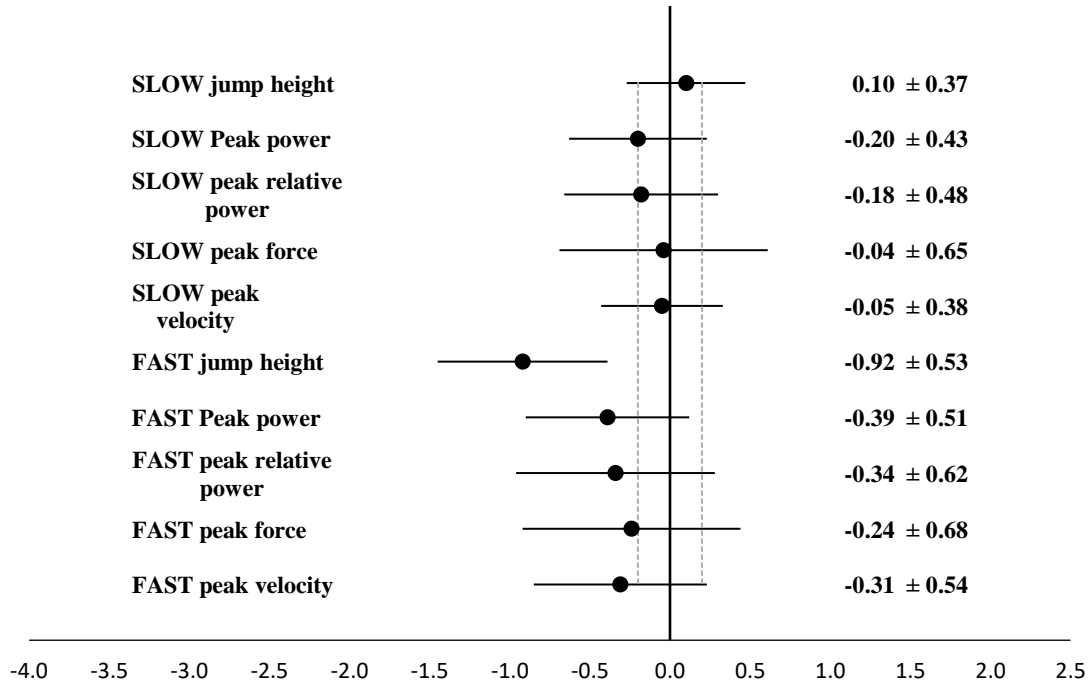
Abbreviations: (W/kg) – wattage per kilogram.



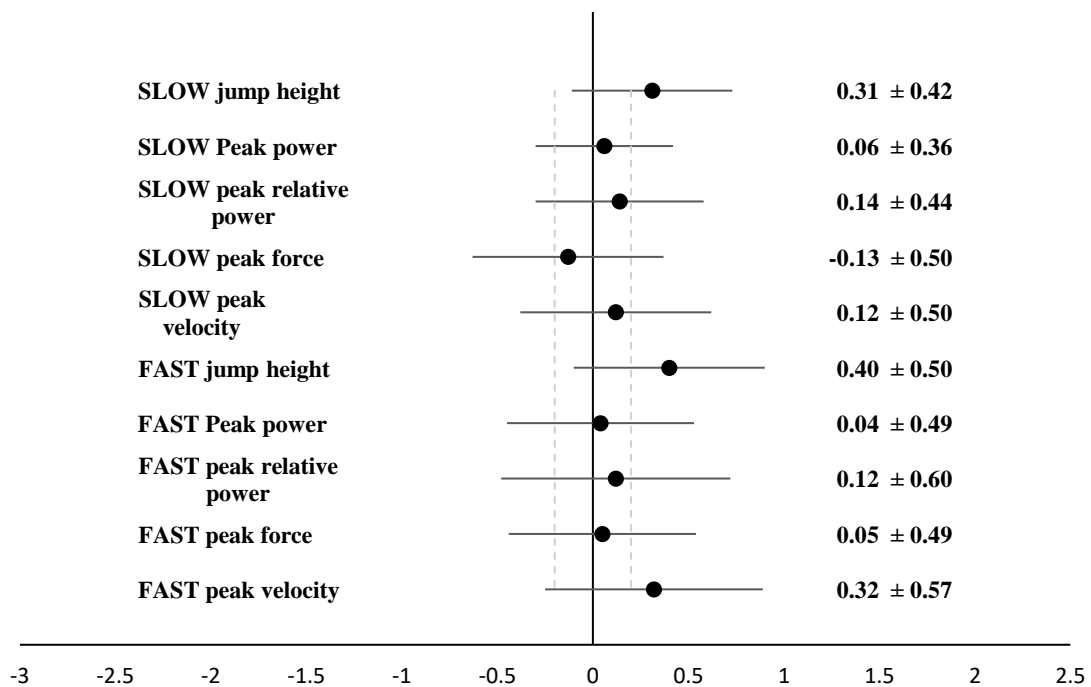
**Fig. 9.** Pre- and post-FAST (70 RPM) intervention results for peak relative power. Individual points are plotted as a line graph ( $n=19$ ), mean values plotted as bars. Values within bars presented as means ( $\pm$  SD).

