The Effect of Variable Resistance Training for the Post Activation Performance Enhancement of the Countermovement Jump

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Declaration

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Abstract

Variable resistance training (VRT) is a modality with applications for sports performance training. It can be incorporated into established training methods for power development, with implications for training efficiency. Complex training has risen in popularity and application within the field of strength and conditioning. The supporting research to date has produced impractical and inconsistent conclusions around specific training prescriptions. Complex utilises the phenomenon of post-activation potentiation (PAP) to acutely enhance neuromuscular performance. This study investigated the effects of a heavy-load barbell back squat with traditional resistance and VRT by steel chains on counter-movement jump (CMJ) performance, specifically for jump height and positive net impulse. Twelve resistance-trained individuals volunteered to participate in three experimental trials. Completion of trials was randomised between the traditional, no-chain, and variable, chain, resistance modes. Participants performed 3 sets of 2 repetitions of each respective back-squat at 85% one-repetition maximum (1RM); variable-resistance from chains amounted to an average of 20% total resistance. Jumps were performed at baseline and at 0.5, 2, 4.5, 8, 12.5, and at 18-minutes after the back squat conditioning activity. Results were analysed for changes in jump height and positive net impulse between exercise conditions and over the time course of recovery. Trivial effect sizes were found between exercise conditions ($d < 0.20$) with mean jump height 2.67% higher in chain than no-chains, with control trial 1.95% greater jump height than chain. Positive net impulse was 2.34 and 2.23% greater in chains than in other trials, respectively. These results show that a complex training set using variable resistance can acutely improve CMJ performance compared to using traditional, free-weight resistance alone or in the absence of a conditioning activity. Jump height was improved at 2 and 4.5 minutes from baseline in chains, whereas a decrease was observed with no-chains. This provides rationale for the use of variable resistance over traditional mode in this context. These time-points also provide a window of application in which practitioners could employ VRT to elicit a PAPE effect either within a complex set or prior to performance.

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Chapter 1 General Introduction

Optimising development of power through specific resistance training is widely practiced for its specificity to the time constraints and athletic demands of sport. Whilst traditional resistance training programs follow a generic exercise order of light resistance followed by heavy resistance linearly across an exercise session (Duthie, Young and Aitken, 2002), alternative strength and power training sequences have been used to a larger degree in recent times.

Advancements in methodologies are common within the strength & conditioning practice and are often associated with claims such as improved training efficiency and effectiveness. Efficiency refers to the optimising the training response to time spent ratio for targeting improvements in physical parameters (Iversen et al., 2021). Whereas effectiveness can be defined as beneficial transfer of sought-after physical qualities to the sporting performance, conventionally termed dynamic correspondence (Verkhoshansky and Siff, 2003). This is ultimately the goal of any resistance training regime. There remains debate as to the extent to which there is direct transfer due to the multifactorial determinants of sporting success. It is also impossible to determine the extent to which an enhancement in performance is attributable to a training stress applied, or whether it is another of the many explanatory factors. Nonetheless, resultant physical adaptations from training have been shown to mitigate the risk of sporting injury, with a dose-response established between strength training and preventive effects (Hoffman, 2017; Lauersen, Andersen and Andersen, 2018).

Secondary to this is the acute physical preparation of an athlete for competition. This has been popularised in the formulation of a R.A.M.P. protocol, denoting phases of a warm-up performed in the set order of raise, activate, mobilise, and potentiate (RAMP) (Jeffreys, 2007). It is the final stage of this structured preparation, potentiate, that largely relates to 'priming' of the neuromuscular system in preparation of high force outputs to follow. The term PAP in the literature arose from research using electrical stimulation to evoke twitch contractions in skeletal muscle (Hamada *et al.*, 2000). The research in this field, and its relevance to sports performance, has grown considerably since then. This expansion has led to certain authors expressing concern at the use of PAP when explaining performance enhancement as it refers to mechanistic factors rather than measured physical outputs (Blazevich and Babault, 2019; Boullosa *et al.*, 2020; Prieske *et al.*, 2020). Said authors argue the distinction should be made by the fact one is electrically evoked and the other is a voluntary muscle action. The measures used to assess this post-activation state are also important. It has been argued post activation performance enhancement (PAPE) is a more accurate description of performance measures of strength and power following voluntary contractions. This acknowledges the presence of the potentiation phenomena but does not claim there is a direct causal effect of an enhanced physiological state. Since muscular activity was not assessed in this study PAPE shall be used for the remainder of this report in reference to a performance enhancement post an activation.

Chapter 2 Literature Review

2.1 Strength and Power Training

2.1.1 Complex and Contrast

It is important at this early stage to differentiate between two often interchangeably used terms for combination resistance training. Firstly, contrast training is a session-wide approach defined as a sequence of contrasting heavy loads at the start and light at the end of the session (Cormier *et al.*, 2020). Complex training is a separate, alternating set-by-set method in which training sets are ordered so a biomechanically similar low-load, power ballistic exercise follows a high-load, resistance exercise (Ebben and Watts, 1998; Duthie, Young and Aitken, 2002). The features of contrast are mirrored in complex, hence the confusion in terms. The main distinction is the exercise sequencing with complex referring to a singular set rather than across the exercise session as a whole as seen in contrast. This intra-set coupling of different exercise modalities is termed a complex pair (Docherty, Robbins and Hodgson, 2004). There is dispute as to the efficacy of the complex method in practice due to methodological constraints, yet proponents have stated it can be 3-fold more effective for power development relative to traditional methods (Chu., 1996).

2.1.2 Historical Perspective

Complex training is believed to have emerged in Soviet Union Olympic training programmes in the late 1960s from the pioneering work of Verkhoshanksy (Verkhoshanksy and Tatyan, 1973). His theories are based on the premise that power training can be targeted as effectively using either heavy-resistance or light to no-load jump training. Complex is a combination of these two by pairing low-velocity, high-load movement with higher-velocity, low-load. This is said to target both the force and velocity aspects of power, explained by: mechanical power = force x velocity (Cormie, McGuigan and Newton, 2011). Gullich and Schmidtbleicher's (1996) work appears to support the complex modality, although their research indirectly investigated this through potentiation responses of skeletal muscle in a classical PAP approach. Earlier, much of the published literature was more akin to combination training by alternating programs daily in separate sessions using discrete methods of plyometric or weights independently (Ford *et al.*, 1983; Adams *et al.*, 1992). In a 1986 NSCA Journal publication the rationale for complex training was detailed. It stated heavy resistance exercise induces tension-dependent neural-based mechanisms through a precontraction of antagonistic muscles resulting in potentiation of successive ballistic exercise (Fleck and Kontor, 1986). For example, back-squat at 90% 1RM was the most common exercise preceding either light or bodyweight jumping, interspersed by an average of 3-4 minutes between exercises. Future complex training publications align with this original framework, with particular attention given to similarity in exercise selection and rest periods (Chu, 1992; Ebben and Blackard, 1997; Fees, 1997; Ebben and Watts, 1998).

2.2 Mechanisms of Action

2.2.1 Potentiation

The mechanism by which complex training is said to enhance subsequent ballistic performance is via neuromuscular enhancement. This is where a maximal or near-to-maximal voluntary muscular contraction induces a potentiated state in the muscle exhibiting as a transient increase in subsequent contractile performance (Sale, 2002; Hodgson, Docherty and Robbins, 2005). PAP is described as an increased neuromuscular excitability, with the analogy used of muscle and central nervous system retaining a ‘memory’ of exerting a high force therefore responding in such a way assuming there is more heavy work required (Verkhoshansky and Tatyan, 1973; Fees, 1997). There are two central theories in which the mechanism of PAP is explained that are broadly classified as either muscular or neural (Sale, 2002; Hodgson, Docherty and Robbins, 2005; Tillin and Bishop, 2009).

The potentiated neuromuscular state occurs after a conditioning contraction, which is referred to herein as the conditioning activity or exercise (Tillin and Bishop, 2009). This muscular contraction may be in the form of a series of evoked twitches or a sustained, tetanic contraction (Sale, 2002). The muscle factors influencing PAP have been termed twitch potentiation, with the neural factors labelled as reflex potentiation (Wallace *et al.*, 2019). The muscular basis of twitch potentiation is the phosphorylation of myosin regulatory light chains (MLC). This results in increased sensitivity of the myofilaments, actin and myosin, to available calcium. The phosphorylated state of MLC renders the myofilaments more sensitive and allows for a higher rate of cross-bridge formation: the force producing muscular state of actin-myosin interaction (Hodgson, Docherty and Robbins, 2005).

Alternatively, reflex potentiation is an increase in neural drive through recruitment of higher order motor units (Trimble and Harp, 1998; Tillin and Bishop, 2009). The H-reflex is used as a measure of electrical potentiation of the efferent, α-motoneuron. This marker can be used to quantify the number of activated motor units, translated as a higher amplitude of H-wave in studies representing PAP (Trimble and Harp, 1998; Folland, Wakamatsu and Fimland, 2008). The potentiated muscle state arising from enhanced conduction of action potentials determines the excitatory effect associated with this theory.

2.2.2 Fatigue-Potentiation Balance

The underlying mechanisms of PAP are generally well-accepted, but the extent to which these directly affect muscle action in a potentiated state is less clear. A feature of PAP is the concurrent potentiated state with the inevitable fatigue induced from the intense conditioning activity. It is the balance of these two conflicting features of contractile history that determines the resultant performance outcome (Lim and Barley, 2016). Notably, fatigue is said to be highest early in recovery and recedes more quickly than PAP (Tillin and Bishop, 2009). In theory, this presents a window of opportunity in which potentiation remains elevated, yet fatigue has subsided enough to realise a PAP effect. Sale (2002) reviewed the role of PAP and presented a schematic model of this relationship (Figure 2-1). An intensive conditioning activity proves highly effective in potentiation but is coupled with high fatigue. Likewise, an approach to minimise fatigue, as in light-moderate intensity (< 60% 1RM), is mostly ineffective for potentiation (Hanson, Leigh and Mynark, 2007). Hence, a delicate balance is required between allowing recovery for the fatigue to dissipate, whilst acknowledging extended recovery, or lighter loading, also reduces any beneficial PAP effect (Sue, Adams and DeBeliso, 2016). This highlights the time-sensitivity and is a key consideration for implementation as complex training. Simply, a conditioning activity that can induce a high degree of PAP, but causes the minimal possible fatigue, is the most desirable outcome.

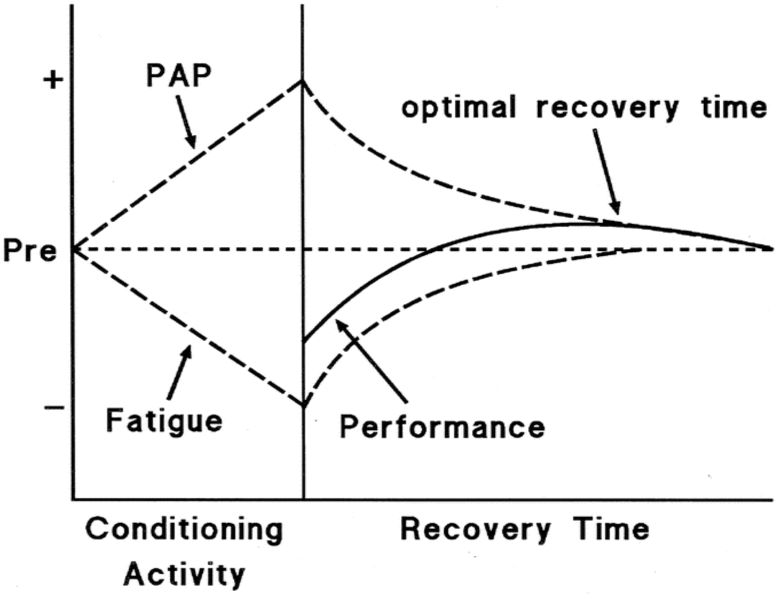

Figure 2-1: model of muscle ‘performance’ response for fatigue-potentiated state. Adapted from Sale (2002).

2.3 Post-activation Performance Enhancement

The mechanical power equation (section 2.1.2) aids our understanding as to how PAP mechanisms may elicit an acute performance benefit. Power can be increased through either decreasing the time in which the force is applied, increasing the force applied over the same time, or combination of the two. There is a lack of evidence of any measurable increases in maximal force application from PAP mechanisms, for these have little effect in conditions of calcium saturation (Tillin and Bishop, 2009). This leaves the time component as where the most effect could be had on unloaded exercises like jumping. This activity requires projection of one’s body mass at a submaximal force output and is constrained by the rate of force development (RFD) (Newton and Kraemer, 1994). This is cited as the target of power interventions and involves a theoretical ‘right-ward’ shift in the force-velocity curve.

Early investigations were inconclusive as to the efficacy of complex training over other means. A comparison of jump squats revealed no significant differences for variables like jump height, yet complex training resulted in a significantly lower mean peak power compared with traditional training (Duthie, Young and Aitken, 2002). Baker (2003) used a contrast and complex set to determine if bench-press throw performance could be enhanced. The complex group showed a 4.5% increase in power output post-test relative to a control, which is an acute potentiation of power performance 3-minutes after a conditioning activity. These contradictory results likely result from the high variability in study groups and methodologies such as training history and rest periods. This evidence also highlights the importance of controlling for said factors. Weber et al. (2008) results were favourable for complex, with squat jumps performed following 'heavy' (85% 1RM) back squats showing significantly higher mean and peak jump height relative to a control. A meta-analysis of more than 30 primary studies indicated a small mean effect-size of 0.38 for a power task in a complex pair (Wilson *et al.*, 2013). Similarly, small to medium effect sizes (0.2-0.5) on jump, throw, and other upper-limb ballistic performance have been reported (Seitz and Haff, 2016). Overall, these reviews specify the key factors modulating the PAPE effect during complex training, which are: conditioning activity type, volume and intensity; rest interval duration; gender; and training status.