Abbreviations: (W/kg) – wattage per kilogram.

**Fig. 10.** Pre- and post-eccentric intervention effect sizes of loaded (25 kg) counter-movement jump height, peak power, relative peak power, peak force, and peak velocity ( $n=19$ ) relative to CONTROL. Values presented as effect sizes  $\pm$  confidence limits [95%].



**Fig. 11.** Pre- and post-eccentric intervention effect sizes of loaded (45 kg) counter-movement jump height, peak power, relative peak power, peak force, and peak velocity ( $n=19$ ) relative to CONTROL. Values presented as effect sizes  $\pm$  confidence limits [95%].



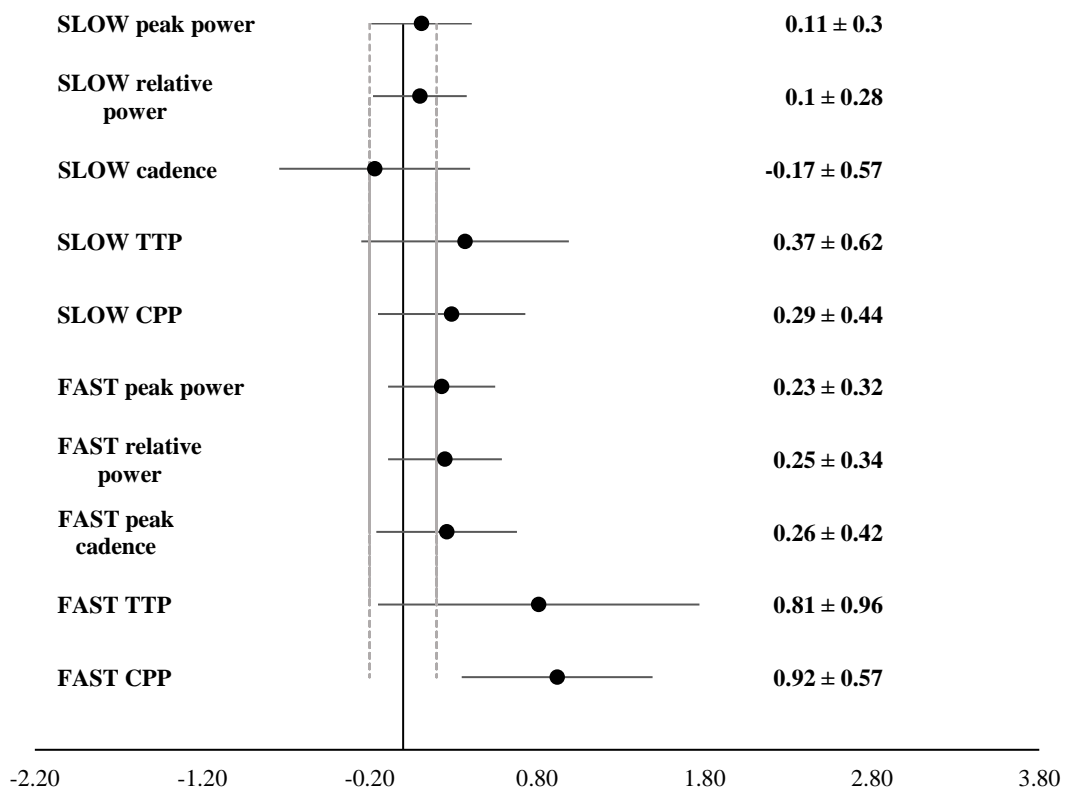
**Table 9.** Loaded counter-movement jump height, peak power, relative peak power, peak force, and peak velocity effect sizes for comparison between SLOW and FAST relative to CONTROL interventions. Values presented as effect sizes  $\pm$  confidence limits [95%].

		SLOW, <i>interpretation</i>	FAST, <i>interpretation</i>
<b>Jump height</b>	-25 kg	0.10 $\pm$ 0.37, <i>trivial</i>	-0.09 $\pm$ 0.53, <i>unclear</i>
	-45 kg	0.31 $\pm$ 0.42, <i>small</i>	0.40 $\pm$ 0.48, <i>small</i>
<b>Peak power</b>	-25 kg	-0.20 $\pm$ 0.43, <i>unclear</i>	-0.39 $\pm$ 0.51, <i>trivial</i>
	-45 kg	0.06 $\pm$ 0.36, <i>unclear</i>	0.04 $\pm$ 0.49, <i>unclear</i>
<b>Relative peak power</b>	-25 kg	-0.18 $\pm$ 0.48, <i>unclear</i>	-0.34 $\pm$ 0.62, <i>unclear</i>
	-45 kg	0.15 $\pm$ 0.44, <i>unclear</i>	0.12 $\pm$ 0.60, <i>unclear</i>
<b>Peak force</b>	-25 kg	-0.04 $\pm$ 0.65, <i>unclear</i>	-0.24 $\pm$ 0.68, <i>unclear</i>
	-45 kg	-0.13 $\pm$ 0.50, <i>unclear</i>	0.05 $\pm$ 0.49, <i>unclear</i>
<b>Peak velocity</b>	-25 kg	-0.05 $\pm$ 0.38, <i>unclear</i>	-0.31 $\pm$ 0.54, <i>unclear</i>
	-45 kg	0.12 $\pm$ 0.50, <i>unclear</i>	0.32 $\pm$ 0.57, <i>unclear</i>

### Six-second peak power test

There were no significant changes found in the six-second peak power test for any of the observed measures. Cadence at which peak power occurred in both FAST and SLOW did not achieve significance however their effect sizes were moderate ( $0.92 \pm 0.56$ ) and small ( $0.28 \pm 0.43$ ) respectively.

**Fig. 12.** 6-second peak power test peak power, relative power, peak cadence, time to peak power, and cadence at peak power pre- and post- eccentric intervention (n=19). Values are effect sizes  $\pm$  confidence limits [95%].



Abbreviations: TTP- Time to peak power, CPP- Cadence at which peak power was achieved.

**Table 5.** 6-second peak power test peak power, relative power, peak cadence, time to peak power, and cadence at peak power effect sizes for comparison between SLOW and FAST relative to CONTROL interventions. Values presented as effect sizes  $\pm$  confidence limits [95%].

	SLOW, <i>interpretation</i>	FAST, <i>interpretation</i>
<b>Peak power</b>	0.11 $\pm$ 0.30, <i>unclear</i>	0.23 $\pm$ 0.32, <i>small</i>
<b>Relative power</b>	0.10 $\pm$ 0.28, <i>trivial</i>	0.25 $\pm$ 0.34, <i>small</i>
<b>Peak cadence</b>	-0.17 $\pm$ 0.57, <i>unclear</i>	0.26 $\pm$ 0.42, <i>small</i>
<b>TTP</b>	0.39 $\pm$ 0.63, <i>unclear</i>	0.80 $\pm$ 0.97, <i>moderate</i>
<b>CPP</b>	0.29 $\pm$ 0.44, <i>small</i>	0.92 $\pm$ 0.57, <i>moderate</i>

## Discussion

This study compared the changes in lower-body expressions of power pre- and post-isokinetic eccentric resistance doses. The main finding was that isokinetic eccentric resistance training did not appear to have a substantive effect on this cohort. Statistically significant differences did exist between conditions for the 45 kg loaded CMJ in relative power with an unclear effect size. No other findings were statistically significant. These results appear to contradict recent literature suggesting eccentrically resisted exercise to be a viable method of inducing PAP in power indices (Beato, Bigby, et al., 2019; Beato et al., 2020; Beato, Stiff, et al., 2019; Bridgeman et al., 2017; de Keijzer et al., 2020; Douglas et al., 2017b).

### Isokinetic eccentric ergometer adaptation

Although individuals completed a familiarization of the isokinetic eccentric ergometer, the contradictory nature of these results suggests the training group may not have been sufficiently familiar with the stimulus and thus unable to produce sufficient resistive force to induce PAP. It is well established that eccentric actions require unique neuromuscular pathways (Enoka, 1988, 1996). Aagaard (2003) notes that the ability to produce maximal eccentric force does require a learning phase, as Duchateau and Enoka (2008) demonstrate by spinal inhibitions depressing ECC capabilities. This is supplemented by the research of Amiridis et al. (1996) wherein active males performed better than sedentary males in

performing eccentric actions. Chiu (2017) also demonstrated that athletically experienced individuals had greater improvement in results following a bout of PAP. This cohort were all highly active with a minimum of 2 years resistance training. Therefore, the lack of change between interventions in this study may have been a result of insufficient neural adaptation prior to the research taking place thus inhibiting the capacity for maximal eccentric force production. This would suggest that eccentric neuromuscular adaptation is unique enough that future research on its potentiating effects may require longer periods of familiarization irrespective of traditional resistance training experience.