2.3.2 Practical Applications

In addition to the literary evidence supporting beneficial PAPE effects, it is important to address how this could be used in a practical setting. The most obvious use in relation to an acute enhancement would be prior to a single-effort, power or speed event. Evidenced by significant improvements in sprint time over 10 metres at 4 minutes following a back squat conditioning activity (Wyland, Van Dorin and Reyes, 2015). Likewise, enhancement of performance has been shown within team sports with an increase in softball bat velocity 6 minutes after an isometric protocol (Gilmore *et al.*, 2019). This evidence supports the use of the PAPE principle as an adjunct to a regular warm-up in the immediate timeframe prior to execution of a sporting task should time and facilities allow. The exercise selection and training type for this warm-up period has also been considered. Low-load or bodyweight plyometrics were recommended in the context of pre-competition warm-ups due to limited access to equipment, space, and time constraints. However, when time is not as limited, such as during a dedicated training session, heavy resistance is said to be most beneficial due to the ability to have extended recovery times and lesser concern of fatigue impacting performance (Handford et al., 2022). In low-intensity, sustained effort disciplines, such as endurance running or cycling, PAPE protocols are unlikely to have any meaningful impact in this author's opinion. The same could be said for team sports such as football in which periods of play last ≥ 45 minutes. However, research has shown improvements in subsequent performance following a brief re-warm over passive rest in the half-time period (Silva *et al.*, 2018). Although not discussed in the research, PAPE protocols could prove useful in this scenario given the need for a brief, high-intensity stimulus required to limit the reduction in performance following an inter-play rest.

A secondary use of this method of training is application across a periodised training programme for a chronic adaptation in power. In a recent meta-analysis, the training intervention effects of complex training over ≥ 3 week duration were found to be positive and large (effect size > 0.8) for jump height, peak velocity and negative but large effect for sprint time (Marshall *et al.*, 2021). Within study comparisons included in the analyses were made between traditional, cluster-set approach, and contrast training. In addition to an acute performance benefit, this provides evidence in support of complex as an effective training structure and secondary use aside from pre-competition.

2.4 Exercise Selection and Order

2.4.1 Biomechanical Similarity

The movement-pattern specificity of the conditioning activity to the subsequent exercise has been discussed as a mediator of PAPE response in athletic populations (Crewther *et al.*, 2011). Plyometric exercise as a conditioning exercise has received attention in direct comparison to heavy-resistance (Sharma *et al.*, 2018). Sharma and colleagues concluded plyometrics are more time efficient and generally effective for potentiation of CMJ in comparison to half-squats at 90% 1RM for 10 repetitions. Such results should be viewed in context, in that the resistance exercise is both high intensity and relatively high volume and the corresponding recovery of 1 to 10-minutes may be incomparable with the less intense plyometric exercise. Although supportive of plyometric activity, these results are likely attributable to the warm-up 'effect' of PAPE as plyometrics are limited in the intensity that can be prescribed (Radcliffe and Radcliffe, 1996).

However, since much of the complex studies utilise resistance training exercise, this requires more attention, including the separate forms of isometric and dynamic.

2.4.2 Isometric or Dynamic

Early PAP investigations into isometric muscle actions used a maximal voluntary contraction (MVC). Heavy loading was performed as 3 repetitions of 3-5-seconds MVC knee extensions preceding a CMJ (French, Kraemer and Cooke, 2003). Results indicated there was no performance benefit to CMJ following 3 x 5-seconds, likely due to a greater fatigue than potentiation, with attention drawn to confounding factors like total conditioning activity volume. For upper-body, the effect of contraction type on PAPE response has also been examined (Esformes *et al.*, 2011). Only isometric conditioning activity potentiated power output, that is after a prolonged rest period of 12-minutes. This agrees with French et al. (2003) in those isometric contractions do elicit potentiation, but only after the high levels of fatigue have dissipated over time. Dynamic contractions provided no benefit over this time-period; however, performance was only assessed at one time-point. Similarly, when examining potentiation response or sprint performance at 4-minute post-conditioning, there was no significant difference observed between 3 x 3-seconds isometric squat, knee-extension MVC, or 3 x 90% 1RM dynamic squat protocols (Lim and Kong, 2013). Whereas others have found isometric is preferable over dynamic (Rixon, Lamont and Bemben, 2007; Esformes *et al.*, 2011; Bogdanis *et al.*, 2014). A review of the 'best' isometric contraction type for potentiation determined brief 5-second MVC as the most effective contraction mode, duration, and intensity. Durations greater than 15-seconds, either in continuous or intermittent activation pattern, induced more fatigue and reduced PAP (Albertas *et al.*, 2019).

The efficacy of dynamic, lower-body conditioning activity has been further investigated. Weber and colleagues (2008) results are in support of this exercise having observed potentiation in squat jump average height and peak forces following five repetitions of back squats at 85% 1RM (Weber *et al.*, 2008). Squat depth has also been identified as mediating PAPE. Parallel squats at 3RM load repetitions with 5-minute recovery resulted in to greater PAPE than the quarter squat equilavent (Esformes and Bampouras, 2013). Authors concluded the greater depth in parallel squats increases activation of gluteus maximum and there is greater amount of total work produced by hip and knee extensors. EMG data supports this in that gluteus maximus activity during concentric muscle action increases as squat depth increases (Caterisano *et al.*, 2002). As a primary hip extensor, inducing potentiation in the gluteal musculature is therefore likely to benefit jump performance using these same primer movers.

These findings are substantiated by others effectively using heavy-load, dynamic resistance exercise across a full range of motion (ROM) and for whom are summarised in Table 2-1 below ((Kilduff *et al.*, 2007, 2008; Crewther *et al.*, 2011; Sue, Adams and DeBeliso, 2016; Scott, Ditroilo and Marshall, 2017).

Table 2-1. Summary of dynamic exercise research.

Author(s)	**Exercise**	**Volume & Intensity**	**Outcome Measure**	**Performance Change**
Kilduff et al (2008)	Back Squat	3 sets of 3 repetitions at 87% 1RM	CMJ: power output, jump height, peak rate of force development	Significant increase from baseline with > 8 minutes recovery
Crewther et al (2011)	Back Squat	1 set at 3RM load	CMJ, sprint performance (5 and 10 m), and 3-m horizontal sled pushes with 100-kg load	Significant increases in CMJ height with no temporal performance improvements in speed and pushing
Sue et al (2016)	Back Squat	1 set at 5RM load	Standing long jump	Significantly greater jump height from baseline across time until 14 minutes
Scott et al (2017)	Back Squat and Hex Bar Deadlift	1 set of 3 repetitions at 93% 1RM	CMJ: peak power output, force and	Significantly improved performance between

			velocity at peak power output, and jump height	2 and 6 minutes in Hex Bar but not Squat.

2.4.3 Olympic Weightlifting

This exercise modality is defined in strength and conditioning as a full body, dynamic movement. The high velocity of movement associated with exercises like the clean and snatch means high mechanical power is required. Initial findings comparing hang clean and back squats reported no significant difference in vertical jump height (McCann and Flanagan, 2010). A study comparing the same exercises concluded hang cleans were superior over back squats for the performance enhancement of CMJ (Andrews *et al.*, 2011). The downside to weightlifting, however, are the technical demands of the exercise, especially at higher relative loads, may negate any benefit obtained from use in a complex pairing. Conversely, it can be argued Olympic weightlifting movements have greater biomechanical similarly to sporting actions. For example, the successive triple extension at the hip, knee and ankle joint during a Olympic lift mimics the start, acceleration phase of a sprint from the blocks (Wild, 2011). Therefore, Olympic weightlifting as a modality could be described as having a high degree of dynamic correspondence and carryover to sporting action.

To conclude, irrespective of the exercise selection in either upper or lower body, the most important aspect is the biomechanical similarity between exercises (Robbins, 2005). Moreover, dynamic exercise is seen as advantageous over isometrics and MVC's, although weightlifting movements show evidence for applicability in the appropriate context. Aside from the suitability in eliciting a PAPE effect, any chosen conditioning activity should be considered for its applicability to complex training. As the literature to date has elucidated, biomechanical similarity within a complex pair is central to any positive benefits.

2.5 Application

2.5.1 Efficiency

One of the key benefits over other power training modalities is the time-efficiency of complex training by blending two separate training modes into effectively one set. In direct conflict to this claim is the lack of agreement in the literature as to the optimal time allowed between exercises, referred to herein as the intra-complex recovery interval (ICRI). This is perhaps why isometric muscle actions may be disregarded in favour of dynamic due to the extended and impractical rest periods required to realise a PAPE effect, if any. This relates to the coexistence of fatigue with potentiation and the factors modulating this balance.

Regarding ICRI, a wide variety of rest times have been reported ranging from ≤ 0.5-minutes to upwards of 20-minutes (Tillin and Bishop, 2009). For the purposes of this review, ICRI shall be distributed according to the classifications outlined by Wilson et al. (2013): immediate (≤ 2 minutes), short (> 2-7 minutes), medium (≥ 7-10 minutes), and prolonged (≥ 10 minutes). The medium to prolonged timings are considered highly impractical notwithstanding any proposed performance benefit due to the duration multiple sets would take. Therefore, authors have cited 5 minutes as the upper threshold, optimally ~3-4 minutes, that perceived benefits received by complex sets would warrant the time investment (Jensen and Ebben, 2003; Lim and Barley, 2016). However, if time is not limited, 8-12 minutes is theoretically the cut-off point to establish a PAPE effect before potentiation decays to a negligible level (Gouvêa *et al.*, 2013). Findings tend to suggest that minimal recovery interval is also highly suboptimal due to the masking effect of muscular fatigue on potentiation. CMJ's performed 60-seconds after a conditioning activity improved peak-power output significantly compared with a 15-second rest interval in a well-trained cohort (Gowtage, Moody and Byrne, 2020). Similarly, a conditioning activity was shown to impair acute CMJ performance after only 10-seconds rest, relative to a baseline jump (Jensen and Ebben, 2003). The absence of any ergogenic effect, or worse a performance impairment, may be attributable to incomplete resynthesis of phosphagen energy system substrates to basal levels following high-intensity conditioning activity. These have been shown to be close to fully restored upwards of 3-minutes (Hultman, Bergström and Anderson, 1967). Substrate repletion is incremental as evidenced in a group of female athletes performing broad jumps, authors detected a significant time and PAPE-effect across 4-minute increments between 2 and 18 minutes (Sue, Adams and DeBeliso, 2016). Significant improvement was found at 2, 6, and 10-minutes, with the greatest change from baseline at 2-minutes (4.8%). The creatine phosphate repletion is partly dependant on the extent of depletion among other factors which could explain favourable response at an early time point (Baker, McCormick and Robergs, 2010). Potentiation of CMJ performance has also been detected at 4, 12, and even 16-minutes following 3RM back squat, however there was evidence of responders and non-responders across respective time-points (Mola, Bruce-Low and Burnet, 2014). Peak power output in ballistic bench press throw was potentiated significantly above baseline levels at 8, 12, and 16-minutes, with an acute decrease in the immediate 15-seconds (Kilduff *et al.*, 2007). Similarly, authors found significant improvements at 8-minutes post-conditioning activity in peak RFD and CMJ height over other time points, with impairment from baseline in the same metrics at 15-seconds (Kilduff *et al.*, 2008). This suggests an individualised approach is required within a more general 'window' of PAPE opportunity, approximately between 4 and 12-minutes based on the available literature.

The ICRI selected should be both context and athlete dependent as has been evidenced. However, there are clear guidelines as to the most applicable for complex training and the factors that can influence the rest period required, from the intensity of conditioning contraction to individual training status.

2.5.2 Training History

Factors associated with modulating PAPE are often attributable to training history, namely relative strength level. This operates in interaction with the ICRI, meaning such factors must be viewed in conjunction when making decisions on complex training prescription.

Chiu (2003) findings indicate longer recovery times are advantageous for PAPE, especially in recreationally trained individuals. Jump performance was potentiated at 5 and 18.5-minutes post-warm-up in an athletically trained cohort. More recently, the effect of strength on PAPE was directly examined and strength was found to modulate the magnitude of response. Stronger individuals, categorised as squat 1RM ≥ 2*body mass, enhanced performance immediately following conditioning contraction whereas weaker individual's performance was impaired (Suchomel *et al.*, 2016). These conclusions were made in the absence of any statistically significant strength level x time interaction effects for jump height or peak power. In addition, findings indicate there is also a temporal profile to strength and PAPE. That being, the stronger of two groups showed the greatest potentiation at 6-minutes in comparison to 9-minutes for weaker cohort, and with a significantly higher overall response (Seitz, de Villarreal and Haff, 2014).

Hence, it can be said stronger individuals tend to benefit from a greater PAPE response, and earlier after a conditioning activity. This is said to arise from greater fatigue resistance due to training regularly with, and thereby recovering from, heavy loading (Chiu, 2003; Suchomel *et al.*, 2016). The fatigue-potentiation balance then shifts in favour of potentiation earlier due to either less fatigue incurred, or fatigue is dissipated at a greater rate. Even so, shorter recovery times are preferable for the applied practitioner in most cases due to logistical constraints and limitations on time dedicated to training.

2.5.3 Conditioning Activity

Having established an optimal range of ICRI, it is important to examine the intensity and volume for the conditioning activity. Volume indicates the density of work performed (sets x reps), whereas intensity indicates the relative effort of a repetition as a percentage of maximum. Alternatively, volume-load is a quantity directly related to mechanical work: an arbitrary unit combining the number of repetitions (distance units) at a set intensity (weight unit) and is considered a system mass volume-load (Haff and Triplett, 2016). This allows for comparisons across studies and is a worthwhile endeavour to equate workload prescriptions.

Within the complex training literature, particularly for back squats preceding vertical jump, an array of conditioning activity intensities has been studied. Different conditioning activity volumes have been studied involving low, moderate, and high-volume, each at 80% 1RM for 1, 3, and 9 repetitions, respectively (Naclerio *et al.*, 2015).The moderate-high volume approach was more effective for PAPE over low volume, and effect sizes were higher for CMJ performance with moderate-volume. These results are substantiated by related meta-analyses showing larger effect size for multiple conditioning sets over single set (ES = 0.69, 0.24) (Seitz and Haff, 2016) A higher maximal load elicits greater PAP than sub-maximal, but only for ‘strong’ individuals which suggests weaker individuals may require a different loading intensity. Inherent to a complex pair is the conditioning activity being of high-intensity, thus heavy load ≥ 85% 1RM are commonly used and form the basis of recommendation (Carter and Greenwood, 2014). Intensities above 70% of 1RM are thought of as effective for activation of either the neural or muscular mechanisms. Furthermore, the conditioning activity should be completed with maximal or near to maximal efforts (Docherty, Robbins and Hodgson, 2004). This then provides the rationale for loading above 70% and closer to 85% 1RM, which could be achieved using a non-traditional loading pattern.

2.6 Variable Resistance Training

The performance benefits credited to complex training are often diminished by the impractical nature of implementation. This has influenced a shift in research focus towards novel methods of resistance in the conditioning activity.