The effects of PAP have been demonstrated to vary between individuals (Hodgson et al., 2005). Güllich and Schmidtbleicher (1996) and Tillin and Bishop (2009) identify there is a complex series of characteristics such as age, training age, training volume involving maximal strength training, sport, and the athlete specific force-velocity ratio are all contributing factors to an ability to elicit PAP. Whilst this cohort was controlled for training age and were all involved in competitive sport, the level at which subjects were competitive was not quantified. Absolute lower-body strength testing prior to research taking place may have been of benefit to examine the effects eccentric interventions had relative to an individual's strength profile.

### **Eccentric ergometer velocity**

Our study used isokinetic speeds of 70 RPM and 35 RPM. Previous literature demonstrates eccentric contractions performed at relatively higher speeds lead to greater increases in type IIb muscle fibre composition and improvements in muscular torque (Paddon-Jones, Leveritt, Lonergan, & Abernethy, 2001). Effect sizes against the two groups was mixed with a trivial ES for SLOW in the drop jump contact time, flight time, and jump height, and a small ES in drop jump RSI and relative power. Small and moderate ES were reported for FAST in the six-second peak power test in peak cadence and cadence at peak power respectively. All other measures were unclear. Examining a range of velocities and the relationship between the

velocity and consequent expressions of force and velocity would provide greater insight into eccentric exercise as a potentiating stimulus.

### **Fatigue-PAP relationship**

Appropriate rest times following PAP have not been clearly quantified (Hodgson et al., 2005; Kilduff et al., 2008; Nibali et al., 2015; Seitz & Haff, 2016; Tillin & Bishop, 2009). Kilduff et al. (2008) noted a rest time of 8 minutes to be appropriate for 70% of their population after a bout of potentiating stimulus, whilst Nibali et al. (2015) found a similar rest time ( $8.58 \pm 3.56$  min) to be of greatest benefit for eccentric actions. Due to resource constraints, we elected to test at only one post-testing time point and thusly collected data 8 minutes post-intervention. Whilst fatigue may have attenuated within this time, evidenced by no significant decrease in performance, this study design did not allow insight into potentiation happening for individuals prior to or after 8 minutes.

### **Drop jump and CMJ**

We tested the drop jump and CMJ as these exertions exist on different areas of the SSC spectrum. Neither measure reported significant overall change. Wirth, Keiner, Szilvas, Hartmann, and Sander (2015) speculate the lack of improvement in the squat jump and CMJ in their respective study may be due to a limited time available for body acceleration. This was corroborated by Horwath, Paulsen, Esping, Seynnes, and Olsson (2019) who demonstrate the CMJ to have a lower utilization of elastic components in the active muscle (Bobbert et al., 1996). Furthermore, the authors suggest that while doses of ECC alters the muscle potential in a more efficient way to traditional resistance training, this does not mean it directly causes an improvement in RFD- a vital determinant in expressions of power (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). The improvement ( $p= 0.02$ ) in relative power in the 45 kg loaded CMJ suggests eccentric potentiation may improve an individual's force-velocity profile when under heavier loads. Douglas, Pearson, Ross, and McGuigan (2018) noted an increase in mass-specific vertical force production after chronic eccentric resistance

training and suggest this may be indicative of an improved muscle stiffness. While relative power in the 25 kg loaded CMJ was not significant (0.07), when considered in conjunction with the improved relative power at 45 kg- it may suggest there could be improved muscle stiffness leading to mass-specific improvement. Future research would benefit from utilizing loads derived from a percentage of the subject's bodyweight as opposed to absolute loads to further elucidate if this is a consistent trend.

### **Six-second peak power test**

The six-second peak power test is a validated method of measuring an individual's capacity to produce unilateral cyclical power (Herbert et al., 2015). No significant changes occurred for any observed metrics; however, moderate effect sizes were found in the cadence at which peak power occurred, and time to peak power. The effect size of time to peak power should be interpreted with caution as pre-test reliability of this metric had an overwhelmingly large coefficient of variation (162.96%) suggesting that, in this cohort, this metric is not a reliable method of inferring change.

### **Conclusions, limitations, and future directions**

This study investigated the effects of isokinetic eccentric resistance exercise on potentiating lower body expressions of force and power. The results of this study indicate that, for this cohort, eccentric resistance exercise largely did not affect these measures. The eccentric interventions did improve relative power in the 45 kg loaded counter-movement jump. Moderate effect sizes were also found after the FAST intervention in time to peak power and cadence at peak power for the six-second peak power test.

Limitations of this study include collecting post-intervention data at one time point, thus limiting available interpretations of the appropriate time-course necessary for PAP to occur in ECC movements. Subjects may not have been adequately experienced in eccentric muscle actions to express maximal eccentric resistance during the intervention thus inhibiting

the potentiating effects of the high-intensity intervention. Future studies could benefit from determining appropriate variables for acutely altering force and velocity characteristics via isokinetic eccentric resistance exercise including training volume and rest-periods. Research investigating expressions of force and velocity across a range of time periods following eccentric interventions would elucidate how distinct the fatigue-intensity relationship is when conditioning with loads super-maximal to an individual's concentric strength. Improvement in the loaded CMJ for relative power may be indicative of an acute improvement in trainees force-velocity profile, which would be of benefit to sports coaches and practitioners, but further investigation is required. Two of the three tests in this study examined effects in the vertical plane of movement. It would be of interest to examine if the same outcome would occur in horizontal expressions of force and power. Further homogeneity of the training group could lead to more insight into eccentric resistance potentiation. Previous literature has suggested stronger individuals may derive greater benefit from eccentric stimuli. Absolute strength indices were not measured prior to our research taking place which may have allowed greater insights as to individual variability.

## **Chapter Four: Discussion and Conclusion**

**Summary:**

A review and synthesis of the existing literature regarding post-activation potentiation and eccentric resistance exercise was undertaken. Key findings of this literature review indicated that post-activation potentiation can lead to improved expressions of force, power, and speed but the magnitude of effect is highly individual. Determinant characteristics of an individual's capacity to potentiate muscle include training age, training history, and overall strength. Throughout the potentiation bout itself, factors such as volume, intensity and appropriate recovery periods are not well understood. Literature has suggested that those with resistance training experience will elicit greater benefit from potentiating exercise relative to sedentary or recreationally trained individuals. A vital aspect of potentiating exercise appears to be the need for the exercise to be at, or near, maximal intensity to best innervate the nervous system via an upregulation of motor unit activation and increased tetanic contractions which remain active in the muscle for a period thereafter.

Eccentric resistance exercise has consistently been demonstrated to induce superior physiological, neuromuscular, and morphological adaptation to that of traditional resistance training methods. An eccentric muscle action can take forces up to 40% greater than the same concentric muscle action. Therefore, eccentric exercise is a novel method of exposing the body to high-intensity muscle actions. Acute effects include an upregulation of satellite cell proliferation which can lead to improved hypertrophic development. It is suggested that unique neuromuscular activity underpins the distinct properties of an eccentric action compared to isometric or concentric actions. It also appears evident that fast-twitch muscle fibres are greater effected by eccentric resistance exercise as the neural gradation of work induces the activation of these muscle fibres to a greater extent than alternative methods of action.

Previous examinations of eccentric resistance exercise and its capacity to potentiate active muscle have predominantly investigated eccentric actions through isoinertial or plyometric methods. This review highlighted a paucity of literature investigating the acute effects of isokinetic eccentric exercise wherein contraction velocity can be greater controlled. Hence, an investigation into the acute effects of isokinetic eccentric resistance exercise was undertaken, examining the effects on force, speed, and power indices for the lower body in resistance trained males. Results indicated an improved relative power production when exposed to isokinetic eccentric resistance actions, but all other measures were unclear.

A secondary study of the reliability of the equipment used to assess the examined force, speed, and power indices was undertaken with unclear findings. Jump height, flight time, and relative power were reliable in the drop jump examined with OptoJump photoelectronic cells. The 25 kg loaded counter-movement jump, jump height, and velocity were reliable whereas the 45 kg loaded counter-movement jump reported reliable measures in jump height, power, relative power, force, and velocity. All counter-movement jumps were measured using a GymAware linear position transducer. In the six-second peak power test, peak cadence and cadence at peak power were reliably reported whereas power, relative power, and time to peak all had large CV values. There also appeared to be a large range of values within the cohort when examining ICC values. This would indicate a largely heterogenous cohort.

### **Practical implications**

From these studies, few practical implications can be inferred. It may be worth further investigating the effects of isokinetic eccentric resistance exercise on relative power measures in lower-body expressions. The clearest implication of this research is the need for higher quality methodological quantification of the training factors necessary to induce post-activation potentiation, including volume, intensity, and recovery. Furthermore, this research

indicated that prior to any eccentric resistance methods being utilised for post-activation potentiating; the subject would benefit from a longer training period beforehand to appropriately adapt the neuromuscular system for eccentric actions. Furthermore, the reliability of equipment for this research was equivocal with the linear position transducer being most reliable in its reporting of the observed measures.

### **Strengths**

This research demonstrated a trend towards an acute improved expression of power relative to bodyweight. This could be indicative of higher intensity isokinetic eccentric resistance actions acutely improving an individual's force-velocity profile.