2.6.1 Emergence as a Modality

Of the published resistance training literature to date, many of the studies employ weight-plated loading (traditional), classed as isotonic exercise: a fixed external resistance that remains constant across the complete exercise lift ROM (Lander et al., 1985; Chandler and Stone, 1991; McCurdy et al., 2009). The features of constant resistance loading in exercise with an ascending strength curve, such as the back squat, have been reviewed extensively (Kulig, Andrews and Hay, 1984; Frost, Cronin and Newton, 2010; Myer *et al.*, 2014). An ascending strength curve describes an increase in force output at nearer the end of the concentric phase (McMaster, Cronin and McGuigan, 2009). In the example of the squat, this begins with an initial lowering phase in which the muscles are contracting eccentrically, followed by a pause at maximal negative displacement, then reversal upwards while the muscle is shortening in a concentric action to return the barbell to the starting point. This strength curve is not exclusive to the squat exercise and therefore upper body equivalents, such as the barbell bench press, are relevant (Lander *et al.*, 1985; Elliott, Wilson and Kerr, 1989). Notably, for multi-joint compound exercises, constant resistance requires the same degree of muscular force across the ROM. Hence, the maximal external resistance that can be lifted is equal to the muscular force exerted at the weakest position of the exercise (Anderson, Sforzo and Sigg, 2008b). This limiting factor is commonly categorised as the 'sticking-region', or rather the sticking 'point': a significant increase in effort and thereby decreased ability to continue movement through the remainder of the ROM (Kompf and Arandjelović, 2016). Objectively, this is evident by a slowing of barbell concentric velocity to which the lifter cannot continue upwards motion and is characterised by a pre and post-sticking region (Saeterbakken, Andersen and Tillaar, 2015).

Described historically as the least mechanically advantageous of the different modes of dynamic exercise, constant resistance invariably places submaximal tension on the muscles through certain phases of the lift (Clarke, 1973; Pipes, 1978). Constant resistance results in specific mechanical advantage and disadvantage across the joint angles of the prime movers of an exercise (Frost, Cronin and Newton, 2010). The ascending strength curve, alternatively the torque-joint angle 'curve', outlines how torque producing capability of the muscle increases across the concentric ROM during ascent. This has been evidenced in biomechanical models of the squat pattern as a greater external force output towards the apex of the lift (Abelbeck, 2002). It must be highlighted that strength curves are often understood as a single joint movement (uni-articular) in which movement is generated by muscles inserting at a uniform point and rotating around a sole axis point. An example of such is a dumbbell bicep curl in which the elbow moves through flexion and extension (McMaster, Cronin and McGuigan, 2009). As such, this type of movement represents a bell-shaped strength curve and is inherently simpler to define compared with a multi-joint exercise in which movement is created with muscle action across three major joints of the hip, knee, and ankle simultaneously. Torque is found to be lowest at the sticking-point, at a larger knee angle, whereas at smaller knee angles torque production is higher and thereby a greater load is capable of being lifted (Israetel *et al.*, 2010; Wallace, Bergstrom and Butterfield, 2018). The concept of biomechanical advantage is understood by the length-tension relationship, in that at specific muscle lengths the muscle tension translates to greater joint moments (Gordon, Huxley and Julian, 1966). Alternatively, at greater squat depth the hamstrings shorten with increased knee flexion below parallel and the muscle tension is insufficient (Glassbrook *et al.*, 2017), identified as the aforementioned 'sticking-point'. Constant resistance, despite its popularity and prevalence, has fundamental limitations related to the demand placed on the active musculature and resultant force output.

2.6.2 Lifting Phases

Another feature of exercises with an ascending strength curve is the presence of a distinct deceleration during the concentric muscle action, evident by a slowing in barbell velocity (PRUE Cormie, Mcguigan and Newton, 2010)(Baker and Newton, 2009; Rivière *et al.*, 2017; Kubo *et al.*, 2018b). Propulsive and braking phases are key aspects differentiating non-ballistic resistance exercise from ballistic efforts (Sanchez-Medina, Perez and Gonzalez-Badillo, 2010). Moreover, the decelerative phase present in non-ballistic covers as much as 30% of total concentric duration (Lake *et al.*, 2012; Kubo *et al.*, 2018a). Kubo and colleague's (2018) hypothesised duration of the deceleration sub-phase would likely increase as total barbell load decreases. In other words, lower loads equate to higher velocity; therefore, higher loads with lower velocity require continued acceleration. By consequence, a greater acceleration phase results in a reduced absolute deceleration duration. This absolute duration of the deceleration sub-phase remains consistent across increasing load, yet the acceleration sub-phase duration increases with load as does the total concentric phase duration.

As expected, an increase in absolute acceleration phase reduces relative duration of deceleration. Therein lies the central limitation of constant resistance in striking the balance in loading between maximising positive impulse and accelerative duration whilst minimising the negative contributions of the decelerative sub-phase. Moreover, to express lower-body force maximally a focus should be placed on selecting an optimal load for exercises that prolong the acceleration sub-phase, like in a ballistic exercise.

2.6.3 Ballistic versus Non-Ballistic Exercises

Non-ballistic exercise is differentiated from ballistic by distinct phases, and the velocities in which these are executed. Namely, the distinction in braking phases, or rather decelerative component. Ballistic exercise can be thought of as projectile outward action, in which an external object (such as barbell) or one's mass, is propelled with sustained acceleration by application of the greatest force possible at a high velocity (Cormie, Mcguigan and Newton, 2010). It is these features which make ballistic resistance modalities preferred for power development over non-ballistic counterparts (Lake *et al.*, 2012; Suchomel *et al.*, 2018). As with all muscle action, the foundational principles of muscle physiology are key to understanding the context (Huxley, 1957; Hill, 1964). The linear force-velocity (F-V) relationship explains how at slower shortening velocity the greater the force generation from skeletal muscle fibres. Inversely, faster fibre shortening, lesser force (Samozino *et al.*, 2012; Alcazar *et al.*, 2019). The torque-angular velocity relationship has also been illustrated, following the pattern of declining torque with increase in fibre shortening velocity (Caldwell, Adams and Whetstone, 1993). In the context of ballistic exercise, performance is determined to a large part by the individuals F-V profile but also from the maximal mechanical power output (Pmax) (Samozino *et al.*, 2012). The latter is described as the greatest external force produced over one full extension, at speed. For the greatest transferability to sporting tasks, such as vertical jumping, it has been contended that exercise selection for power development is based on mechanical power output (Wilson *et al.*, 1993).

All resistance exercises can be largely classified along the F-V continuum. This includes intensity and the exercise selected (Cronin, McNair and Marshall, 2003). A trade-off exists in exercise selection between maximising force at the deficit of velocity, or vice-versa. For instance, a heavy constant resistance back-squat is placed on the upwards, left-side curve of force, and is performed with a considerably lower velocity than a jump squat. The jump squat is performed with significantly higher velocity specific to assigned exercise intensity (Baker, Nance and Moore, 2001). As the F-V curve dictates, this increase in velocity is at the expense of time to generate force, through less cross-bridge formation and lower resultant contractile force (Zatsiorsky and Kraemer, 2006). This 'sweet-spot' describes the optimal load for greatest force production in the shortest time, and the goal of strength and power training is ultimately to provide a chronic stimulus that induces a right-ward shift in the F-V curve. In practice, this means an exercise can be performed with heavier loads at equivalent velocities as before, having increased the RFD.

As evidenced, strength and power training in practice is often a weighing-up of what ‘end’ of the F-V curve is targeted by the combination of exercise selection and intensity. Often, practitioners will opt to train with moderate loads at higher velocities. However, contrary to this, is the discovery of velocity-specific training adaptations from higher loads lifted with fast ‘intent’ in the absence of high movement velocity. This relates to another characterisation of a ballistic exercise as the intention to maximise velocity across the ROM (Desmedt and Godaux, 1977). Intent is a concept of recruiting high-frequency motor unit, and high rates of force development against a load that renders the subsequent muscle contraction more isometric than concentric in nature. The intention to rapidly perform a movement against a high resistance, resulting in low velocity, can elicit a velocity-specific training response (Behm and Sale, 1993). More recently, this has been discussed within neuromuscular power, as to how the recruitment of high-threshold motor units affects Pmax (Cormie, McGuigan and Newton, 2011). As intent is predominantly neural in action, the pattern of muscle activation during such activities warrants discussion.

A resistance training modality that is closer to the velocity of a ballistic exercise whilst maintaining high force generation features of a non-ballistic exercise could be the solution for drawbacks of each respective modality. Likewise, maintaining velocity throughout the lift ROM is likely to reduce the decelerative sub-phase duration. Constant resistance is flawed in the ability to maximally activate the musculature throughout the ROM and matching the biomechanical advantage and torque production of strength curves. Sporting actions are generally ballistic in nature such as throws, jumps, drives therefore athletic performance should be trained as such. The research, although ambiguous, does indicate the unique F-V characteristics associated with variable resistance training (VRT) could provide this. This has been substantiated in the similarity of kinetic and kinematic patterns between variable resisted squats and ballistic equivalents (Israetel *et al.*, 2010).

2.6.4 Application of VRT

To match the strength curve of an exercise to the external resistance applied, a variable resistance method of training can be introduced. VRT is defined broadly as an alteration in the resistance applied and mechanical loading experienced across an exercise ROM (Wallace, Winchester and McGuigan, 2006; Mina *et al.*, 2014). In short, this is explained by reduced resistance (unloading) when torque production is lower; and resistance is greater (loading) when there is a higher mechanical advantage. This results in distinct kinetic and kinematics differences compared with other forms like constant resistance. Another benefit is the alteration in external resistance closer aligns with the ascending strength curve of the squat exercise. Firstly adopted as a tool for use in rehabilitation (Thomas, Müller and Busse, 2005), the advent of VRT within the strength and conditioning field has progressively increased. Early systems employed a series of cams and levers in fixed path resistance machines that operate by altering the external moment arm to match musculoskeletal torque production (Smith, 1982). A “dynamic variable resistance” device was created for which the kinetics determine resistive torque that changes according to human torque production (Ariel, 1976; Johnson, Colodny and Jackson, 1990). Based on the equation for torque as the product of force and moment arm length, changes can be made from variations in either. The resistive load remains fixed, meaning the variable resistance must be achieved through changes in moment arm length, specifically the radius of the cam system (McMaster, Cronin and McGuigan, 2009). A central limitation of the cam and levers approach is the lack of practical application. This is evident from research adopting uni-articular movements, such as knee flexion and extension, further limiting the applicability to multi-articular exercise, like the squat. Therein lies the disadvantage of such systems in sports performance as movements are not conventionally trained to occur under such controlled, fixed-path and restrictive ranges. Due to often non-weight bearing design of these systems, the activation of antagonistic and structural muscles may further be impeded (Foran, 1985). Nonetheless, this system still has merits and a place in rehabilitation for isolated muscle contractions (Dalleau *et al.*, 2010).

The nature of accommodating resistance means resistance is increased when strength is higher and decreased when strength is too. This remains true for all variable resistance methods and is espoused as the key advantage over using constant resistance. If VRT is to be used, then the means of applying the accommodating resistance should be specific to the exercise and the associated strength curve.

2.6.5 Current Methods

To make VRT more practically applicable to athletic performance training, a technique that can be utilised with conventional exercises was needed. This presented in the form of two equipment types: rubber-based elastic resistance, referred to herein as band resistance; and standard link steel chains, known as chain resistance. These are alike as the resistance increases with greater ROM, yet the manner this increase occurs differs. By design, bands have viscoelastic properties and are best described as having a tension-deformation relationship in which tension, or resistance, increases with deformation (stretch) in a curvilinear manner. Chains accommodate an exercise in a linear fashion, with resistance increasing with vertical displacement from the floor (McMaster, Cronin and McGuigan, 2009). As displacement from the ground increases, and the chain links unfurl and leave the ground in successive links, the resistive mass acting against the upward movement of the barbell increases. Both forms have been shown to effectively complement an ascending strength curve therefore are applicable to exercises such as the squat or bench press (Berning, Coker and Adams, 2004; Wallace, Winchester and McGuigan, 2006; Baker and Newton, 2009; McCurdy *et al.*, 2009; Israetel *et al.*, 2010; Saeterbakken, Andersen and Tillaar, 2015; Nijem *et al.*, 2016; Iversen *et al.*, 2017; Kubo *et al.*, 2018a; Wallace, Bergstrom and Butterfield, 2018).

Kinematic analyses highlight significantly greater barbell concentric phase velocity in squats with bands compared with free-weight (Saeterbakken, Andersen and Tillaar, 2015). Kubo (2018) reported greater mechanical power output, velocity, and total force during the decelerative phase of the back squat when using bands. Isratel (2010) research noted a significantly higher force in the final 10% of the concentric phase in squats with bands than without, coupled with higher velocity and power values near completion of the lift ROM. Conversely, others have reported no conceivable advantage for using bands over constant resistance free-weights (Ebben and Jensen, 2002). Likewise, chains have received a mixture of reviews. Baker and Newton (2009) reported a significant alteration in force and velocity profile of the barbell bench press when accommodated with chains. Both mean and peak concentric velocities were greater in chain condition. Similarly, the inclusion of chains to deadlifts, yet another ascending strength curve, led to significant increases in peak force and impulse relative to constant resistance; importantly, this occurred during the latter concentric portions to maintain positive acceleration across the ROM (Swinton *et al.*, 2011). Like bands, the benefits of chains have also been refuted (Ebben and Jensen, 2002). Providing a variable resistance across an exercise's ROM also protects the joints and muscles at the weakest portions of the lift. The unloading when the chain weight collects on the floor, thereby reduced resistance, is subjectively protective against injury at the shoulder joint in the bench press exercise relative to constant resistance (McCurdy *et al.*, 2009). In theory, the same could be said for the squat exercise as unloading in the lower portions of the lift may have a protective effect on spinal injury if an excessive anterior torso lean is present. Each of these resistance means are most akin to an ascending strength curve. Despite these shared benefits, the two methods differ in their usability and application in the field which is an important consideration when selecting a preferred VRT modality.

2.6.6 Practical Considerations

Practically, it is worthwhile to consider not only the technique but how it would be implemented, the safety, and the possible drawbacks. Bands and chains are similar in their application of resistance, however the material properties of each impart unique features. As described in 2.6.5, bands operate by tension-deformation and require a fixed attachment point for the stretch to originate. Bands have been commonly attached by a looped technique around the pegs at the bottom of a power rack and looped on the inside on the barbell cuff at the top, creating a triangular shape set-up (Berning, Coker and Adams, 2004). (McMaster, Cronin and McGuigan, 2010; Stevenson *et al.*, 2010; Wilson and Kritz, 2014). Alternatively, a choked attachment involves looping the band through itself to create a knot at the bottom that is anchored around a central rack peg, which is again looped over the barbell at the top in the same fashion (Shoepe *et al.*, 2011). This improves safety as when there is less band tension at the bottom of the eccentric phase there is a risk of the band slipping off and elastic recoiling; the choked attachment lessens the risk of this compared with the looped. In both instances, the band length taken up by stretch for attachment contributes to the total resistance (McMaster, Cronin and McGuigan, 2010). This is an important consideration for quantifying load for this mode in athletes of different heights. This is commonly determined by standing erect with the barbell on the shoulders to calculate the force exerted whilst standing on a force plate (Wallace, Winchester and McGuigan, 2006). This result can be paired with the percentage deformation, or change from resting length, to develop an equation to calculate the resistance experienced at different band lengths (Thomas, Müller and Busse, 2005). The additional time-investment this incurs to a research study, and the error involved, may reduce the inter-subject reliability. These equations rely on the resting length remaining constant and unchanged. The elastic properties of bands result in degradation with repeated use which can cause permanent stretch deformation and change the assumed resting length, leading to mean tension imbalances of between 8-19% (McMaster, Cronin and McGuigan, 2010). This reduces the safety and also validity of band resistance as changes in elasticity affect the calculation of length-tension based on elastic modulus for which is dependent on non-permanent deformation (Galpin *et al.*, 2015). Chronic training studies employing band resistance should therefore control for, through regular reassessment of, band resting length. A period of familiarisation is often required when adopting any new form of training, but particularly in the case of bands. The unfamiliarity of the active tension exerted when un-racking the barbell requires balance and coordination before the descent phase of a squat. This is coupled with the increase in eccentric velocity by the bands pulling downwards inducing a greater demand on technique. In well-trained athletes, this delivers a benefit in that the stretch reflex from fast eccentric loading and lengthening, termed pre-stretch, uses the SSC for an increased concentric force (Bosco and Komi, 1979; Doan *et al.*, 2002) Conversely, inexperienced resistance trained athletes may not possess the necessary SSC capacity (stiffness) to tolerate additional eccentric load, hence the recommendation to act with caution when applying in novice lifters (Shoepe *et al.*, 2011).

Chains also require a method by which they can be attached the barbell. Due to the linear-mass relationship, they offer the convenience of only requiring suspension from a single point, that being the barbell, and removing the need for anchoring to a fixed ground point. There are two well-established methods to achieve this: Firstly, the linear-hung approach suspends the heavy chain directly from the barbell cuff via clamps (Berning, Coker and Adams, 2004). A supplemental method, first proposed by Dermody (2003), follows the same principle but instead suspends the weighted chain closer to the ground by way of an intermediary light chain, termed the double-looped technique. For the same given length of chain, the linear-hung method means there is a lesser total loading and unloading and the actual average resistance is different (Neelly, Terry and Morris, 2010). When expressed as variable resistance efficiency, calculated from maximal load (N) at top of lift minus the minimal load at bottom and expressed as a percentage of total maximal load, double-looped bettered linear by between 35-60%. This can be attributed to the degree of chain link unloading in that upwards of 90% of chain weight was unloaded and reloaded compared with less than 50% in the linear-hung. To prevent disruption in exercise performance due to chain oscillation, it is also recommended 2-3 chain links remain on the floor at the top of the lift. The adoption of the double-looped technique highlights a secondary advantage of chains use over bands as an equated amount of variable resistance can be prescribed across a diverse participant group by adjusting only the smaller chain for height. Steel chains also have much greater longevity than bands as they are not subject to the stretch-deformation and have next-to-no risk of damage and breakage. There is continued debate as to the most efficacious mode of VRT, yet the practical advantages and the validity and reliability of chains make them more suited to chronic training studies and for the applied practitioner. Although, the unique tension properties of bands have a place in rehabilitation and may be used in the right context. To maximise the variable resistance stimulus the double-looped technique should be employed with chains.

A secondary key issue is determining the actual resistance provided. A common problem in both research and in practical application is ascertaining the specific load incurred at different points across the ROM (Wallace et al., 2006). This is expressed similarly across both chains and bands as a function of displacement. In short, resistance increases with increased displacement and is greater with band width and chain link diameter (McMaster, Cronin and McGuigan, 2010). The factors determining the resistance in bands are as follows: resting length, environmental conditions (humidity), and band dimensions such as cross-sectional area; and for steel chains: material density, link diameter, and total length of chain section. As a gravity-dependent means of resistance, chain link unloading is the constant factor, operating under the notion each link is identical. The question remains of at which point through the exercise ROM is the resistance measured. Arguably, an average resistance is more reflective of this modality as it only remains a set value at a single position. Resistance has been quantified at the catch position of the clean and prior to descent phase for the back squat using chains and bands, respectively (Wallace, Winchester and McGuigan, 2006; Berning, Coker and Briggs, 2008). For both, this measures the greatest resistance experienced across the entire lift, however it is important to note that when using chains, surplus links unloaded on the floor in the top position do not contribute. Average band resistance has been utilised in bench press investigations by summing the forces measured at the maximum and minimum of the ROM then dividing by two to obtain the mean (Rivière *et al.*, 2017). This has also been applied in combination resistance training, using both constant and variable elastic resistance, to determine the average variable resistance across back squat and bench press ROM by subtracting from bar weight (Anderson, Sforzo and Sigg, 2008b).

Having reviewed the established methods to calculate the resistance of different modes, it is important to determine which is the best variable load to use. That being, the load that facilitates maximal power output for a given exercise as evidenced in kinematic and kinetic analyses of VRT (Swinton *et al.*, 2011). A further consideration is whether the exercise should comprise of entirely variable resistance or a combination of traditional with variable. It is inconceivable that chains or bands could be used independently to provide high loading intensities at a sizable percentage of 1RM. This is evident in the literature as studies generally tend to compare constant resistance supplemented with variable resistance versus constant resistance alone at an equivalent intensity (Anderson, Sforzo and Sigg, 2008b; Baker and Newton, 2009; Israetel *et al.*, 2010; Shoepe *et al.*, 2011; Swinton *et al.*, 2011; Galpin *et al.*, 2015). Intervention studies have also considered the use of modalities independently of one another (Ghigiarelli *et al.*, 2009; McCurdy *et al.*, 2009). Of note, authors like Israetel (2010) identified the importance of equating total work in allowing for equivocal comparisons to be made between combined and single conditions, as well as normalising average resistance across ROM (Galpin *et al.*, 2015). In combined resistance studies specifically, Ebben and Jensen (2002) showed no significant differences between variable and constant resistance in muscle activation and ground reaction forces (GRF) when using 10% variable resistance in the combined modality. At greater variable proportions, peak power and force during the back squat increased when total load was comprised of between 20 to 35% of variable resistance compared to 100% of constant resistance alone (Wallace, Winchester and McGuigan, 2006). Comparisons have also been made between higher and lower variable contributions, namely 35% to 15%, with the remainder made of constant resistance at 65 and 85%, respectively (Galpin *et al.*, 2015). Results indicate variable resistance from bands provided little to no benefit when lifting at 60% 1RM but greater resistance from bands (35%) was favourable at 85% 1RM for peak and relative power as well as velocity markers compared with lower band resistance (15%) and a no-bands at all condition. This indicates a more is better approach when it comes to magnitude of variable resistance. However, studies have indicated a ceiling effect, especially at higher total loading intensities (> 85% 1RM). Using 35% variable resistant resulted in lower mean power relative to more moderate equivalent of 20% band resistance (Wallace, Winchester and McGuigan, 2006). This moderate load has been validated in bench press studies using circa 75% 1RM total load comprised of 60% 1RM constant plated resistance plus a standardised 17.5 kg of chain resistance across all subjects (Baker and Newton, 2009). Authors stated this equates to between 12-16% of individual 1RM, meaning the chains contribution is more akin to the 20% of total load. In the combined condition, positive results were obtained with significant increase in both peak and mean concentric velocity relative to constant resistance alone. Similarly, Kubo and colleagues (2018) used markedly lower total intensity (56% 1RM) across different proportions of variable band resistance for the back squat. Mean mechanical power output was significantly higher in a condition with 80:20 free-weight to band ratio compared to a no-band, 100% constant resistance squat. The studies cited generally expressed the amount of variable resistance as a percentage of total load however others chose to use variable resistance as a % 1RM. With variable resistance contributions as high as 40-50% of one's 1RM having been recommended (Ghigiarelli *et al.*, 2009). This adds another scope of complexity in drawing conclusions about prescribing load contributions, and the best approach for employing this across a diverse group of varied strength levels. A solution to which, is to set a desired ratio of accommodating resistance to plate-weighted barbell load and express as a percentage of total. Rather than employ an arbitrarily defined ratio of accommodating to free-weight resistance, future research may seek to establish an optimal individualised using a form of force-velocity profiling, namely mean of power and velocity in the propulsive concentric phase. This is done with the aim to elicit a greater maximal PAP response within the constraints of testing procedures and accommodating resistance available.

In summary, the ‘optimal’ load is within the range of 20% (± 5%) variable resistance contribution to total load and is recommended when performing ascending strength curve exercises at higher intensities (> 75% 1RM). This is high enough to experience the benefits of variable resistance, but not so great that the variable resistance begins to inhibit lifting performance over constant resistance alone.

2.6.7 Exercise Selection

In consideration that not all exercises are created equal, certain exercises, such as ballistic or non-ballistic, have different rationale and effectiveness when using VRT. In reference to section 2.6.3, ballistic exercise is clearly distinct from non-ballistic exercise. A well-studied sub-group within ballistic exercise is Olympic weightlifting, which has also been the focus of study using VRT modes (Coker, Berning and Briggs, 2006; Berning, Coker and Briggs, 2008). This differs from ballistic exercise as the barbell is constantly accelerated into projection until the catch position in which velocity returns to zero and in the absence of a clear deceleration period of a non-ballistic squat (Kawamori *et al.*, 2005). For the clean exercise, there was no benefit to maximal bar velocity and RFD detected for use of combined chain resistance over free-weight alone at 80 and 85% 1RM total load, however the percentage contribution from chains was only 5% which may have had a negligible effect. Additionally, kinetic and kinematic results showed no changes between traditional and combined chain resistance in lift execution (Coker, Berning and Briggs, 2006). In short, this evidence does not support the idea of using combined variable resistance modes over traditional barbell resistance for weightlifting in this context. Moreover, authors have cited additional safety concerns in such lifts as the risk to observers is increased with the dynamic nature of the lift and the displacement of chains, for instance (Berning, Coker and Adams, 2004).

Besides a lack of compatibility with VRT, weightlifting is a well-established approach for power development. Training for power has been surmised as follows: “near-maximal concentric-only contractions performed as fast as possible" (Schmidtbleicher, 1992). The question could then be posed if non-ballistic exercise can be adapted to fit this construct. Termed the Anderson and Pin squat within powerlifting, or concentric-only in published research, the movement involves driving upwards in the ascent phase from a static start at the bottom of the movement. This means only the concentric portion of the lift is performed. Beginning from a dead-stop position and moving upwards minimises the SSC contribution from eccentric phase and certain sticking-points can be isolated with adjustments to safety rack. The closest this has been investigated is with partial ROM squats performed with either ballistically or not (Suchomel *et al.*, 2015). The focus was on jump potentiation rather than lift kinematics and conclusions were made that ballistic outperformed non-ballistic equivalents. Concentric and partial ROM has merits in allowing for supramaximal training loads at certain points in a training block. Lifting velocity has also been compared between traditional (full eccentric and concentric actions) and a concentric-only half-squat, performed both as non-ballistic and ballistic. Mean propulsive velocity was higher using a traditional approach than concentric-only at each relative load (% 1RM) (Pérez-Castilla *et al.*, 2020). The ballistic variant outperformed non-ballistic within the traditional technique. Overall, conclusions were made that ballistic is better than non-ballistic and that traditional supersedes concentric-only for the outcome variable of concentric barbell velocity. Given the ingenuity of the partial ROM and concentric-only approach, it is yet to be fully examined empirically therefore traditional full ROM for exercises like the squat would continue to be recommended in this context based on the available findings. Different VRT modes used with non-ballistic exercises appear to have a positive impact on velocity profile whereas ballistic exercise has little to no benefit. Still, non-ballistic exercise performed in a ballistic manner has promise should this be investigated further.

2.7 Outcome Measures of PAPE

To quantify the extent to which a complex training approach potentiates performance it is imperative to collect objective data. Having a marker pre to post conditioning activity allows for a comparison on performance improvements or impairments. The following subsections will outline the rationale for the use of different CMJ metrics and the approach used to obtain these.

2.7.1 Vertical Jump Assessment

A common approach to assess lower-body ballistic performance is using a CMJ. This involves a rapid flexion of the hips and knees to shift the COM downwards followed by a reversal of movement and extend forcefully to propel the body upwards, and the hands remain placed on the hips throughout (arms akimbo) (Van Hooren and Zolotarjova, 2017; Sánchez-Sixto, Harrison and Floría, 2018). Easy to perform and non-fatiguing, the CMJ is the preferred field test to inform on neuromuscular force production and SSC capacity (McMahon *et al.*, 2018). A metric often relayed to an athlete is the output measure of jump height. The underlying driver behind a higher jump height is a greater vertical impulse: achieved by applying either more total force in the same time or increasing duration of force application, such as increasing the depth of the countermovement (Sánchez-Sixto, Harrison and Floría, 2018). When expressed relative to body mass, net vertical impulse is highly correlated to jump performance and is a relationship that exists independent of counter-movement depth (Kirby *et al.*, 2011). The strategy employed by the athlete to achieve maximal height is one that can be manipulated through other means. Jump strategy, such as counter-movement depth, has been noted as a confounding variable in the relationship between muscular power and jump performance (Sánchez-Sixto, Harrison and Floría, 2018). Squat depth during the descent is equivalent to the push-off distance, that being the extension distance the lower limbs move through from maximal negative displacement to take-off (Morin *et al.*, 2019). Comparable to Sánchez-Sixto and colleagues (2018) results, both counter-movement depth and body mass confound the relationship between jump height and muscle power (Markovic *et al.*, 2014). When such variables are controlled for, peak power and jump height have a significantly higher correlation.