### **Limitations**

Limitations for this research include a relatively small cohort size ( $n=19$ ). Whilst efforts were made to homogenise the group towards a cohort with greater muscular strength, this was not clearly demonstrated by only collecting years of experience. Greater methodological quality may have included an absolute strength measure prior to recruitment to further homogenise the group and have greater likelihood of a cohort better suited to the exposure of super-maximal intensity. As there has been few studies investigating eccentric exercise as a means of inducing post-activation potentiation, there was little precedent when selecting intensity, volume, and recovery with all measures instead derivative of paired muscle action methodologies. Therefore, it is unclear if a manipulation of these variables would have indicated greater magnitudes of change. Collecting data at one time point post-intervention also meant there was little indication as to whether other individuals required a greater or shorter recovery period to best elicit PAP. In the reliability study, limitations such as standardising footwear, absolute strength levels, and multiple exertions for the six-second peak power test may have improved reliability.

## **Future Research**

Future examination into the effects of post-activation potentiation should first investigate the quantification of training variables best suited. Clearer understanding of training volumes, recovery time and intensities would elucidate what is best practice when implementing PAP protocols. Furthermore, greater clarity is needed regarding the relationship of eccentric resistance training and its acute effects on force, speed, and power. Research specifically investigating the necessary time-course for neuromuscular adaptation to occur for an individual to be capable of producing maximal eccentric force would enable practitioners to implement appropriate mesocycles preceding training blocks wherein eccentric force is necessary. Furthermore, data collections at multiple time-points post-eccentric bouts of exercise for measures of force, speed, and power could elucidate if eccentric actions require unique recovery periods. Investigations surrounding the relationship between eccentric exercise as a means of potentiating horizontal expressions of athletic characteristics may provide insight as to the potential benefits of isokinetic eccentric exercise in a cyclical biomechanical manner.

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# Appendices

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THE UNIVERSITY OF  
**WAIKATO**  
*Te Whare Wānanga o Waikato*

11 January 2021

Cam Olsen  
Health Sport Human Performance  
By email: [cameronjamesolsen@gmail.com](mailto:cameronjamesolsen@gmail.com)

Dear Cam

**HREC(Health)2019#70 : Effects of Isokinetic Eccentric Resistance Training in Highly Trained Athletes**

Thank you for your responses to the committee feedback.

We are now pleased to provide formal approval.

Please contact the committee by email ([humanethics@waikato.ac.nz](mailto:humanethics@waikato.ac.nz)) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

A handwritten signature in black ink, appearing to read 'RM' followed by a flourish.

---

**Emeritus Professor Roger Moltzen MNZM**  
**Chairperson**  
**University of Waikato Human Research Ethics Committee**

## *Informed Consent Form for Participants*

**Title** – Effects of Isokinetic Eccentric Resistance Training in Highly Trained Athletes.

*I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.*

*I also understand that:*

- *I am free to withdraw from the study at any time or to decline to answer any particular questions.*
- *I can withdraw any information I have provided up to two weeks after participating in the research activities by contacting the principal investigator.*
- *Any data or answers will remain confidential in regards to my identity through a coding system.*
- *The data might be published, so every effort will be made to ensure confidentiality and anonymity. However, anonymity cannot be guaranteed.*

*I agree to provide information to the researchers under the conditions of confidentiality set out on **the Participant Information Sheet**.*

*Consent to Participate*

*I agree to participate in this study under the conditions set out in the Participant Information Sheet.*

**Participant:**

**Researcher:**

**Signature:**

\_\_\_\_\_

\_\_\_\_\_

**Name:**

\_\_\_\_\_

\_\_\_\_\_

**Date:**

\_\_\_\_\_

\_\_\_\_\_



THE UNIVERSITY OF  
**WAIKATO**  
*Te Whare Wānanga o Waikato*

**Effects of Isokinetic Eccentric Resistance Training in Highly Trained Athletes.**

**Baseline Questionnaire**

Name: .....

Date of Birth: .....

Height: ..... Weight:  
.....

Sex: ..... Health status:  
.....

Weight training experience (Years, Months): .....

## Physical Activity Readiness Questionnaire (PAR-Q) and You

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly:

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

<b>If you answered:</b>	<b>YES to one or more questions</b>
	<p>Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.</p> <ul style="list-style-type: none"> <li>You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.</li> <li>Find out which community programs are safe and helpful for you.</li> </ul>
	<b>NO to all questions</b>
	<p>If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:</p> <ul style="list-style-type: none"> <li>Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.</li> <li>Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.</li> </ul>
	<p><b>Delay becoming much more active:</b></p> <ul style="list-style-type: none"> <li>If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or</li> <li>If you are or may be pregnant – talk to your doctor before you start becoming more active.</li> </ul>
	<p>Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.</p>

Informed use of the PAR-Q: Reprinted from ACSM's Health/Fitness Facility Standards and Guidelines, 1997 by American College of Sports Medicine

**Table 11.** Drop jump reactive strength index, relative power, ground contact time, flight time, and jump height pre- and post- isokinetic eccentric intervention ( $n=19$ ). Values are means  $\pm$  standard deviations.

	SLOW		
	Pre	Post	Change
<b>RSI</b>	1.55 $\pm$ 0.36	1.57 $\pm$ 0.3	0.02 $\pm$ 0.01
<b>Relative power (W/kg)</b>	43.75 $\pm$ 7.75	44.25 $\pm$ 6.49	0.5 $\pm$ 0.35
<b>CT (s)</b>	0.25 $\pm$ 0.04	0.24 $\pm$ 0.04	-0.01 $\pm$ 0.01
<b>FT (s)</b>	0.56 $\pm$ 0.04	0.56 $\pm$ 0.04	0.00 $\pm$ 0.00
<b>Jump height (cm)</b>	38.24 $\pm$ 5.17	38.98 $\pm$ 5.42	0.74 $\pm$ 0.52
	CONTROL		
	Pre	Post	Change
<b>RSI</b>	1.47 $\pm$ 0.42	1.53 $\pm$ 0.37	0.06 $\pm$ 0.04
<b>Relative power (W/kg)</b>	41.98 $\pm$ 9.06	0.25 $\pm$ 0.04	1.18 $\pm$ 0.83
<b>CT (s)</b>	0.26 $\pm$ 0.06	0.25 $\pm$ 0.04	-0.01 $\pm$ 0.01
<b>FT (s)</b>	0.56 $\pm$ 0.04	0.56 $\pm$ 0.04	0.00 $\pm$ 0.00
<b>Jump height (cm)</b>	37.42 $\pm$ 6.00	38.22 $\pm$ 5.95	0.8 $\pm$ 0.57
	FAST		
	Pre	Post	Change
<b>RSI</b>	1.6 $\pm$ 0.41	1.53 $\pm$ 0.29	-0.07 $\pm$ 0.05
<b>Relative power (W/kg)</b>	44.63 $\pm$ 8.86	43.2 $\pm$ 6.33	-1.43 $\pm$ 1.01
<b>CT (s)</b>	0.24 $\pm$ 0.05	0.25 $\pm$ 0.04	0.01 $\pm$ 0.01
<b>FT (s)</b>	0.56 $\pm$ 0.04	0.56 $\pm$ 0.04	0.00 $\pm$ 0.00
<b>Jump height (cm)</b>	38.36 $\pm$ 5.73	38.44 $\pm$ 5.57	0.08 $\pm$ 0.06

**Table 12.** Loaded counter-movement jump height, peak power, relative peak power, peak force, and peak velocity pre- and post-eccentric intervention ( $n=19$ ). Values are presented as means  $\pm$  standard deviations.

	SLOW			CONTROL			FAST		
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
<b>Jump height (m)</b>									
-25 kg	0.46 $\pm$ 0.07	0.47 $\pm$ 0.09	0.02 $\pm$ 0.01	0.44 $\pm$ 0.11	0.45 $\pm$ 0.08	0.01 $\pm$ 0.01	0.46 $\pm$ 0.08	0.46 $\pm$ 0.07	0.00 $\pm$ 0.00
-45 kg	0.35 $\pm$ 0.05	0.36 $\pm$ 0.05	0.01 $\pm$ 0.00	0.34 $\pm$ 0.06	0.34 $\pm$ 0.05	0.00 $\pm$ 0.00	0.35 $\pm$ 0.05	0.37 $\pm$ 0.05	0.02 $\pm$ 0.01
<b>Peak power (W)</b>									
-25 kg	5747.57 $\pm$ 888.06	5899.01 $\pm$ 1084.97	151.44 $\pm$ 107.09	5480.20 $\pm$ 859.64	5785.67 $\pm$ 858.89	305.47 $\pm$ 216.00	5923.56 $\pm$ 831.69	5936.31 $\pm$ 1091.58	12.74 $\pm$ 9.01
-45 kg	5325.40 $\pm$ 792.75	5446.44 $\pm$ 666.20	121.04 $\pm$ 85.59	5198.82 $\pm$ 649.78	5301.96 $\pm$ 729.49	103.14 $\pm$ 72.93	5429.69 $\pm$ 671.92	5571.58 $\pm$ 825.19	141.89 $\pm$ 100.33
<b>Peak relative power (W/kg)</b>									
-25 kg	69.95 $\pm$ 9.00	71.55 $\pm$ 9.71	1.61 $\pm$ 1.14	67.37 $\pm$ 13.38	69.91 $\pm$ 9.32	2.54 $\pm$ 1.80	72.19 $\pm$ 9.72	72.54 $\pm$ 9.20	0.34 $\pm$ 0.24
-45 kg	64.62 $\pm$ 6.20	66.37 $\pm$ 7.01	1.74 $\pm$ 1.23	63.54 $\pm$ 8.76	64.03 $\pm$ 7.66	0.49 $\pm$ 0.35	66.26 $\pm$ 8.26	67.69 $\pm$ 7.03	1.44 $\pm$ 1.02
<b>Peak force (N)</b>									
-25 kg	3012.01 $\pm$ 533.28	3072.28 $\pm$ 614.66	60.27 $\pm$ 42.62	2953.41 $\pm$ 574.53	3000.22 $\pm$ 559.44	46.81 $\pm$ 33.10	3054.96 $\pm$ 672.77	2975.21 $\pm$ 531.63	-79.75 $\pm$ 56.39
-45 kg	2846.71 $\pm$ 528.80	2934.52 $\pm$ 560.83	87.81 $\pm$ 62.09	2823.06 $\pm$ 503.87	2941.95 $\pm$ 387.04	118.89 $\pm$ 84.07	2918.19 $\pm$ 557.80	3114.52 $\pm$ 816.20	196.33 $\pm$ 138.82
<b>Peak velocity (m/s)</b>									
-25 kg	2.98 $\pm$ 0.24	3.04 $\pm$ 0.28	0.06 $\pm$ 0.04	2.92 $\pm$ 0.37	2.97 $\pm$ 0.26	0.04 $\pm$ 0.03	2.99 $\pm$ 0.25	2.98 $\pm$ 0.23	-0.01 $\pm$ 0.01
-45 kg	2.62 $\pm$ 0.20	2.64 $\pm$ 0.17	0.02 $\pm$ 0.01	2.57 $\pm$ 0.20	2.57 $\pm$ 0.20	0.00 $\pm$ 0.00	2.61 $\pm$ 0.19	2.67 $\pm$ 0.17	0.06 $\pm$ 0.04