Although out with the scope of this review, it is important to briefly discuss the two primary methods used for calculation of jump height: take-off velocity and time-in air/flight-time. The latter is used primarily by contact mat devices that detect a reduction in pressure from bodyweight, or the breaking of optical beam in case of a contact grid or optoelectronic device such as ‘Optojump’. This records the duration until pressure is detected, or beam broken, on landing (Glatthorn *et al.*, 2011). Contact mats and grids systematically overestimated vertical jump height despite high consistency of measurement relative to criterion system of force plates.

The validity of these devices has been questioned due to the susceptibility to manipulation by technique of the jumper to artificially extend the time off the ground. This is achieved by flexing at the hip, knee, and ankle prior to landing, or by tucking the body by flexing at the hip to elevate the COM (Moir, 2008). Correction equations have been proposed when using such devices to account for flawed determination of jump height (McMahon, Jones and Comfort, 2016). Results showed a contact mat proved a reliable measure of jump height (ICC = .96), yet significantly overestimated jump height relative to the reference force plate system; thus, to retain validity, authors advocate for using an equation to account for overstated jump height. These results agree with Moir (2008) who directly investigated the take-off velocity against the time-in-air method. Authors showed acceptable reliability, but inadequacies in the flight time method resulted in overestimation between ~3-4%. Instead, it is wise to use take-off velocity, should force plate technology be available, to ensure high validity based on these jump height definitions (Baumgartner and Jackson, 1998). The evidence provided allows for practitioners to ensure their measures are valid given the equipment to hand, and the possible sources of error in the data. A solution to control for this is to use devices that exclusively calculate jump height using the take-off velocity approach, such as force plates.

It is worthwhile to acknowledge the impact the menstrual cycle phase may have on power performance for the female participants with respect to male counterparts. Recent research found no diffences in strength and power, specifically CMJ, performance in female athletes between the follicular and luteal phase (Dasa *et al.*, 2021). Publications remain sparse in this area therefore it is important to still consider this factor until the evidence either supports or disproves any influence. Moreover, given the notable physical side effects female athletes can experience through using hormonal contraceptive use and the possible indirect negative effects on performance (Martin *et al.*, 2018).

It has been argued that the link established between mechanical power and jump performance is misguided, and what is indirectly measured is in fact the impulse produced to determine the outcome of jump height. The net impulse of both propulsive and braking force is responsible for propelling of body mass upwards(Kirby *et al.*, 2011) (Kirby *et al.*, 2011; Mizuguchi, 2012). Jump ability arises from the take-off velocity, as this is achieved from impulse generated not the muscular power and validated by Newton's second law of motion in the impulse-momentum relationship. A proponent of the theory proclaimed a 'perfect' relationship between impulse and jump-height (r = 1) (Winter, 2005). However, when studied directly, there exists a less than perfect correlation between relative net vertical impulse and CMJ height (r = .925) (Kirby *et al.*, 2011). It has been purported as a useful consideration for practitioners to implement impulse over peak force or power for insights to jump performance (Kirby *et al.*, 2011; McBride *et al.*, 2011; Winter *et al.*, 2016; Mundy *et al.*, 2017). In order to accuratley detect changes in athletic performance it is important to selelct metrics that are reliable.

Although biomechanically sound as a kinetic variable, and undeniable mathematically, using impulse alone to integrate jump height has been reviewed to ensure this provides a both valid and reliable marker of jump performance. It was shown net vertical impulse is highly significantly correlated with jump height in the CMJ in contrast to peak force which showed a negative, non-significant correlation with this metric (Kirby *et al.*, 2011). Considering reliability, studies have shown jump height to have acceptably high intra-class correlation coefficients of 0.88 and 0.87 in collegiate level athletes. For impulse,

Metrics not deemed to have acceptable reliability, defined as ICC > 0.8, in the same cohorts included relative peak force (ICC = 0.76), eccentric duration (ICC = 0.76), and concentric RFD (ICC = 0.57) (Byrne *et al.*, 2017; Merrigan *et al.*, 2020). Jump height has been shown to have an interday coefficient of variation (CV) of < 5 % and is considered an 'output' metric based on the goal of maximising height from the ground (Gathercole *et al.*, 2014). The use of jump height is therefore supported as it has established acceptable reliability and is relatable and easy to understand from a performance standpoint. However, rate and duration metrics have shown to be less reliable and do not warrant inclusion to measure changes in performance in repeated measures. Within the downwards or eccentric phase of the CMJ, depth and the eccentric braking RFD also showed high reliability (ICC = 0.90, 0.87, respectively) (Merrigan *et al.*, 2020). Moreover, eccentric RFD is said to be a predictor of jump performance in its representation of the ability to utilise the SSC (Laffaye and Wagner, 2013).

To conclude, it is not the jump height per se, but the mechanisms underpinning this that reflect true vertical jump performance, and which provide actionable feedback for training. Jump height could be used in conjunction with impulse. This would account for the underlying mechanics as explained by Newton's second law in that a higher jump height is achieved as a result of increased velocity at take-off which is determined by the impulse generated (Winter *et al.*, 2016). Metrics of interest could therefore be jump height and positive net impulse to provide a reliable and valid measure of the CMJ that remain sensitive to performance changes. Secondary metrics that merit consideration include peak power, braking (eccentric) RFD and countermovement depth. The latter of the three can be used to analyse changes in jump strategy or technique (Markovic *et al.*, 2014; Sánchez-Sixto, Harrison and Floría, 2018).

2.7.2 Portable Force Plates

The applicability of force plates to performance assessment accelerated the innovation for greater mobility and accessibility of such devices. As an alternative to immobile laboratory-based embedded platforms, portable-force plates offer a unique benefit. Hawkin Dynamics (HD) brought to the market the first portable and wireless device that connects to a tablet device via Bluetooth and uploads data direct to an online, cloud-based platform. The usability of this device across all environments warrants its consideration for use. The validity and reliability of this system was examined in a recent thesis which supported its use relative to a criterion, embedded force-plate device (Hudson, 2020).

Force plates provide a wealth of information on an array of different outcome and explanatory metrics (Lake *et al.*, 2012). Variables underpinning jump height, and indirectly time to take-off and take-off velocity, have been identified as impulse and mean force metrics (Lake *et al.*, 2018). Propulsive impulse and force variables were found to have greater within-session reliability and lower variation (R > .96; CV < 3.7%) than braking equivalents. These preliminary findings support the concept of impulse-momentum relationship to explain jump performance. A similar 2016 results concur with the above showing an agreement between portable and the lab based Kistler force platforms. Vertical impulse, time to and peak force were highly correlated between measures (r > .985). Recent results support the primary hypothesis that portable plates can be used interchangeably with a reference system to assess CMJ performance (Raymond *et al.*, 2018). Regarding the portability, floor surface such as differences between concrete and rubber matted floor were highlighted as a possible confounding factor in the reliability of metrics. Caution should be exercised if using across multiple surfaces to obtain reliable values that can detect functionally significant changes in performance. A grounding best resembling the criterion, gold-standard lab measure should be used, such as a concrete surface to minimise noise.

2.8 Research Rationale

As shown, the evidence for the use of VRT in the context of complex training is limited. Complex training has been established as an effective resistance training modality as evidenced by the numerous publications since its conception (Fleck and Kontor, 1986; Fees, 1997; Docherty, Robbins and Hodgson, 2004; Carter and Greenwood, 2014; Lim and Barley, 2016; Cormier *et al.*, 2020). However, despite claims of improved time-efficiency over traditionally ordered training, the extended ICRI employed in previous studies do not necessarily support this notion. Meta-analyses have shown the optimal rest-periods for potentiation benefit to be between 7-10 minutes based on a mean effect size of 0.7 (Wilson *et al.*, 2013). With favourable results only achieved with what could be referred to as extended rest periods. Complex training may then be deemed impractical in scenarios in which training time is already limited, hence the recommendation made for a optimal recovery time of between 3 and 4 minutes when in an applied setting (Lim and Barley, 2016). This time frame in line with the first publications on the topic (Fleck and Kontor, 1986). This highlights the disconnect between the scientific research and the realities and constraints of sports performance. Previous research has sought to address the issue and minimise the rest period required. Findings showed that peak power output is significantly increased with 60 seconds rest relative to an immediate jump effort at 15 seconds (Gowtage, Moody and Byrne, 2020). Albeit using a small sample size and a design failing to compare against a longer recovery time, such as the optimal 4 minutes cited in their paper, it provides evidence for performance benefit to be attained within a time-efficient window. However, much of the published research to date favours longer recovery intervals that are perhaps no more efficient than traditionally ordered resistance training for power development. Previous research has attempted to bridge this gap via novel application of VRT within a complex arrangement. Novelty in research is understood as provision of additional insight into a field of knowledge. Using a new study design or technique that has not been previously reported can lead to original findings and address emerging questions. The rationale for employing VRT is that the heavy loads (> 85% 1RM) typically used for complex training can result in performance impairment from fatigue that potentially masks any potentiation benefit early during recovery. Authors have therefore proposed that a combination of a moderate load accommodated by variable resistance may provide a similar enhancement but with reduced fatigue (Scott, Ditroilo and Marshall, 2018). Positive results have been documented, with a combined band condition providing 30% of total resistance shown to significantly decrease 10 metre sprint time 4 minutes after completing a set of back squats compared to no observable changes when using standard resistance alone (Wyland, Van Dorin and Reyes, 2015). Moreover, paused box squats at moderate resistance with the addition of bands were found to potentiate peak power output using a brief recovery of 90 seconds with large to very large effect size (Baker, 2008). Scott and colleagues (2018) suggest the benefit of VRT in this context relates to the increased contraction velocities across the exercise ROM, particularly in concentric action, which has greater transfer to the following plyometric action.

The current investigation is proposed to expand on recent work through direct comparison between traditional and variable resistance within a complex set. This was designed to isolate the effect of VRT on potentiation of jump performance across a spectrum of previously investigated recovery times to determine time-dependent effects alongside a condition-specific effect. The research intends to answer what effect the addition of VRT by chains has on vertical jump performance when performed in a complex set arrangement.

2.9 Aims & Objectives

The aim of this study was to determine the PAPE effect of a chain-resisted back squat preceding a CMJ in a complex set arrangement. It was hypothesised that:

- The chained complex set would elicit greater PAPE than traditional resistance within a single session; and
- Observed performance enhancement would be experienced at an earlier time-point across the post-CA period following chain squats

Chapter 3 Application of VRT to Complex Training

3.1 Methods

3.1.1 Research Design

This study used a within subject, repeated-measures cross-over design. Participants were required to attend three separate experimental sessions. An initial session was attended by all participants which included baseline measures and the control trial. The two further experimental trials were then performed in a randomised order.

3.1.2 Equipment

Hawkin dyanimc (HD) portable force plates were the force measurement system used in this investigation. The system records at a sampling frequency of 1000 Hz and was used on top of the centre section of an ESP™ Fitness (Elite Sport Performance Technologies Ltd) lifting platform (Figure 4-1). Data was collected using the Google Commerce Ltd *Hawkin Capture* application (Hawkin Capture Android Application v7.3.1, Hawkin Dynamics, Westbrook, ME, USA).

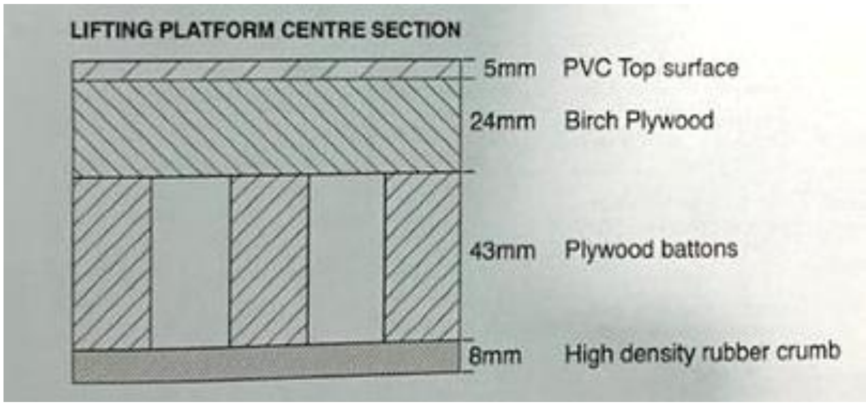

Figure 3-1. Schematic of lifting platform centre section.

A total of eight galvanized short-link steel chains with a diameter of 12 mm in identical lengths of 1-metre were used (GSproducts, Dudley, England). Steel chains were attached with 10 mm diameter steel bow shackles and 2.5 m long, 4.5 mm diameter zinc-plated [adjusting] chains on each side. These three components together constitute the entire system mass minus the weight of the barbell.

All trials were performed upon the lifting platform and within a Half Rack (ESP fitness, Loughborough, U.K.) using a 20 kg Men's Olympic training barbell (Uesaka Barbell Company, Tokyo, Japan), which is calibrated to within 0.5 kg of international weightlifting (IWF) standards. Traditional resistance was provided from custom-made ESP-Uesaka Competition plates ranging from 0.5 to 25 kg (UESAKA Barbell Company, Tokyo, Japan).

3.1.3 Protocol

Participants were required to attend an initial session to provide informed consent; collect height and body mass; determine 1RM back squat; learn warm-up protocol; and conduct the control experimental trial. Standing height (cm) was collected with a counter-weighted 'Harpenden' portable stadiometer (*Holtain limited*), and body mass (kg) using a digital scale (*SECA*).

Participants were directed through a dynamic warm-up routine (Table 3-1) by the principal researcher. This was designed to prepare the musculature for the movements involved in the bilateral squat pattern and vertical jump. Specific exercises selected were single-leg hip airplane with knee-drive (Pinfold, Harnett and Cochrane, 2018); supine bridge, quadruped arm and leg lift, and standing static lunge (Ekstrom, Donatelli and Carp, 2007); side lying gluteal clam with 60 degrees hip flexion (Distefano *et al.*, 2009).

Exercise	Sets	Repetitions
Single-leg hip airplane	1	6*
Supine bridge	1	10
Bird-dog	1	6*
Side lying gluteal clam	1	10*
Body weight squats	1	6

Table 3-1. Structure of the dynamic warm-up performed as ordered. *Each side

The attainment of 1RM back squat was completed according to National Strength and Conditioning Association (NSCA) guidelines under qualified supervision. Briefly, this consisted of a systematic increase in load to the point at which only one complete repetition can be executed whilst maintaining ‘proper’ technique (Haff and Triplett, 2016). Participants were instructed to self-select a warm-up load allowing 3-5 repetitions comfortably, followed by a 2-minute rest, then a further load increase of between 10-20% towards a near-maximal load for 2-3 repetitions, followed by a 2–4-minute rest. A final load increase was made for a first attempt at a 1RM. This was repeated by increasing and decreasing load until an admissible 1RM lift was attained: defined as a ‘parallel’ squat depth in which the inguinal fold of the hip is at least level with the knee joint. Subjectively, this is observed as the horizontal centre line of the thigh being parallel to the floor.

A period of time was allocated for participants to practice CMJ technique following a demonstration and verbal description. Instruction was given to complete the jump with arms fixed on the hips (akimbo) to control for differences in jump strategy observed with the use of arm-swing (Cheng *et al.*, 2008; Vaverka *et al.*, 2016). Participants were instructed to self-select a preferred countermovement depth before reversing this movement and rapidly extending the lower limb joints with the goal of projecting one's body mass vertically for maximal height. The extended posture was encouraged throughout flight phase, and cueing to avoid tucking or piking the lower limbs by flexing at the knee or hip.

A minimum 15 minute period of recovery followed the 1RM testing and CMJ practice. A baseline maximal effort CMJ was then recorded. This was followed by 5-minutes of passive rest before a timer was started to record jump efforts across the ICRI. A single maximal effort CMJ was performed at the following time-points: 0.5, 2, 4.5, 8, 12.5, and 18 minutes. A 30-second notice was provided for participants to regain their stance on the plates before recording.

In the no-chains trial, resistance was provided by plate weights alone to a total load of 85% 1RM. Plates were added evenly to each end of the barbell until the calculated working load was achieved to the nearest 0.5 kg. The chain trial used a combination of plate weighted resistance and pairs of steel chains. When used together, this totalled 85% 1RM at the top of the lift ROM. Average contribution of chains to total resistance for participants was 20.1 ± 3.5%. Once the appropriate numbers of chain pairs were selected, the remainder required to be made up from plates was calculated by subtracting the chain resistance total from the target intensity of conditioning activity back squats. Chains were affixed to the barbell as depicted in appendix 1.

On arrival, participants were reminded of the warm-up and instructed to complete the protocol in prescribed order. Following this, three submaximal repetitions were completed at 50% of one's 1RM for the back squat conditioning activity with either chains or traditional resistance as a specific warm-up to prepare for a high-intensity effort (Ribeiro *et al.*, 2020). A further 5-minute recovery period was allowed for residual fatigue from the warm-up to dissipate prior to a baseline CMJ. Subjects then performed 3 sets of 2 repetitions at 85% 1RM, with an auto-regulated inter-set rest period of around 15-30 seconds, which is consistent with the cluster set approach (Haff, Burgess and Stone, 2008). Upon re-racking of the bar after the final set, a stopwatch was started for subsequent CMJs as outlined in the control session at the same time-points of 0.5, 2, 4.5, 8, 12.5, and 18 minutes. A minimum of five days separated the chain and no-chain trials, with both conducted at the same time of day. This is to account for circadian rhythms in muscle strength and torque production of the knee and hip extensor musculature (Zhang, Dube and Esser, 2009).

3.1.4 Participants

A total of 12 ($n_{male} = 9$, $n_{female} = 3$) individuals volunteered for the study (mean ± SD: age = 22.7 ± 3.96 years old; mass = 79.3 ± 19.4 kg; height = 174.8 ± 9.4 cm). Inclusion criteria were a self-reported minimum 6 months of structured resistance training experience (training age = 2.4 ± 0.56 years) and demonstrate proficiency in the key technical aspects of the barbell back squat and CMJ. Participants were disqualified from taking part if there was any sign or reporting of musculoskeletal injury in either the lower limb or spinal area that would impair, or be worsened by, participation. This extends to answering 'yes' to ≥ 1 question in the PAR-Q. Evidence was collected for informed consent, training history and suitability to exercise (PAR-Q). Voluntary written consent was given on arrival at the initial familiarisation session. Ethical approval was granted by the University Ethics Committee: approval number UEC20/88.

3.1.5 Data Processing

Selected dependent variables were jump height (m) and positive net impulse (N.s). Jump height is defined as the maximal distance the centre of mass (COM) is vertically displaced, calculated using the velocity at take-off. Take-off point is defined as the last moment of weighting on the plate. Positive net impulse is the total impulse recorded above system weight of the propulsive and braking phases. This can be identified as the area under the curve, but above zero, on a force-time curve plot.

3.1.6 Statistical Analyses

No formal statistical analyses were conducted due to the sample size used. Results were produced using custom Microsoft Excel tables and data analysis formula (Microsoft Excel for Windows).

3.2 Results

Tables 3-2 displays 1RM test results. In absolute terms, the average load lifted was 124 kg with a large standard deviation (50.7 kg). When expressed relative to body mass, calculated by dividing 1RM load (kg) by body mass (kg), the mean 1RM was 1.53 with a standard deviation of 0.35. All participants self-reported as trained, with an average 2.4-year history of structured resistance training and standard deviation of 0.6

Comparison results between conditions are presented in table 3-3. Across all variables, mean score was higher in chain than in no-chain trial. For depth of countermovement, mean distance was greater by 0.01 m in chain than no-chain with control having lowest depth of -0.31 m. Average propulsive force, peak propulsive power and force at minimum displacement was greater in control trial than both exercise conditions. Positive net impulse, average braking force and time to take-off was higher in chain trial than control.

Table 3-4 provides the comparison results between conditions for jump height. The greatest percentage change was between no-chain and control by -4.5% with a trivial effect size (d < 0.20). For positive net impulse, the largest difference lies between chain and control by 2.34%, also with a trivial effect size (d < 0.20). Across both variables, jumps in chain trial increased by 2.67 and 2.23% over the no-chain trial.

Table 3-2. Participant physical performance and training status characteristics.

		mean ± SD
1RM back squat	Absolute load (kg)	124.17 ± 50.7
	Relative load ($kg \cdot kg^{-1}$)	1.53 ± 0.35
Training History	Age (years)	2.4 ± 0.6

	CMJ variables (mean ± SD)		
	Chain	No-chain	Control
Jump Height (m)	0.32 ± 0.07	0.31 ± 0.08	0.32 ± 0.09
Positive Net Impulse (N·s)	295.46 ± 71.02	289.02 ± 68.50	288.71 ± 70.61
Peak Propulsive Power (W)	3725.71 ± 1092.18	3707.81 ± 1069.00	3769.35 ± 1072.85
Braking RFD (N·s^{-1})	5900.44 ± 2129.90	5803.68 ± 1494.03	6495.20 ± 2066.92
Countermovement depth (m)	-0.34 ± 0.06	-0.33 ± 0.06	-0.31 ± 0.06
Force at minimum displacement (N)	1763.78 ± 418.04	1736.69 ± 371.88	1780.64 ± 374.79
Average Braking Force (N)	1352.57 ± 286.75	1342.50 ± 274.74	1346.96 ± 262.98
Average Propulsive Force (N)	1479.39 ± 396.14	1458.55 ± 364.93	1499.46 ± 388.26
Time to take-off (s)	0.85 ± 0.12	0.84 ± 0.11	0.80 ± 0.15

Table 3-3. Descriptive statistics of CMJ variables by exercise condition, averaged of all jumps completed post-conditioning activity.

Table 3-4. Percentage change in mean and effect size (cohen's d) for jump height and positive net impulse between exercise conditions. Average for jumps completed post-conditoning activity

	Jump Height		**Positive Net Impulse**	
	Change (%)	**Cohen's d**	**Change (%)**	**Cohen's d**
Chain - Control	**-1.95**	**-0.08**	**2.34**	**0.10**
No-chain – Control	**-4.5**	**-0.18**	**0.1**	**0.004**
Chain – No-chain	**2.67**	**0.11**	**2.23**	**0.09**

Table 3-5. Percentage change in mean of jump height from baseline across jump interval by each condition. Effect size reported as cohen's d.

	Change (%)		**Cohen's d**	
Jump interval	Chain	No-chain	Chain	No-chain
0.5	-2.56	-3.43	-0.12	-0.17
2	2.49	-1.50	0.11	-0.06
4.5	1.66	-2.93	0.07	-0.13
8	-1.10	-2.83	-0.05	-0.12
12.5	-3.04	-8.18	-0.13	-0.36
18	-5.21	-8.79	-0.24	-0.43

Table 3-6. Percentage change in mean of positive net impulse from baseline across jump interval by each condition. Effect size reported as cohen's d

	Change (%)		Cohen's d	
Jump interval	Chain	No-chain	Chain	No-chain
0.5	0.52	0.10	0.02	0.01
2	2.23	-2.14	0.09	-0.09
4.5	1.86	-1.24	0.07	-0.05
8	0.29	-2.12	0.01	-0.09
12.5	-1.58	-4.12	-0.07	-0.17
18	-2.48	-3.72	-0.10	-0.15

As table 3-5 shows, the greatest mean change from baseline of –8.79% was observed at 18 minutes under no-chain condition with a small effect size (0.2 ≤ d < 0.5). This followed a trend of negative mean difference from baseline under this condition with similar change of –8.18% at 12.5 minutes. The greatest change from baseline in chain trial also occurred at 18 minutes by –5.21%, with a small effect size. Mean change at all other time points had trivial effect sizes (d < 0.20). In both chain and no-chain trials, jump height decreased at 0.5 minutes by –2.56% and –3.43%, respectively. A positive mean change of 2.49% was found at 2 minutes in chains which reduced to 1.66% at 4.5 minutes. This continued to decrease beyond 4.5 minutes with an increasing negative percentage change to 18 minutes. These results are also displayed in Figure 3-2 showing change over time-course of jumps. Positive change is only visible between 0.5 and 8 minutes in the chain trial. There is a steady decline observed beyond a high of 2 minutes which continues from 8 minutes onwards. The trend for no-chain trial shows an immediate decline, a brief recovery at 2 minutes followed by a steady decline again before a marked large negative difference beyond 8 minutes.

The percentage change across jump interval was minimal and less pronounced overall for impulse (Figure 3-6). The greatest positive mean change of 2.23% occurred at 2-minutes with chains. The greatest negative change of -4.12% occurred at 12.5 minutes under no-chain condition. All effect sizes reported for this variable were trivial ($d < 0.20$). Under both conditions a similar trend was observed for impulse (Figure 3-3). There was a positive percentage change from 0.5 to 8 minutes with a negative decline from 12.5 to 18 minutes. For no-chains, there was minimal observable change immediately at 0.5 minutes which declined at 2 minutes before an increase, but remaining negative, to 4.5 minutes after which there was a decline to 18 minutes.

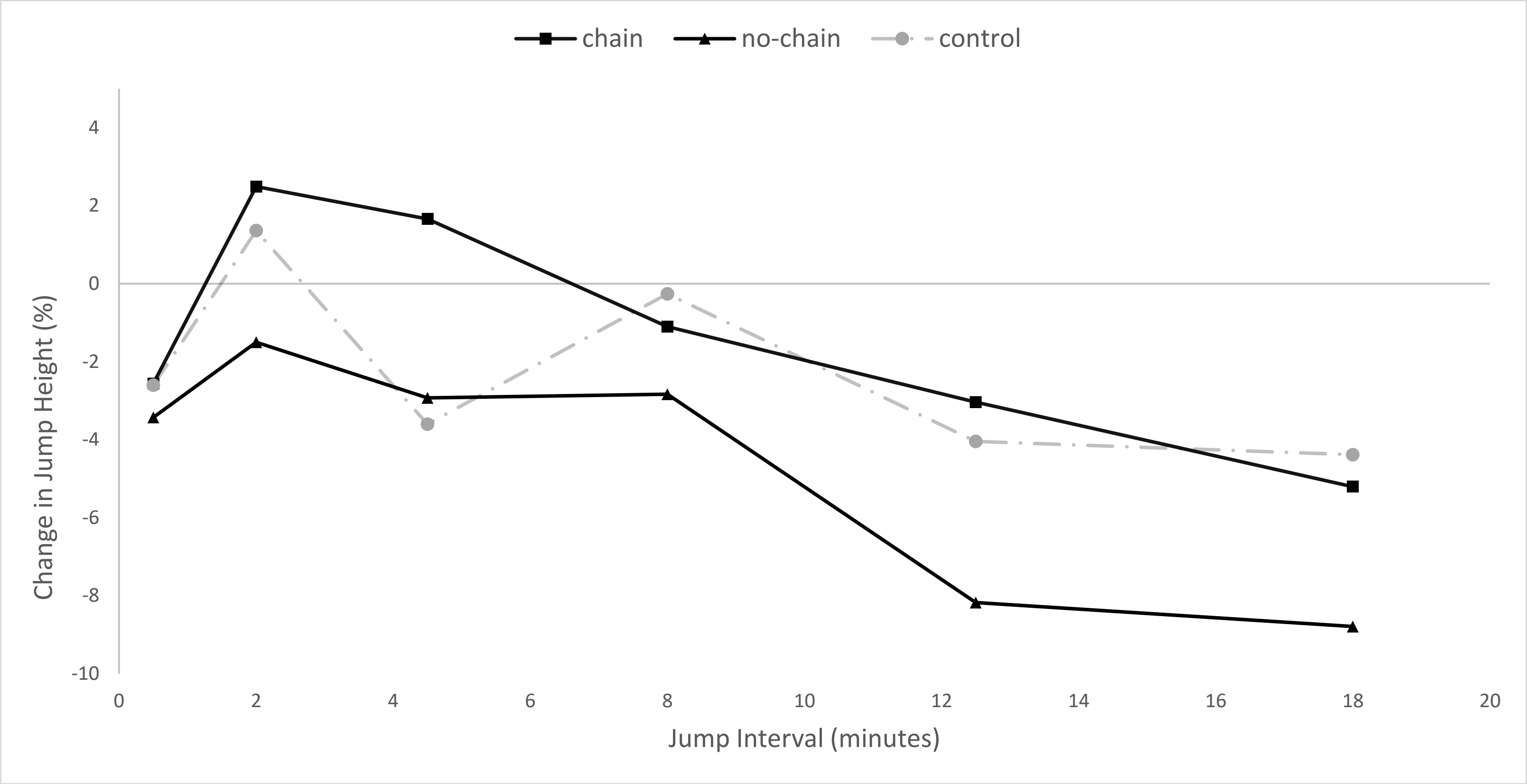

Figure 3-2. Mean change in jump height over time for experimental conditions. Results are expressed as the percentage change from baseline jump recorded for each respective session.