Abbreviations: (m)- metres; (W)- wattage; (W/kg)- wattage per kilogram; (N)- newtons; (m/s)- metres per second

**Table 13.** 6-second peak power test peak power, relative power, peak cadence, time to peak power, and cadence at peak power pre- and post-eccentric intervention ( $n=19$ ). Values are means  $\pm$  standard deviations.

	SLOW		
	Pre	Post	Change
<b>Peak power (W)</b>	1211.63 $\pm$ 293.07	1258.16 $\pm$ 145.99	46.53 $\pm$ 32.90
<b>Relative power (W/kg)</b>	14.73 $\pm$ 3.56	15.37 $\pm$ 1.83	0.64 $\pm$ 0.45
<b>Peak cadence (RPM)</b>	132.37 $\pm$ 7.37	130.32 $\pm$ 5.15	-2.05 $\pm$ 1.45
<b>TTP (s)</b>	2.04 $\pm$ 1.20	1.88 $\pm$ 1.12	;-0.16 $\pm$ 0.11
<b>CPP (RPM)</b>	130.42 $\pm$ 5.89	128.84 $\pm$ 5.12	-1.58 $\pm$ 1.12
	CONTROL		
	Pre	Post	Change
<b>Peak power (W)</b>	1240.53 $\pm$ 141.15	1219.21 $\pm$ 169.51	-21.32 $\pm$ 15.07
<b>Relative power (W/kg)</b>	15.18 $\pm$ 2.08	14.87 $\pm$ 2.01	-0.31 $\pm$ 0.22
<b>Peak cadence (RPM)</b>	131.42 $\pm$ 7.07	130.16 $\pm$ 5.22	-1.26 $\pm$ 0.89
<b>TTP (s)</b>	2.00 $\pm$ 0.94	1.83 $\pm$ 1.22	-0.17 $\pm$ 0.12
<b>CPP (RPM)</b>	129.74 $\pm$ 6.97	126.26 $\pm$ 7.40	-3.47 $\pm$ 2.46
	FAST		
	Pre	Post	Change
<b>Peak power (W)</b>	1266.37 $\pm$ 180.22	1279.21 $\pm$ 172.34	12.84 $\pm$ 9.08
<b>Relative power (W/kg)</b>	15.42 $\pm$ 1.92	15.58 $\pm$ 1.93	0.17 $\pm$ 0.12
<b>Peak cadence (RPM)</b>	131.00 $\pm$ 6.51	131.37 $\pm$ 6.34	0.37 $\pm$ 0.26
<b>TTP (s)</b>	2.00 $\pm$ 1.66	1.75 $\pm$ 0.76	-0.25 $\pm$ 0.17
<b>CPP (RPM)</b>	126.79 $\pm$ 6.65	129.63 $\pm$ 5.91	2.84 $\pm$ 2.01