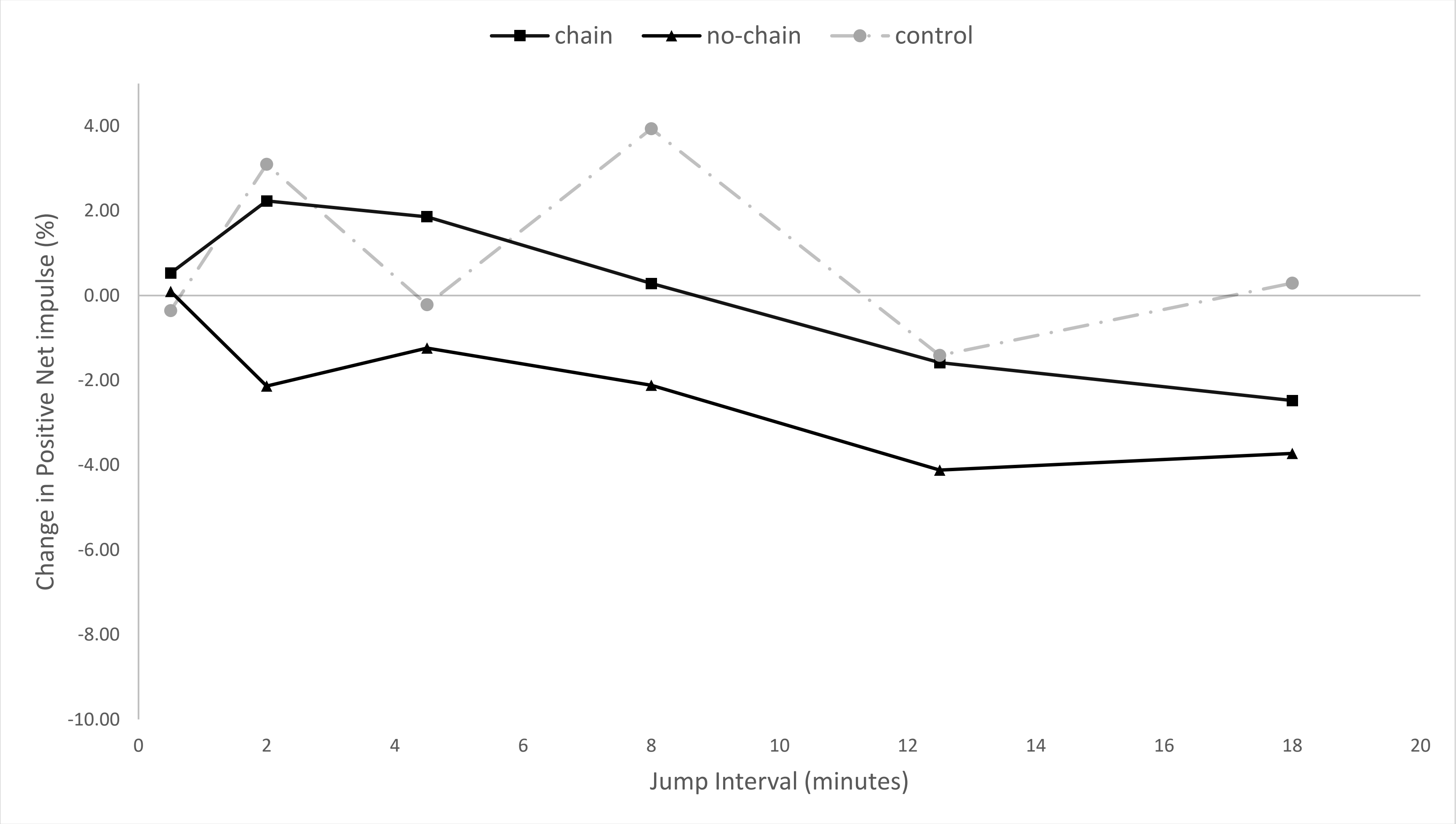

Figure 3-3. Mean change in positive net impulse over time for experimental conditions. Results are expressed as the percentage change from baseline jump recorded for each respective session.

3.3 Discussion

The primary aim of this study was to investigate the acute effects of using variable resistance in a complex set on vertical jump performance. Main findings of the research demonstrate that the use of variable resistance chains with a back squat is effective at improving performance in a vertical jump at certain time points relative to an equivalent no-chain, traditional resistance. Also, traditional resistance resulted in a performance decrement that increased over time and was, on average, less than a passive control.

For exercise condition, the mean jump height was higher in the control trial than no-chain by 4.5%. This was also found in chains but by a decrease of 1.95% relative to control. Jumps performed following chain squats were also, on average, improved over a no-chain equivalent for both jump height and positive net impulse by 2.67 and 2.23%, respectively. This can be interpreted that the no-chains condition impaired performance to a greater extent than chains, therefore confirming the first hypothesis. These results are in line with previous research in which no significant improvements were reported following a heavy, back squat condition (Jensen and Ebben, 2003; McCann and Flanagan, 2010; Scott, Ditroilo and Marshall, 2017). However, findings substantiating the use of variable resistance in complex training are lacking. The difference in response between exercise conditions employed in this study may be explained by the nature of VRT. As reviewed previously, VRT alters the resistance experienced across the ROM and involves a degree of eccentric unloading relative to constant resistance. Reducing the load towards the bottom of the lift means the total eccentric work is less than a free-weight equivalent and fatigue is also decreased as a result. This provides an explanation to why performance decreased in no-chains relative to the control in which there was no fatiguing stimulus applied. Moreover, VRT results in higher concentric velocities and power output (Saeterbakken, Andersen and Tillaar, 2015; Kubo *et al.*, 2018a). Given promising findings following high-velocity Olympic lifts (Andrews *et al.*, 2011), it is credible to assume the PAPE benefits VRT provides in complex training is velocity-specific. However, as movement velocities were not recorded in this study, the author does not attest that the squats using chains were performed faster than without. To confirm whether this is true, future work could employ technologies such as a linear position transducer as an objective measure of lifting velocity (Moreno Villanueva, Pino Ortega and Rico-González, 2021).

A difference in response between key metrics of jump height and positive net impulse was observed across the time points and at the session level average. Impulse was 2.34% greater in chain trial than in control whereas there was a decrease of 1.95% in mean jump height for chains versus control (Table 3-4). Considering tables 3-5 and 3-6, the percentage change in impulse was positive at all but two time-points, whereas for jump height there was a more pronounced percentage decrease at four of six recovery intervals. Therefore, the impulse appears maintained despite a decrease in jump height. This finding is unusual and is difficult to explain given the interrelatedness of variables from the same jump. Possible reasons may be related to jump strategy between conditions, for instance longer braking phases and smaller forces earlier in the CMJ action over a longer total duration would result in same impulse but may not translate to greater take-off velocity and therefore higher jump height. This theory, however, is unsupported by the literature. Sanchez-sixto et al. (2018) found a larger countermovement increases jump height because of greater net vertical impulse. Corroborated by results showing highly significant correlations of net vertical impulse to jump height, independent of changes in squat depth of countermovement (Kirby *et al.*, 2011). Analysis of force-time curves may also help to explain and visualise this concept, which is covered in a comprehensive biomechanical review of GRF profiles of the CMJ (Cohen *et al.*, 2020). Positive net impulse is the total impulse of the propulsive and braking phases above system weight. Changes in duration or magnitude of force in each phase could perhaps change the resultant impulse. Also, the phase in which force is applied has influence on take-off velocity and overall jump height. Propulsion and braking phase duration and the corresponding average forces could explain these findings. There was longer duration of both phases in chain trial jumps than control along with a greater average braking force (Table 3-3). Interestingly, average propulsive force was higher in control than in chains. Previous research has shown a 5% increase in weighting phase impulse for the maximum PAPE response (McCann and Flanagan, 2010). The weighting, rather than unweighting, impulse is comparable to this study as positive net impulse describes the period in which GRF's are collected above system weight.

In future experimentation, authors could consider other GRF metrics that provide information on absolute magnitudes of force like peak propulsive force.

Under both conditions, jump height and impulse at the immediate time-point of 30 seconds decreased from baseline. This is consistent with previous work in which 10-30 seconds recovery resulted in significant decreases in jump performance (Jensen and Ebben, 2003; Kilduff *et al.*, 2008; Crewther *et al.*, 2011; Scott, Ditroilo and Marshall, 2018; Gowtage, Moody and Byrne, 2020). This could be explained by fatigue being predominant over potentiation following any heavy conditioning activity. In other words, early in recovery any PAPE effects are masked by fatigue regardless of resistance mode applied. This can be understood by Sale's (2002) fatigue-potentiation model (Figure 2-1) and acknowledgement of the coexistence of fatigue and potentiation (Tillin and Bishop, 2009). Notably, performance recovers under the chain condition as observed by a positive change from baseline at 2 and 4.5 minutes for jump height and at 0.5, 2, 4.5, and 8 minutes in impulse, although change at 0.5 and 8 minutes were minimal (≤ 0.5%). This is consistent with the mechanisms discussed by Tillin and Bishop (2009) that fatigue dissipates at a faster rate than potentiation and there is a point at which a PAPE effect could be realised when potentiation is dominant. By definition, PAP is transient in action (Sale, 2002) therefore the findings of only brief improvements in performance are understandable. This appears to be the case following chain squats, however, change from baseline was negative across all timepoints in no-chain trial for both metrics. This fails to show a PAPE effect and likely fatigue outweighs the potentiation induced. Increasingly negative changes over the time course of multiple jumps indicate an accumulation effect of fatigue, however no additive effects have not been reported in the literature to this author's knowledge. It is fair to speculate changes observed at latter time points may be unrelated to physiological changes entirely and more reflective of changes in jump strategy or effort relating to arousal levels. Decreases in performance beyond 10 minutes have been reported in meta-analyses (Wilson *et al.*, 2013), however the authors offered no explanation for this finding. Current findings provide support for use of shorter time frames. In contrast, prolonged recovery of 8-12 minutes has been favoured when using heavy, traditional resistance modes (Gouvêa *et al.*, 2013). This effect was not currently evident as no-chain, traditional failed to elicit any measurable PAPE response, and performance was measured during the time frame and beyond. Improvements in performance have been reported at earlier time between the window of 30 seconds and 10 minutes. Gowtage et al. (2020) reported significant improvements in peak power output at 60 seconds in comparison with 15 seconds following 3 repetitions of front squat at 80% 1RM. This does provide support for use of minimal recovery times over immediate; however, this research did not investigate jumps performed at time-points beyond the 60 seconds and failed to include a baseline jump to compare against. Longer ICRI than this warrant consideration, such as the range between 2-7 minutes classified as ‘short’ and as employed in this study (Wilson *et al.*, 2013). Taken together, shorter ICRI have been shown to be more effective than longer times previously reported in the literature. This confirms another hypothesis of this study that application of chains as VRT can elicit a PAPE earlier in the time course. It provides the applied practitioner confidence that, in athletic populations and with variable resistance, complex training is implementable within a narrower window than that provided in recommendation papers of between 1-12 minutes (Carter and Greenwood, 2014).

It is worthwhile to consider the strength levels and training history of this study group. Improved PAPE responses have been shown to be mediated by strength (Chiu, 2003; Wilson *et al.*, 2013; Seitz, de Villarreal and Haff, 2014). Fitness increases with training age which for strength involves muscle cross-sectional area and contractile protein structure (Chiu and Barnes, 2003). Stronger individuals can achieve greater PAPE response from shorter ICRI and higher intensity conditioning activities, with the reverse true for weaker individuals. This is linked to training history as those with higher age are likely to have developed greater strength than novice strength trainers, evidenced by larger ES for trained individuals (ES = 0.53) than in inexperienced individuals (ES = 0.07) (Seitz and Haff, 2016). Average training history of participants in this current study was 2.4 years which is in line with the ‘experienced’ classification of >2 years training by Seitz and Haff (2016). It could be inferred that more experienced individuals like those recruited for this study would exhibit greater PAPE effects than inexperienced counterparts. However, no grouping by training history was made and it cannot be determined that this influenced the response. Relative strength gives an indication of muscle force per unit of cross-sectional area (Maughan, Watson and Weir, 1984). For example, two athletes with an equal mass of 50 kg can lift 75 and 100 kg, respectively. The latter has a relative strength of 2 $kg \cdot kg^{-1}$ and is effectively stronger, can produce higher maximal force against resistance, per kg than the former whose relative strength is 1.5 $kg \cdot kg^{-1}$. Expressing strength as such allows comparisons across participants Muscle fiber pennation angle is also related to force production (Ikegawa *et al.*, 2008) in addition to the neural adaptations experienced from resistance training such as greater agonist activation (Jenkins *et al.*, 2017). Since muscle architecture or muscle activation via EMG were not assessed any conclusions drawn are speculative and it is suggested future research seek to measure muscular underpinnings of strength should this be considered relevant for PAPE. Whether or not strength was a mediating factor in the PAPE response within this current study remains unexplained but based on previous research it would warrant investigation. Relative strength thresholds have been reported as > 1.75 and > 1.5 kg·kg of bodyweight for men and women, respectively (Seitz and Haff, 2016). Practical guidelines published for complex training have detailed target relative strength values of ≥ 1.8 1RM (Lim and Barley, 2016). The majority of the present study participants were male, with an average 1RM of 1.53 which falls short of this threshold. It may also explain the negative responses especially in the no-chain trial as participants were perhaps overly fatigued from the conditioning activity to elicit any PAPE effects. Stronger individuals have been theorised to experience this benefit not because of a faster potentiation response per se, but instead an enhanced ability to withstand the fatigue induced by the intense conditioning activity (Chiu and Barnes, 2003). Thereby, with lower starting levels of fatigue, and a possible higher rate of dissipation, it can be speculated that PAP would be observed sooner in such individuals. This is speculative since fatigue was not directly measured and was interpreted as a decrease in jump performance compared to a passive control. Future investigations into PAPE could therefore group individuals by relative strength levels and training experience to determine whether this mediates the responses observed.

In summary, and based on the evidence to date, eliciting a PAPE response is determined by the balance of fatigue and potentiation at the muscular level (Tillin and Bishop, 2009; Seitz and Haff, 2016). This is influenced by characteristics of the conditioning activity, which this study primarily investigated, in combination with the physical characteristics of the individuals studied. This study compared different forms of resistance training for the same exercise at a set volume and intensity across different ICRI. These results highlight that use of this volume and intensity of conditioning activity with traditional resistance offer no additional benefit within a complex set over a control. The fatigue induced by traditional resistance at this intensity prescription likely outweighed any benefit from muscular potentiation. However, the unique loading pattern VRT provides elicited a PAPE response thus validating its use as an effective modality in place of traditional resistance for complex training.

3.3.1 Limitations

A central limitation to this study is the lack of standardisation of the total resistance between conditions. Although resistance was established as 85% of one's 1RM at the top of the back squat, there was no calculation made for the changing resistance across the ROM when using chains. This is likely to have resulted in the lifter experiencing 85% across the full ROM during traditional with substantially less within chain conditions during the unloading portion. Including the average opposed to the total at end range would have equated the conditions. The omittance of any correction has implications for interpretation of results as the mechanical work performed is greater and fatigue likely higher under traditional conditions through lifting a higher average load. Simply performing the squats on top of the force plates would have sufficed, as has been done previously (Israetel *et al.*, 2010). Another solution is to average the load incurred across the ROM when using variable resistance and then to use this prescription to equate the load for traditional resistance (Anderson, Sforzo and Sigg, 2008a; Galpin *et al.*, 2015). For example, the top of a chain resisted squat was determined as 90% 1RM and at the end ROM. With chains unloaded, this was then hypothetically only 65% 1RM meaning an average load of 77.5%. The traditional, no-chain would therefore be able to add this using plate-weights only. The

The total intensity of exercise for conditioning activity was standardised between participants. However, due to high absolute strength and a finite number of chain pairs, the percentage of total bar load chains provided varied considerably across participants. The average ratio of variable resistance: constant in this current study was 20%. Significantly higher power values occur with a VR of 20% versus 35% at an intensity of 85% 1RM (Wallace, Winchester and McGuigan, 2006). GRF's of chained squats was no different than traditional resistance when VR ratio was only 10% (Ebben and Jensen, 2002). These findings suggest that the magnitude of resistance from a variable form is a discerning factor in kinetically altering an exercise. An upper variable resistance ratio was decided on for this study however, due to large variation in absolute 1RM, the chain combination that brought an individual closest to this figure was selected. There were only four increments of chains at the investigator's disposal which resulted in a large deviation across individuals with VR ratio ranging from 13.4 to as much as 24.6%. The stronger individuals, receiving a lesser contribution from chains than weaker counterparts, may in fact not exhibit a positive PAP response as would be expected. At these higher lifting intensities, the change between conditions is lessened therefore the ability to discern a difference could be diminished. In future experimentations one of two solutions could be considered. Firstly, one would seek to employ a greater number of chain combinations at smaller increments to account for inter-individual differences in strength. Secondly, should the same equipment be used, those with very high strength would be excluded because of the resultant low variable resistance ratio.

Lastly, a larger sample size pooling from a diverse group of athletes with varying maximal strength levels would allow for greater statistical power for detection of effects and thorough statistical analyses to occur. This study included a subset of females for which the effect of menstrual cycles on power performance was not considered. If this study was to be repeated, awareness of the effect this may have on performance and the variations over multiple experimental trials would be useful. Furthermore, higher numbers of participants would allow for distinct groups to be assigned for strength levels, training age or athletic background. Results could then be analysed using said factors as additional independent variables to evaluate whether this influences the PAPE response.

3.4 Practical Applications

Strength and conditioning coaches and other applied practitioners have been provided with evidence in support of the combining VRT and complex training. The methods by which chains can be implemented have been outlined along with benefits of how VRT may overcome some of the practical drawbacks of complex training with regards to time. Of interest, are the findings that jump performance is increased from baseline by chains at 2 minutes. The ability to enhance performance in a short timeframe has applications to sporting performance. For example, using a chain-resisted squat as a power training technique would all for an entire set to be completed in 3 minutes or less, accounting for the time to perform the conditioning activity and 2-minute ICRI. This is in comparison to performing straight sets of both high and low load exercises separately with a recommended 3-5 minutes rest between each set of single or multiple-efforts (Haff and Triplett, 2016) Moreover, this could be used prior to performance of single-effort jumping events like the high or long-jump should the facilities be available to setup the squat arrangement. Access to facilities and setup required remains a primary limiting factor in applying the complex training method pre-competition or as a component of an extended preparatory warm-up.

Given the equivocal nature of the current findings, the factors identified in research as modulating the PAPE response, such as training history and exercise modality of the conditioning activity, remain pertinent and warrant consideration before implementation. Variable resistance in the form of chains appears advantageous over traditional resistance in this complex arrangement. Other factors worthy of consideration before utilising this training method include the selection of practically feasible ICRI's and the specific exercise selection, including the volume and intensity prescribed. Moreover, this research helps to inform the applied practitioner on how variable resistance is best arranged and for conventional exercises like the barbell back squat. It also provides coaches with a method to accurately prescribe training intensities by quantifying the variable resistance equipment. It was evidenced that with readily available and affordable equipment in the form of light chains and carabiners, steel chains can be attached quickly and securely without requiring modifications to the rack or lifting platform itself. This provides reassurance to professionals working with limited resources that VRT is an accessible resistance modality should they wish to employ it.

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Appendix A. Pilot testing to quantify resistance modes

A series of pilot tests were performed to determine the weight of variable resistance equipment using the HD wireless dual platform force plate system (Hawkin Dynamics, Westbrook, ME, USA). This quantification of the weight of the steel chains allowed accurate comparisons to be made between measuring in-situ versus an estimated, aggregate weight from weighing of the sub-components independently. This was to confirm the assumption the weight recorded from sub-components when measured individually would be the same as when the system weight was measured directly as in the trial setup.

Each component was weighed together to generate a sum for the weight (N) of a single chain system (Figure 1). This was then multiplied by a set number of chains to calculate an estimate of total system static weight and expressed as mass (kg) for each chain pairing (Table 1). Any weight contribution from additional carabiners (< 1 N) was regarded as negligible. Data was collected using the 'free run' test protocol for average total force (N). Components were weighed using the right [hardware] plate whilst the left 'slave' plate remained unused (Figure 1B).

This trial sought to identify differences between the indirect estimate and the directly measured mass of the chain system. The latter refers to when chains are affixed to the barbell. The steel chain(s) remain in proximity to the floor and were suspended from the barbell by way of the bow shackle and carabiner via the adjusting chain (Figure 2), termed the double-looped technique (Neelly, Terry and Morris, 2010). Firstly, the participant's weight was recorded with a 20 kg barbell resting across the posterior deltoids in the 'high bar' position (Myer *et al.*, 2014). The total force for this arrangement was measured, adding chains sequentially from 1 to a total of 4 per side. The actual weight of the system (N) was calculated by subtracting the force exerted by the participant and the barbell alone. The sum of this, when deducted from the force exerted with a said number of chains, is taken as a direct measure of the system. The protocol was adapted from previous literature using bands (Wallace, Winchester and McGuigan, 2006; Scott, Ditroilo and Marshall, 2018), and a similar system using an adjustable rack for chains (McMaster, Cronin and McGuigan, 2010). In both instances, by either zeroing the force plate between measures, or subtracting the known constant of body weight plus barbell from total force, the sum is equal to that of the chains.

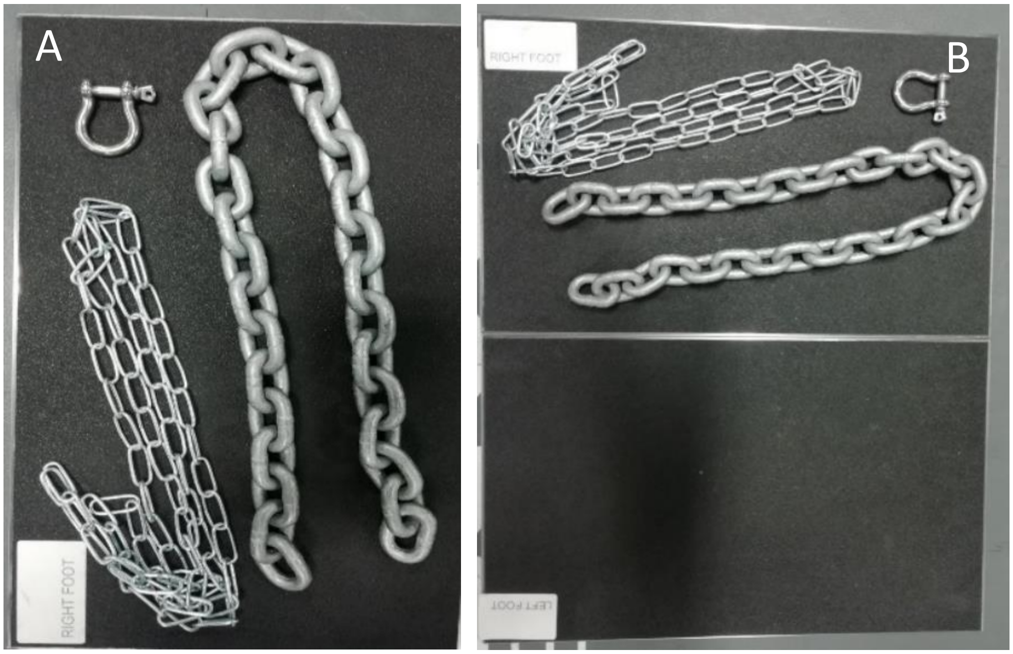

Figure 1. A) arrangement of chain system: one steel chain, bow shackle, and adjusting chain. B) unilateral measure using right plate only.

The length of the adjusting chain that corresponds to two links remaining on the floor at full range of motion (ROM) was then determined. The participant was instructed to remain “flat footed” and stand upright with full hip and knee extension (Figure 2). On one side of the adjusting chain the number of links between the barbell to attachment onto carabiner were recorded.

Figure 2. Arrangement of 4-chain system using the double-looped technique to a barbell and details the chain unloading.

Differences between the estimated and directly measured system weight for each chain combination are displayed in Table 1. The difference between indirect-direct increased in a stepwise fashion with an increasing number of chains. The greatest difference was observed in 4 chains and smallest for 1 chain with a mean difference of 3.7 and 0.3 kg, respectively. When expressed as percentage change there is an approximate 0.05% greater change in indirect-direct from 1 to 2 chains which reduces between 3 to 4 chains. The results of both measurement approaches were highly correlated as documented in Figure 3 ($R^2 = 0.99$).

Table 1. comparative results between indirect and direct total system weight (N), differences expressed as mean and percentage change.

number of chains (Per side)	Indirect		Direct (mean ± SD)		Δ between methods (indirect-direct) (mean)	
	Mass (kg)	Weight (N)	Mass (kg)	Weight (N)	Weight (N)	Percentage (%)
1	7.2	70.3	6.8 ± 0.03	67.2 ± 0.31	3.1	4.6
2	14.3	140.6	13.0 ± 0.37	127.2 ± 3.65	13.4	10.5
3	21.6	212.2	18.9 ± 0.31	185.5 ± 3.08	26.7	14.4
4	28.8	282.5	25.1 ± 0.37	246.0 ± 3.62	36.5	14.8

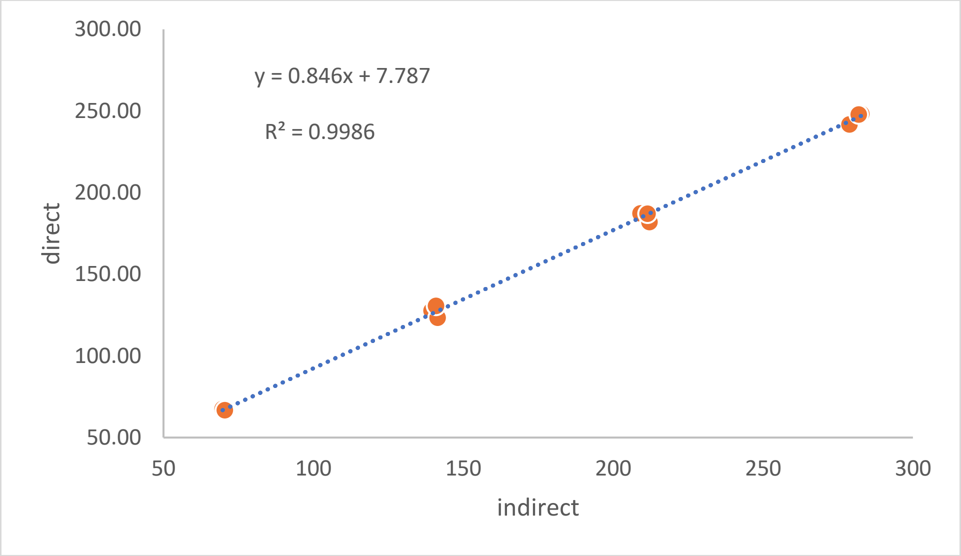

Figure 3. Scatterplot of relationship between measures.

This testing established an accurate and replicable approach for researchers and practitioners alike to know the resistance provided in such an arrangement. Chain features including total length, link diameter, and density are said to influence the total weight (McMaster, Cronin and McGuigan, 2009). Comparative tables matching chain total length and link diameter to the mass of the system have been produced (Berning, Coker and Adams, 2004). Investigations of materials prior to use in experimentation is necessary to evaluate the effect of: number of starting unloaded chain links; the combination of multiple chain attachments; and the suspension of the chains in a vertical fashion on total system weight.

Secondly, having determined the mass, it was important to also optimise the technique used to attach and suspend the chains: namely, the application of the double-looped technique. In practice, the links resting on floor mitigate any oscillation and swing as has been recommended to minimise the influence on performance of the squat (Berning, Coker and Adams, 2004; Neelly, Terry and Morris, 2010). The discriminating factor between double-looped and linear-hung methods was the degree of unloading at the bottom-most ROM of the squat: 80-90% in double-looped versus 35-45% in linear. The linear hung supplies less total variable resistance, almost a 2-fold difference, due to more of the chain mass remaining loaded thereby acting as static resistance, which is more analogous to traditional resistance. In short, to maximise the degree of variable resistance applied the double-looped technique is preferred over other methods.

The resistive load across the four chain pairings was established by recording the weight using the direct method. This can then be used when applying the chains as a variable resistance means in this context. Using the direct measurement method allows for manipulation of chain height without having a meaningful impact on the total weight of the system. Since the resistance applied for each chain pairing is now known, the resistance can be prescribed at a specified %1RM.